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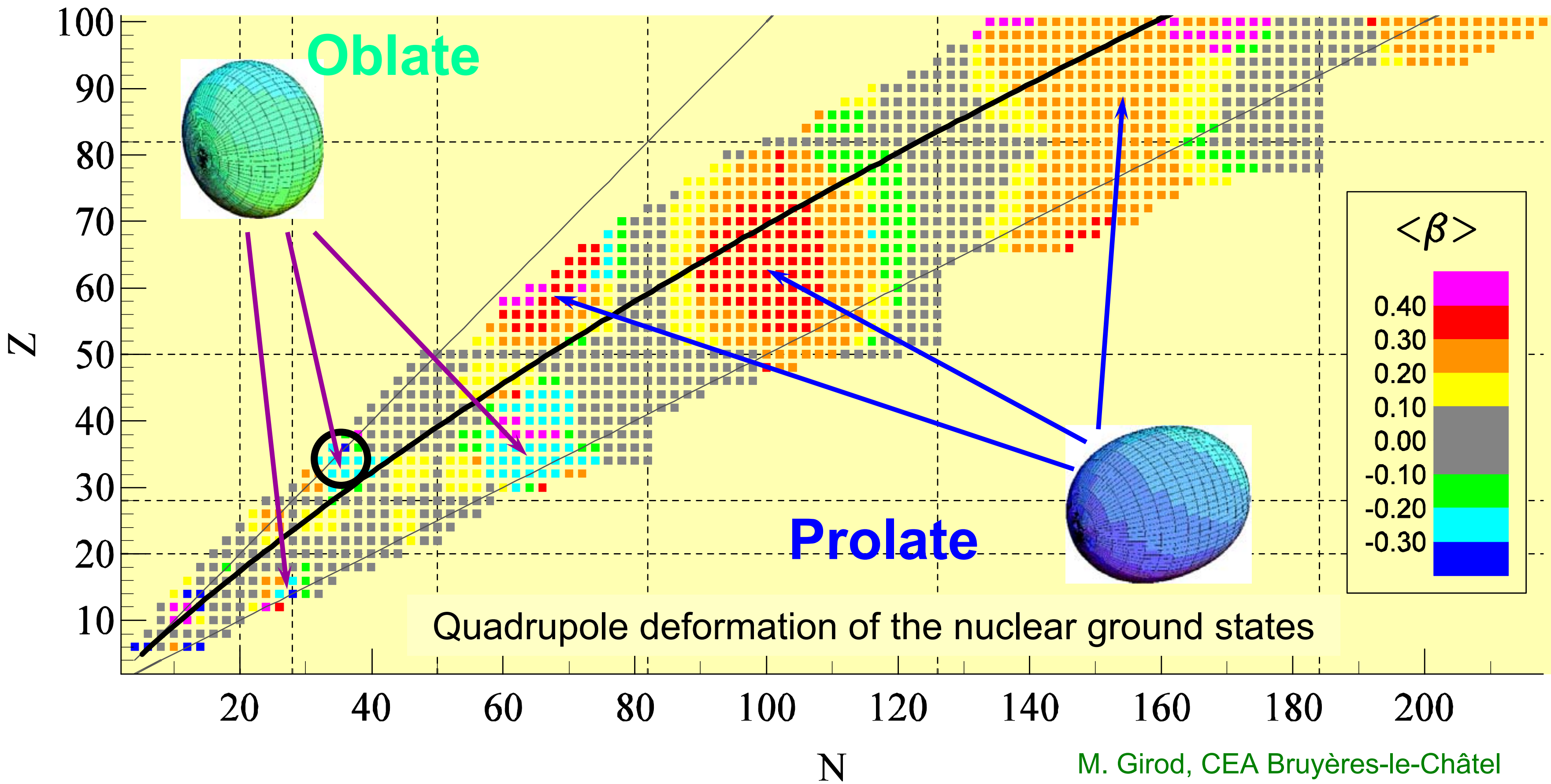
Shape coexistence in light Krypton isotopes

- Introduction : Shape coexistence
- "Safe" Coulomb excitation of RIBs
- RDDS Lifetime measurement
- Results and conclusions

Andreas Görgen

DAPNIA / Service de Physique Nucléaire
Commissariat à l'Énergie Atomique, Saclay

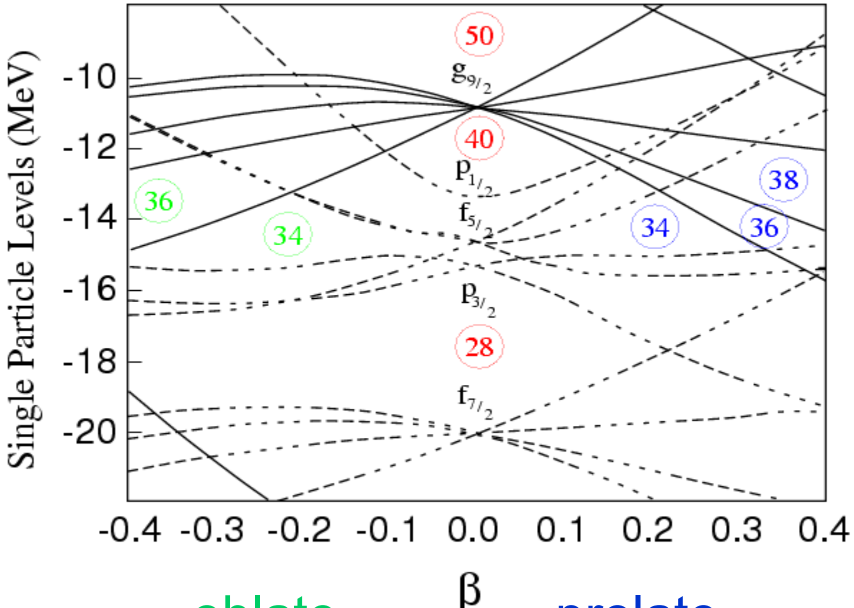
Shapes of atomic nuclei

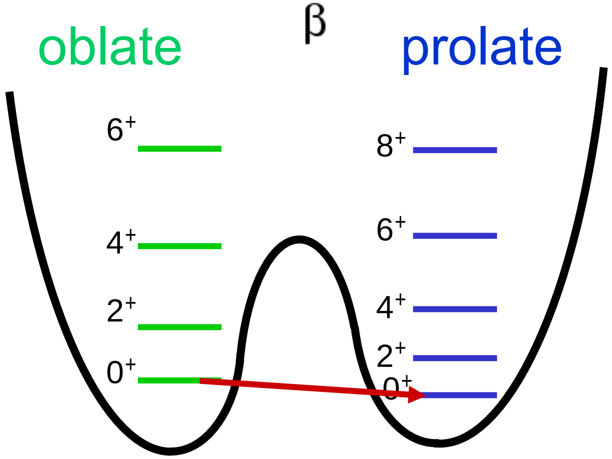


M. Girod, CEA Bruyères-le-Châtel

- oblate ground states predicted for *A~70* near *N=Z*
- prolate and oblate states within small energy range
  ⇒ shape coexistence

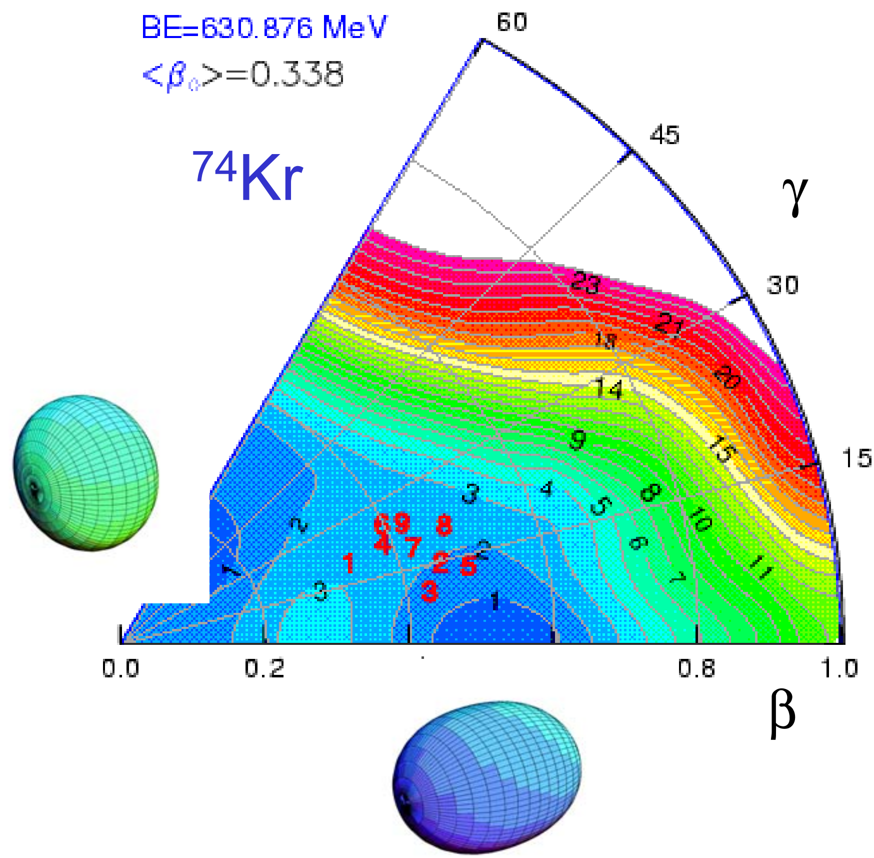
Shape coexistence





shape coexistence expected in

$^{72}_{36}Kr_{36}$ $^{74}_{36}Kr_{38}$ $^{68}_{34}Se_{34}$ $^{70}_{34}Se_{36}$

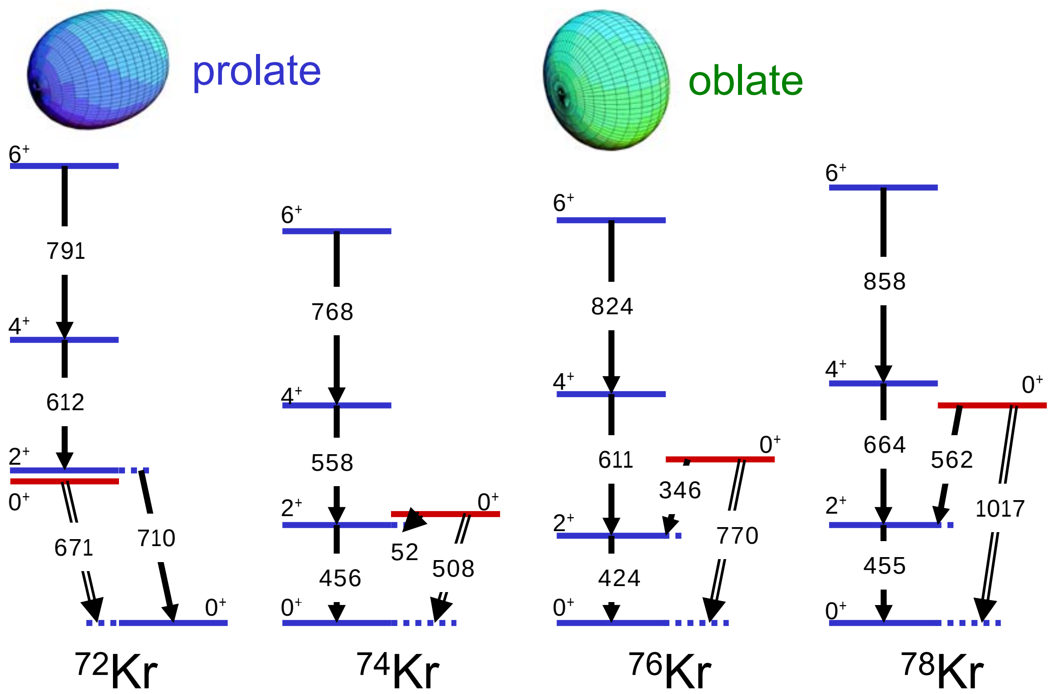


Shape isomer, E0 transition

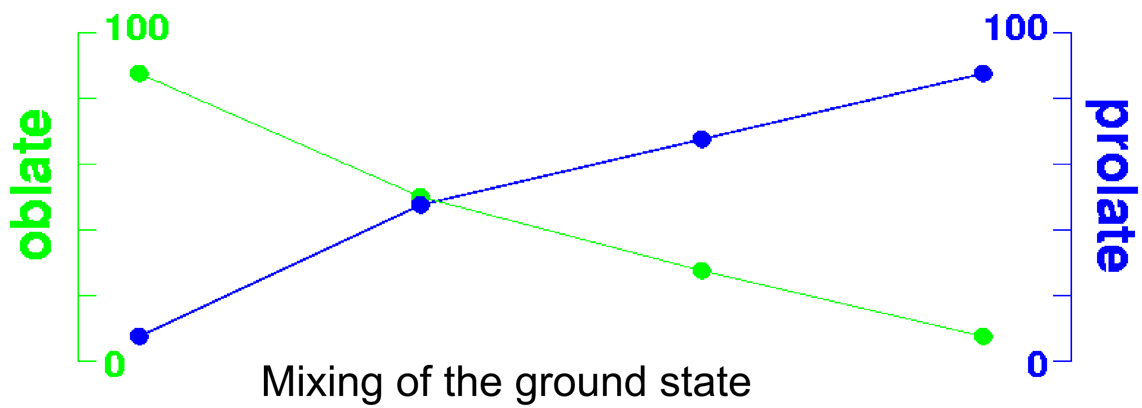
Configuration mixing: $\left|\psi(0_1^+)\right\rangle = a\left|\varphi_{pro}\right\rangle + b\left|\varphi_{obl}\right\rangle$

$$\left|\psi(0_2^+)\right\rangle = a\left|\varphi_{obl}\right\rangle - b\left|\varphi_{pro}\right\rangle$$

Systematics of the light krypton isotopes



$\rho^2(E0)$ $72 \cdot 10^{-3}$ $85 \cdot 10^{-3}$ $79 \cdot 10^{-3}$ $47 \cdot 10^{-3}$



- energy of excited 0^+
- E0 strengths $\rho^2(E0)$
- configuration mixing

- Inversion of ground state shape for ^{72}Kr

- Coulomb excitation to determine the nuclear shapes directly

E. Bouchez et. al.,
Phys. Rev. Lett. 90, 082502 (2003)

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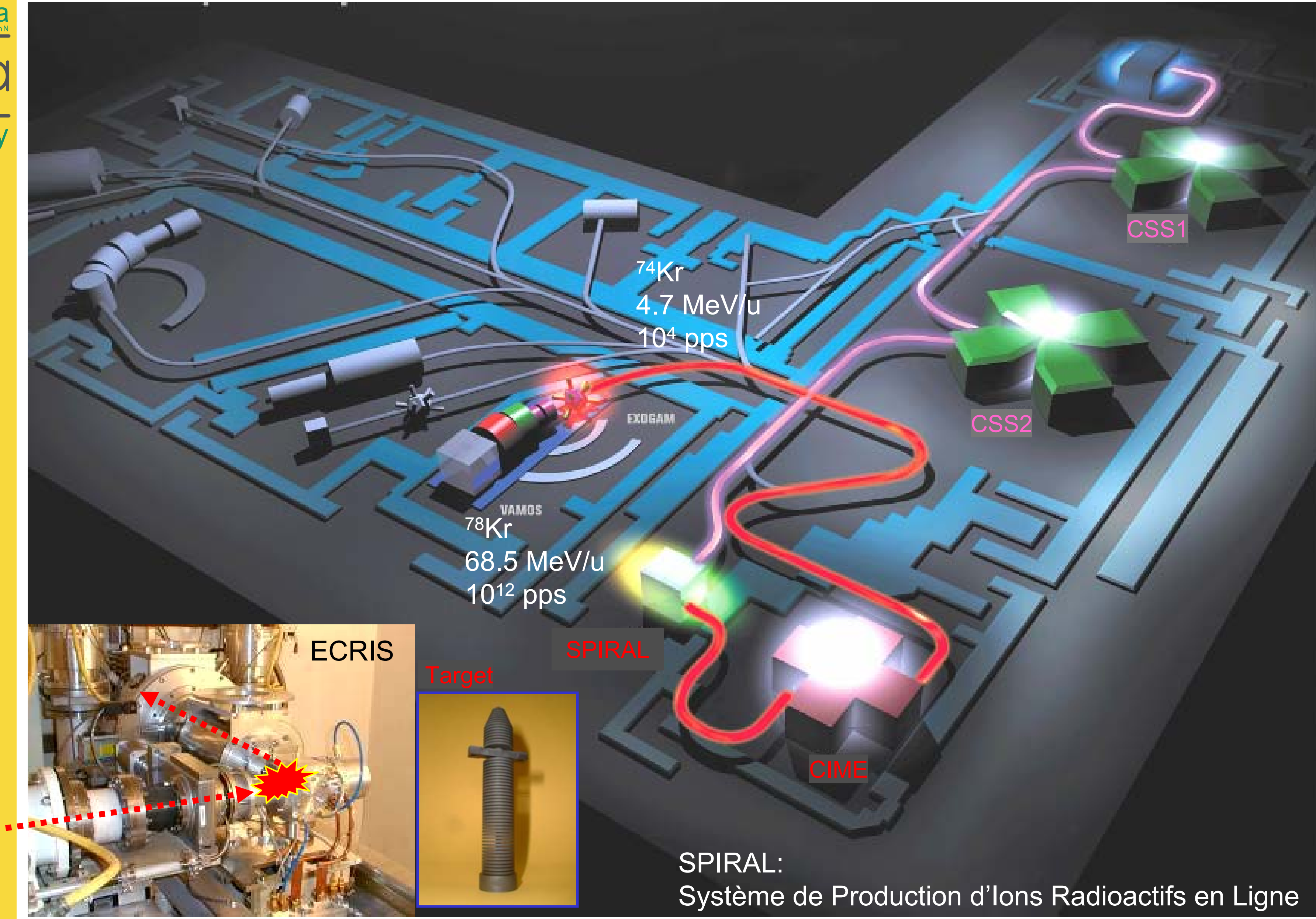
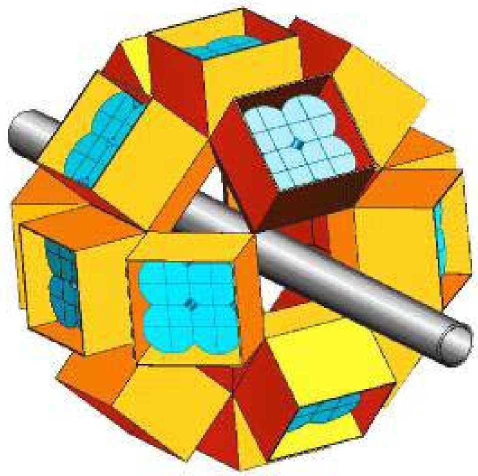
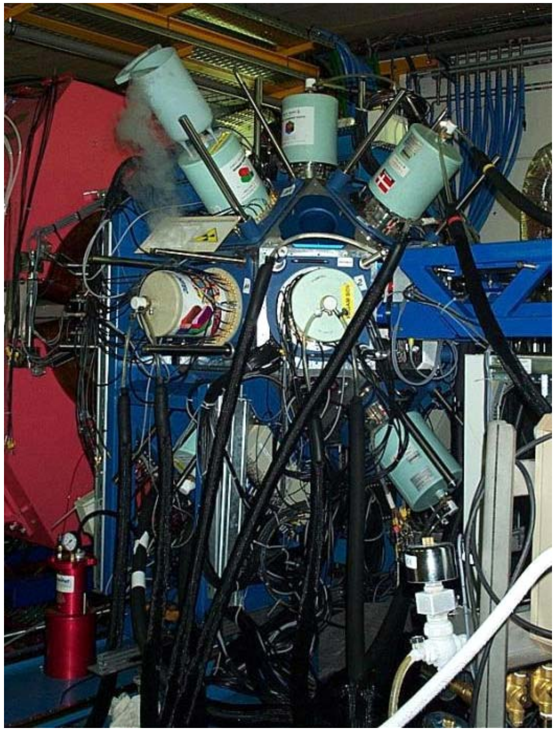
Radioactive beam production: SPIRAL

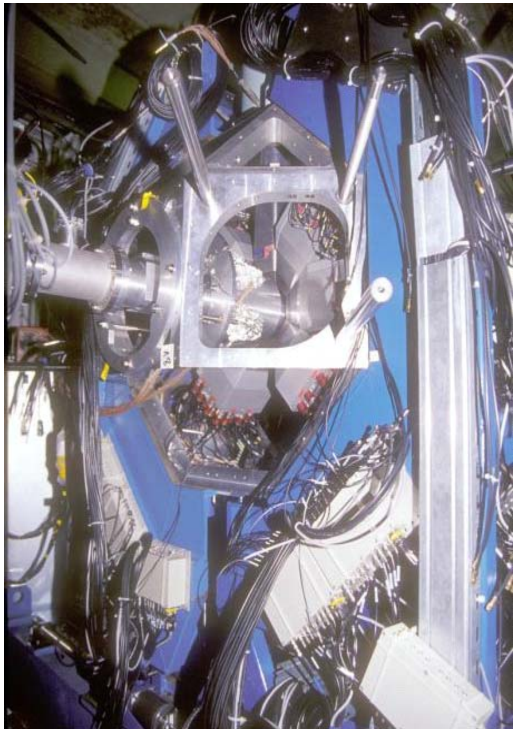


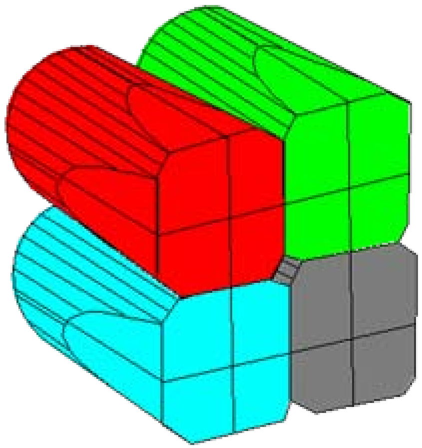
EXOGAM



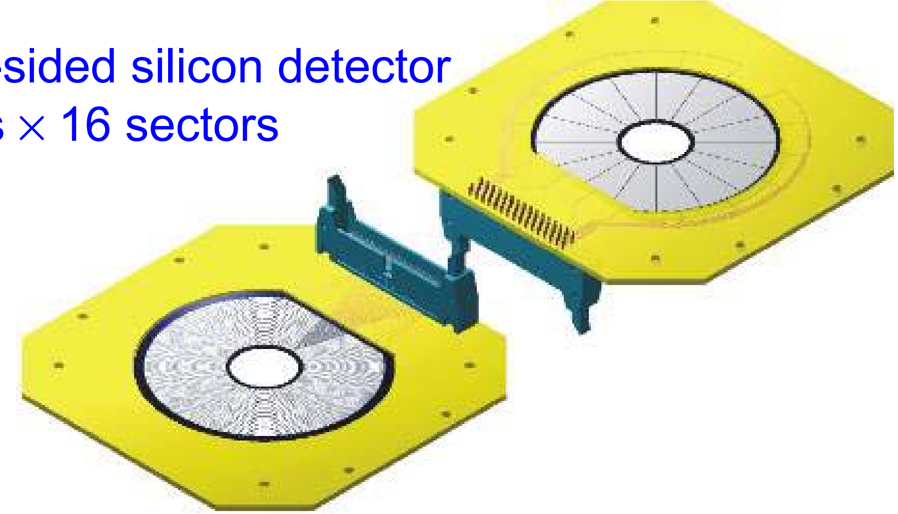
16 large Ge Clover detectors
4 × 4 segmented







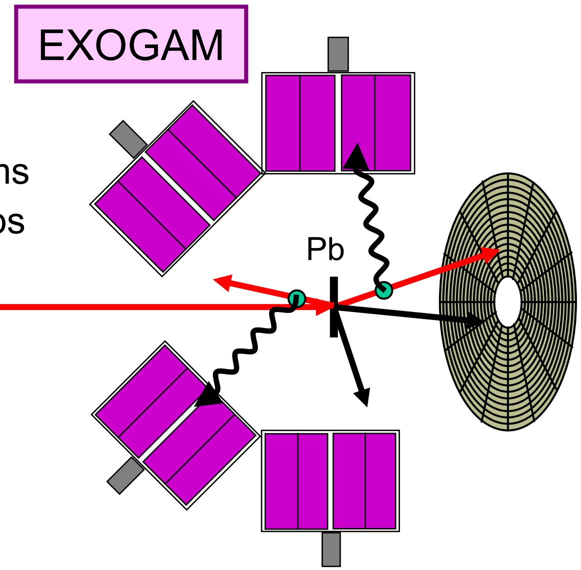
Double-sided silicon detector
48 rings × 16 sectors

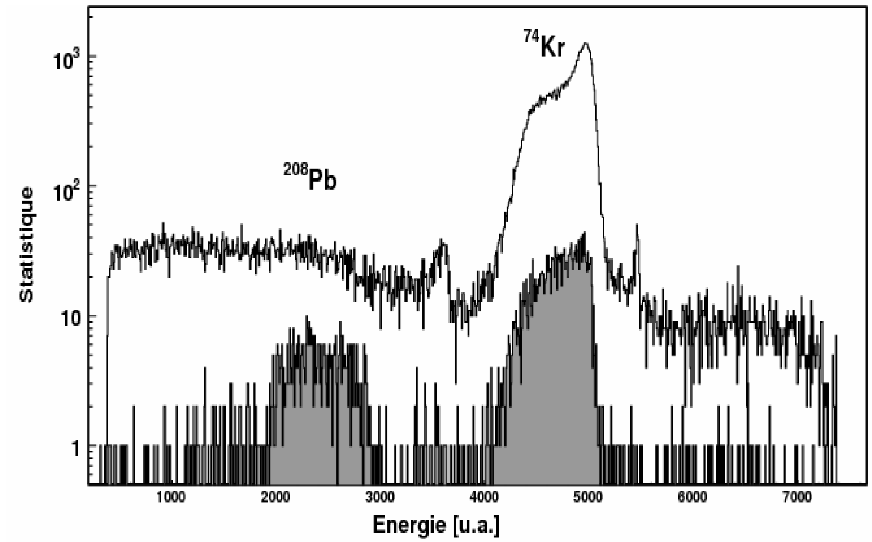


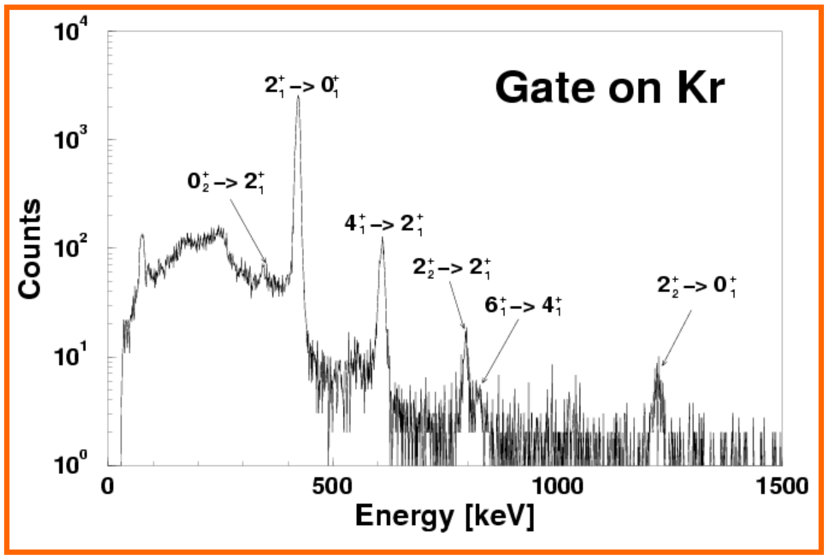
Coulomb excitation of ^{74}Kr and ^{76}Kr

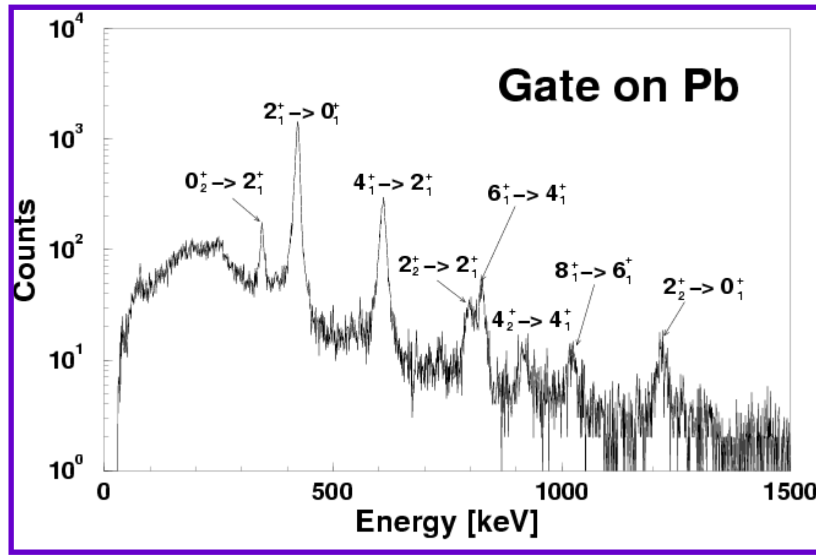
SPIRAL beams
^{76}Kr 5×10^5 pps
^{74}Kr 10^4 pps

4.7 MeV/u









Acta Phys. Pol. B 36, 1281 (2005)

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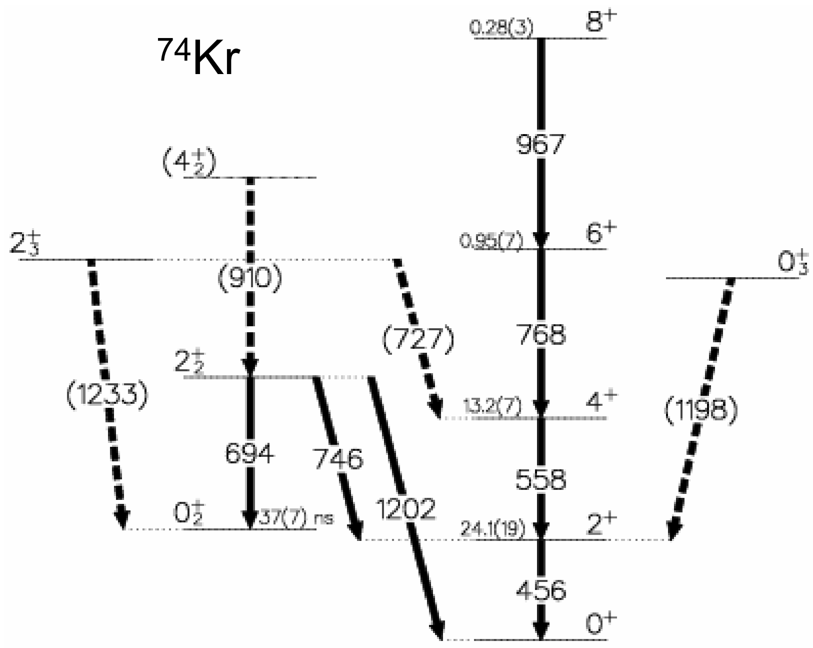
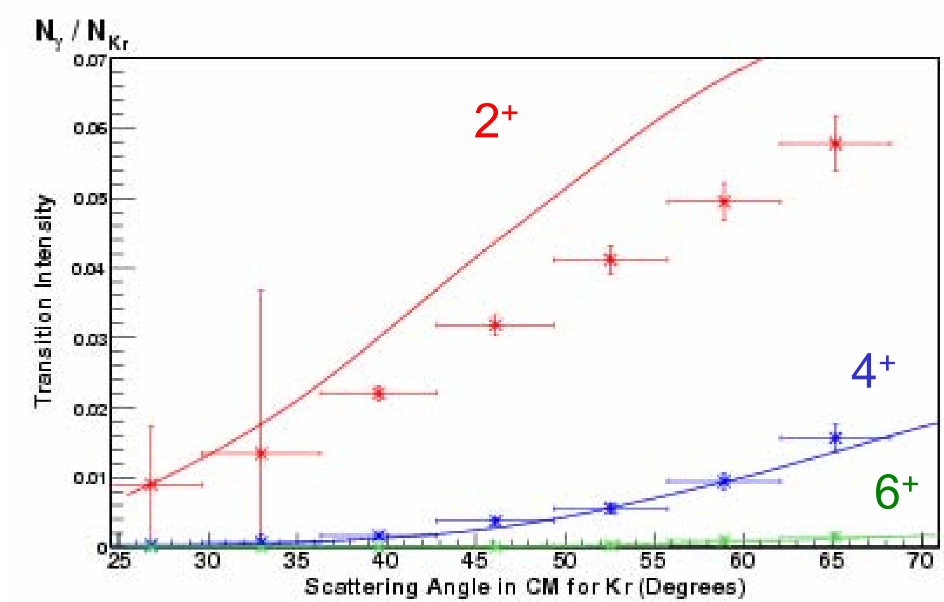
Coulomb excitation analysis : GOSIA*

*D. Cline, C.Y. Wu, T. Czosnyka; Univ. of Rochester



- γ yields as function of scattering angle: differential cross section
- least squares fit of ~ 30 matrix elements (transitional and diagonal)
- experimental spectroscopic data
  - lifetimes
  - branching ratios

- Yields from Coulomb excitation inconsistent with published lifetimes, especially for 4^+ in ^{74}Kr
- New RDM lifetime measurement



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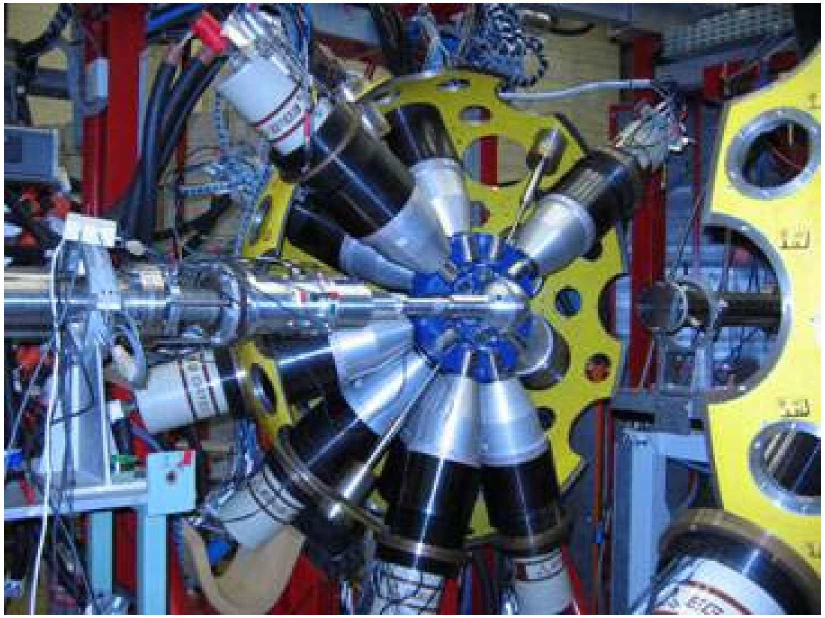
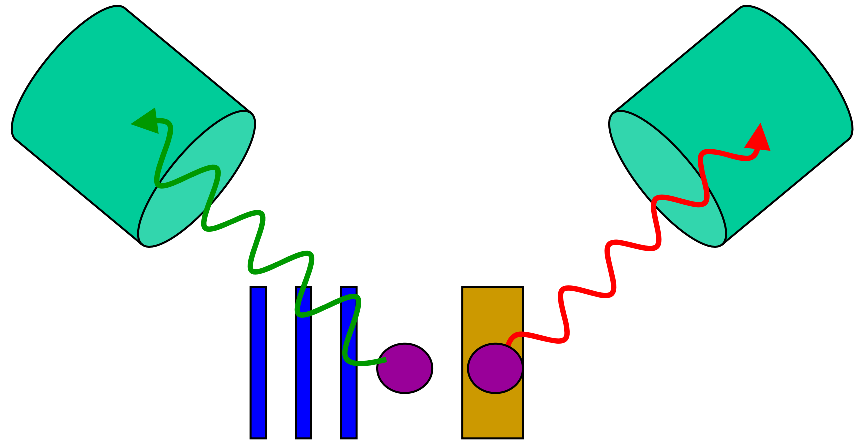
Lifetime measurement with GASP and the Köln Plunger

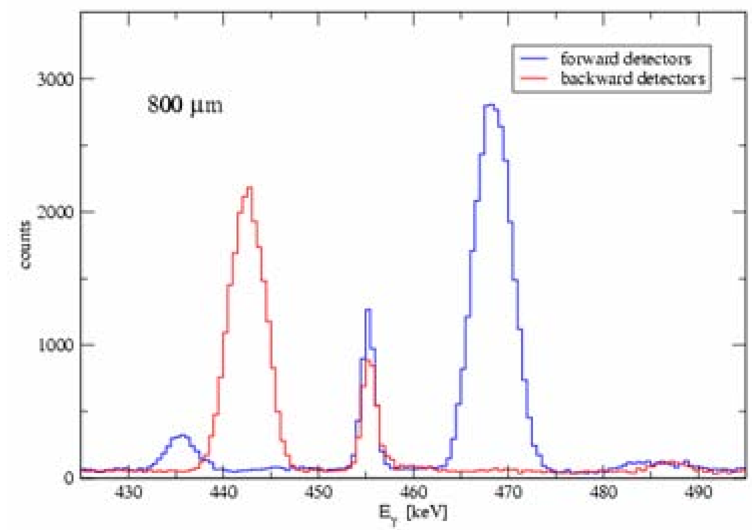


$^{40}Ca(^{40}Ca,a2p)^{74}Kr$

$^{40}Ca(^{40}Ca,4p)^{76}Kr$

124 MeV





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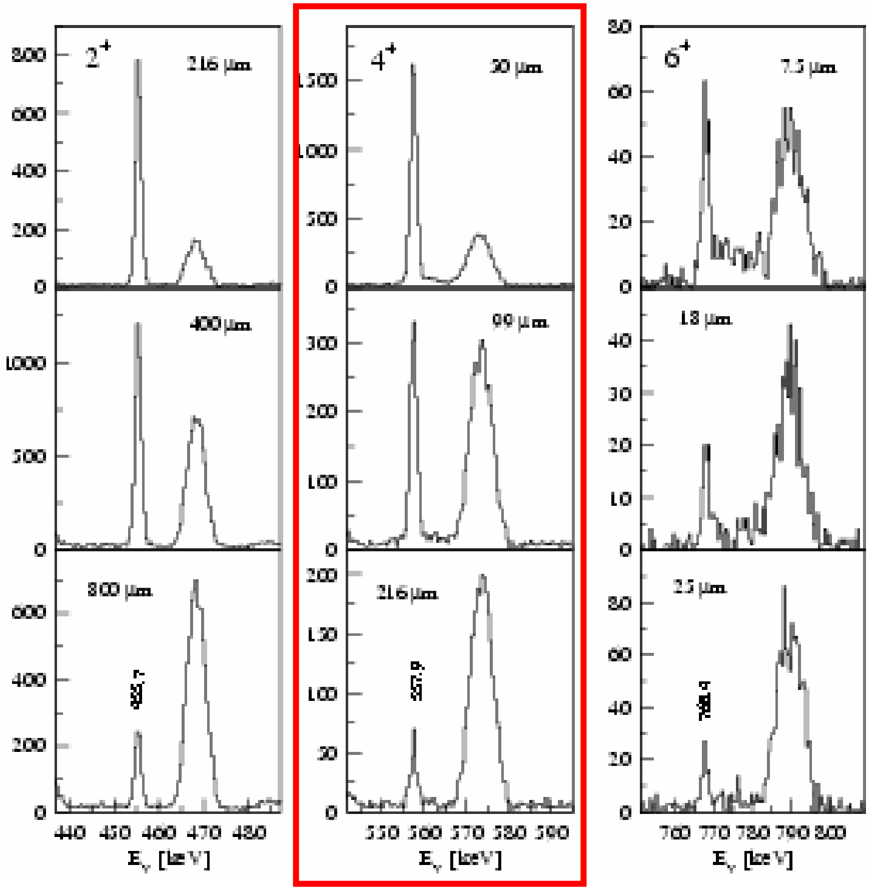
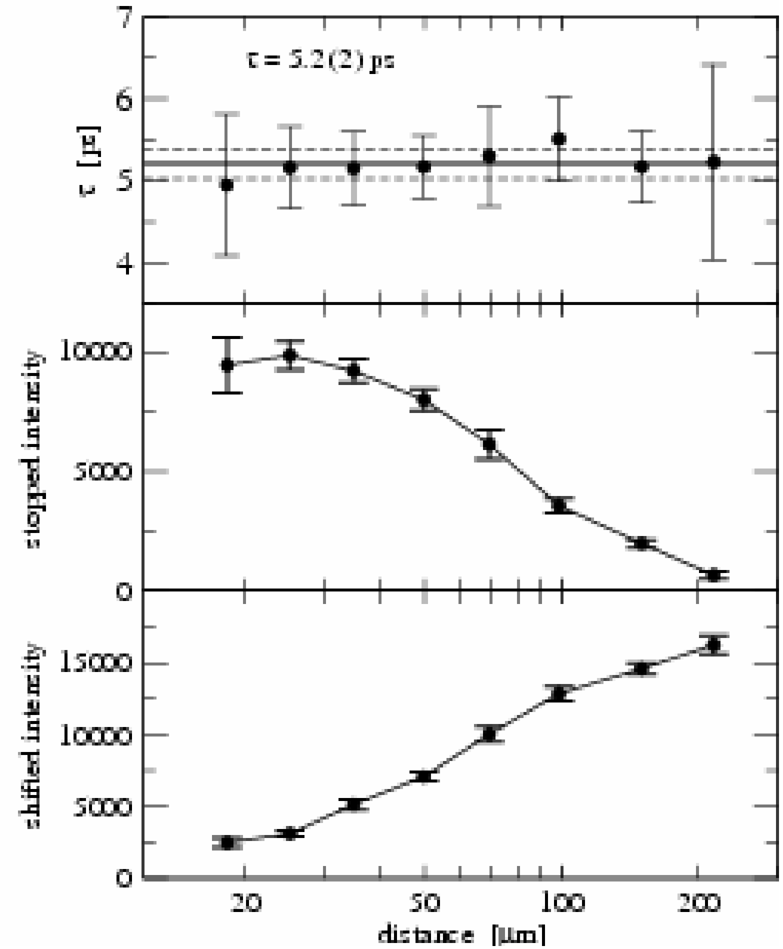
Differential decay curve method

^{74}Kr

- forward detectors (36°)
- gated from above



Example: ^{74}Kr , 4$^+$, 36°

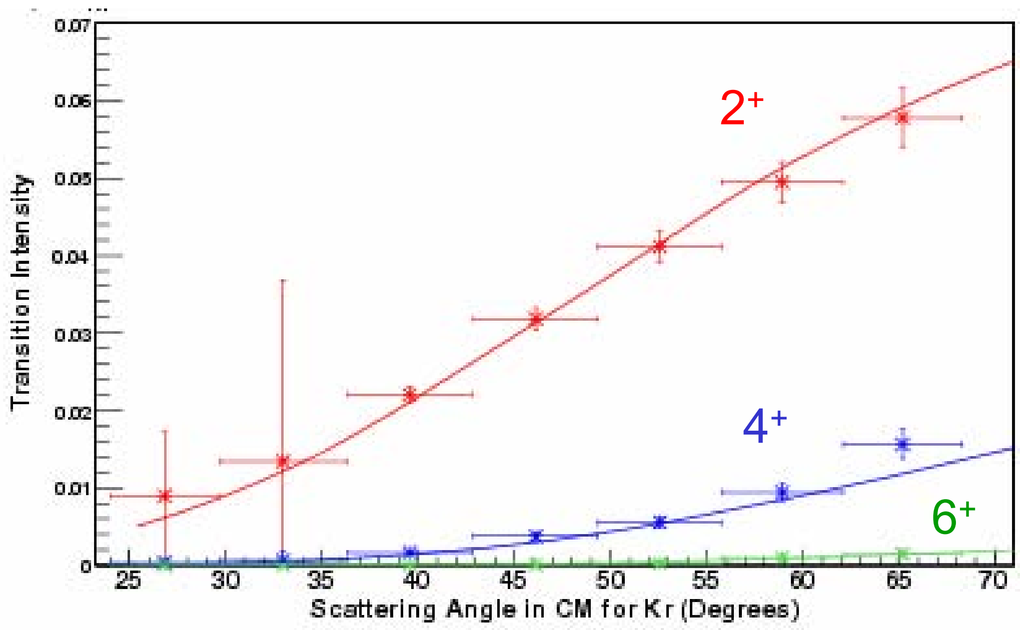


Eur. Phys. J. A 26, 153 (2005)

Lifetime results

Eur. Phys. J. A 26, 153 (2005)

^{74}Kr	2^+	4^+	^{76}Kr	2^+	4^+	
new	33.8(6)	5.2(2)	new	41.5(8)	3.67(9)	[ps]
	28.8(57)	13.2(7)		35.3(10)	4.8(5)	[ps]
	J. Roth et al., J.Phys.G, L25 (1984)			B. Wörmann et al., NPA 431, 170 (1984)		



Results consistent with transition probabilities from Coulomb excitation.

Lifetimes used to constrain GOSIA fit.

⇒ enhanced sensitivity for non-yrast transitions and diagonal matrix elements

Shape coexistence in light Krypton isotopes

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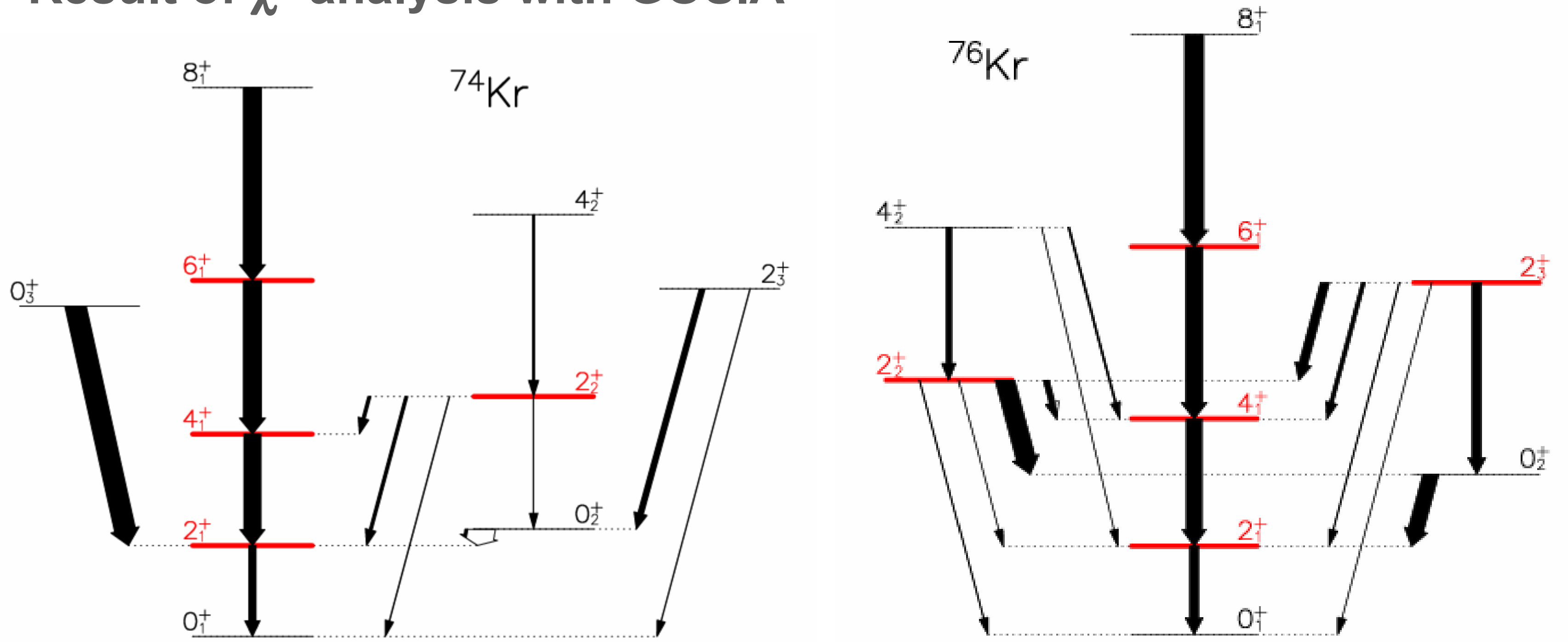
Result of χ^2 analysis with GOSIA



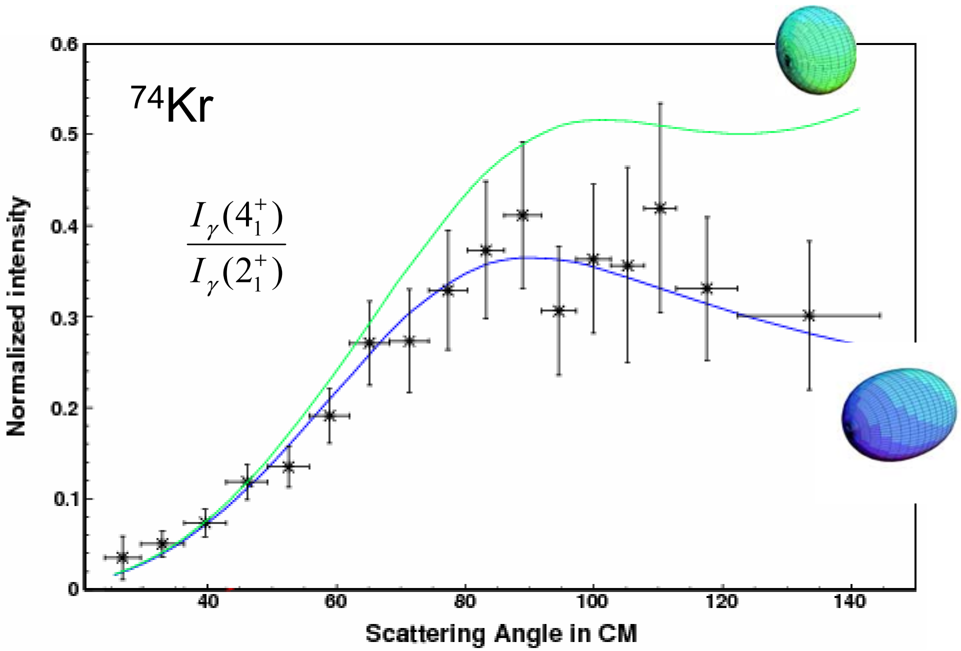
- 14 transitional E2 matrix elements
- 18 transitional E2 matrix elements

$$B(E2) = \frac{\left|\left\langle I_f \left\| \mathrm{M}(E2) \right\| I_i \right\rangle\right|^2}{2I_i + 1}$$

- 4 diagonal E2 matrix elements
- 5 diagonal E2 matrix elements

$$eQ_0 = \sqrt{\frac{16\pi}{5}} \frac{1}{\sqrt{2I+1}} \frac{\left\langle I \left\| \mathrm{M}(E2) \right\| I \right\rangle}{\left\langle I\,0\,2\,0 \middle| I\,0 \right\rangle}$$

Sensitivity to quadrupole moments



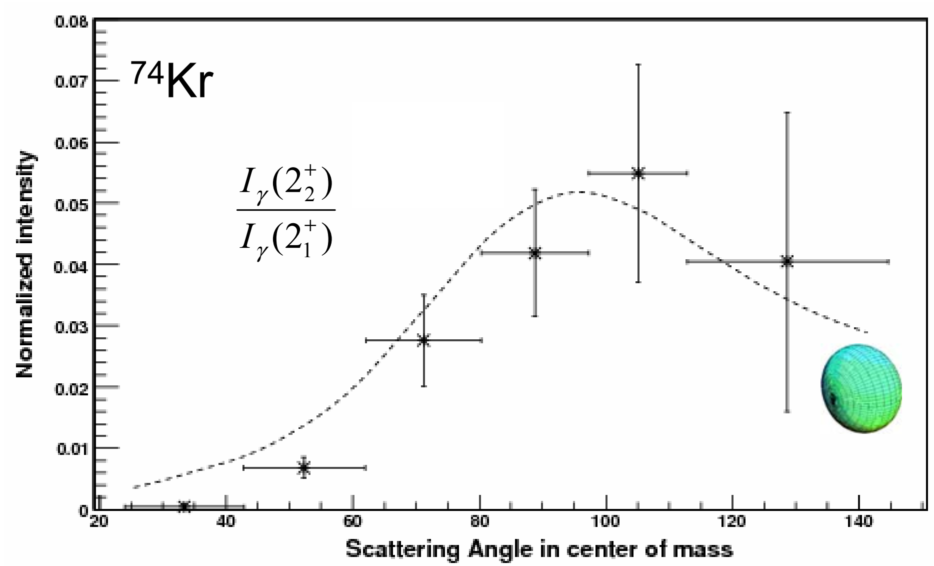
full χ^2 minimization:

$$\langle 2_1^+ \| M(E2) \| 2_1^+ \rangle = -0.70^{+0.33}_{-0.30}$$

$$\langle 4_1^+ \| M(E2) \| 4_1^+ \rangle = -1.02^{+0.59}_{-0.21}$$

negative matrix element
(positive quadrupole moment Q_0)

$\Rightarrow$ prolate shape

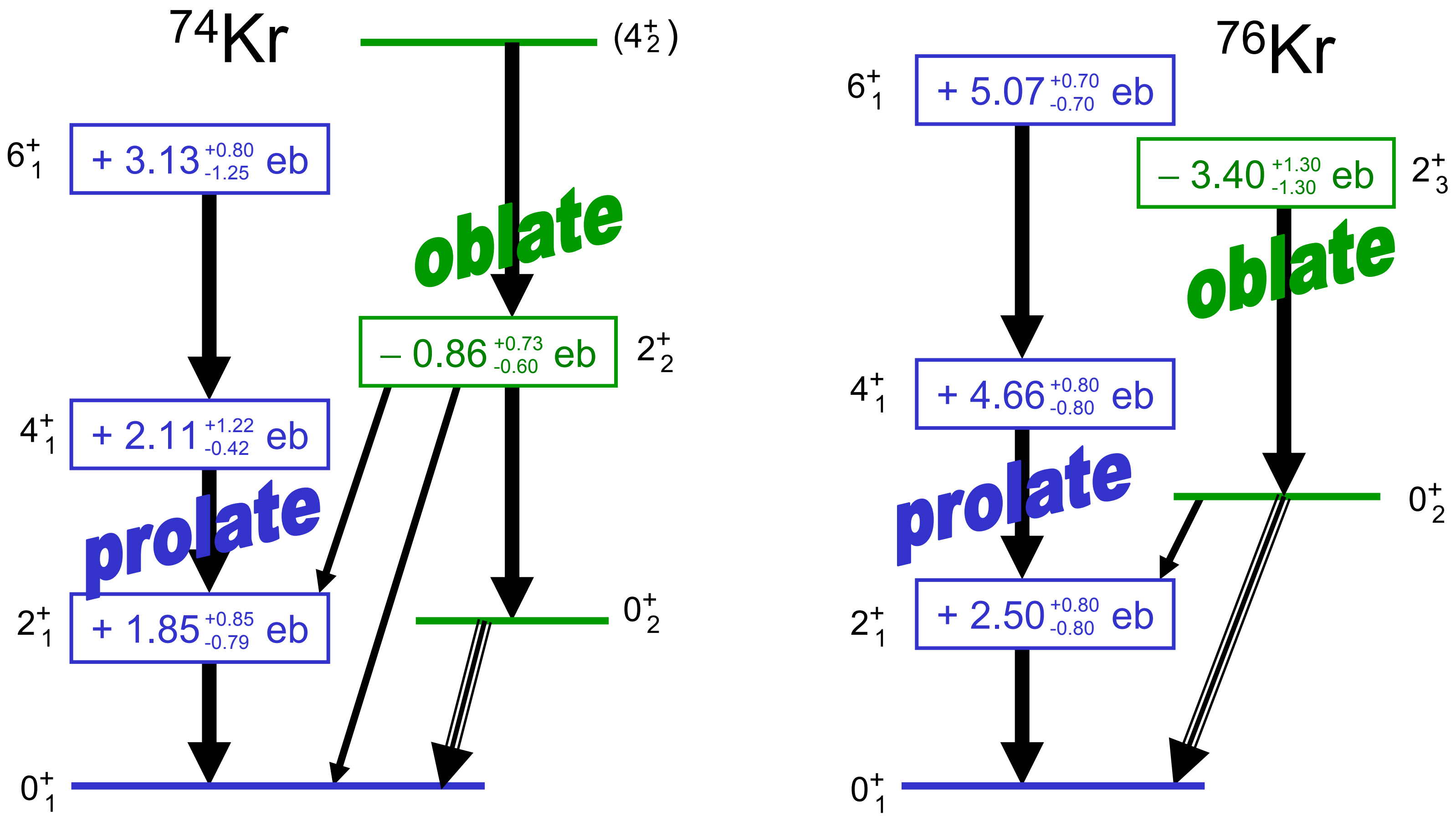


$$\langle 2_2^+ \| M(E2) \| 2_2^+ \rangle = +0.33^{+0.28}_{-0.23}$$

positive matrix element
(negative quadrupole moment Q_0)

$\Rightarrow$ oblate shape

Quadrupole moments Q_0 in ^{74}Kr and ^{76}Kr

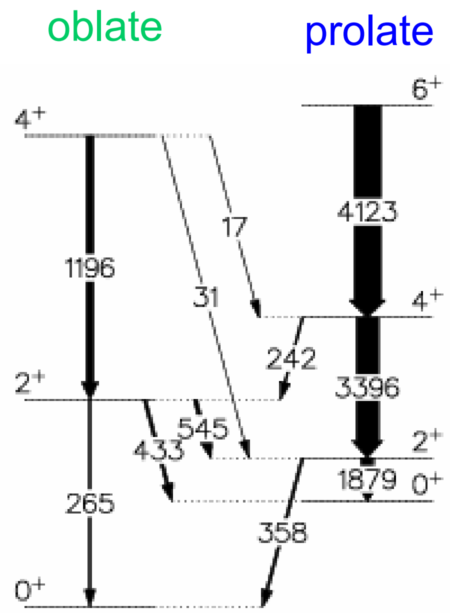


E. Clément et al., to be published

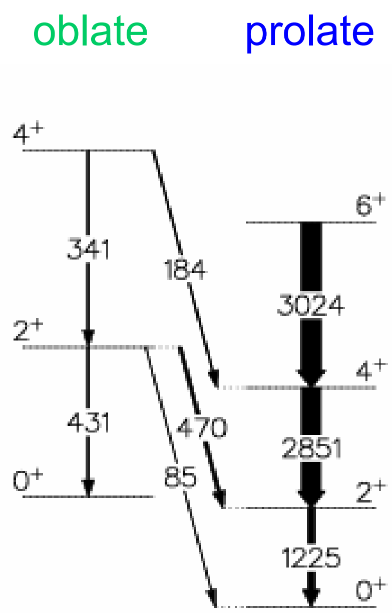
- direct confirmation of the prolate – oblate shape coexistence
- first reorientation measurement with radioactive beam

Comparison with theory: ^{74}Kr

B(E2) values in e^2fm^4

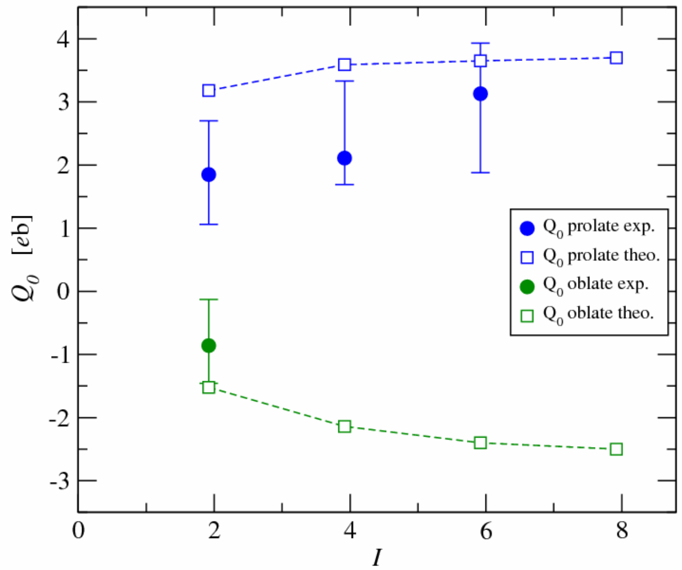


theory: HFB(SLy6) + GCM
M. Bender, P. Bonche,
P.-H. Heenen, priv. comm.



experimental

Quadrupole moments



- ordering of prolate and oblate states inversed
- reduced strength of $2^+ \rightarrow 0^+$ transition reproduced $\Rightarrow$ mixing
- in-band B(E2) values and Q_0 too large $\Rightarrow$ deformation

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Summary

- low-energy projectile Coulomb excitation with RIB
  - transitional and diagonal matrix elements for ^{74,76}Kr
  - first reorientation measurement with RIB
- Plunger lifetime measurement after fusion-evaporation
  - complementary measurement of B(E2) values
- direct confirmation of shape coexistence in light Kr
  - quantitative understanding
  - important input for theory
- new program to study neutron-rich Ar isotopes
  - experiment on ^{44}Ar successfully completed last week
  - stay tuned…

Collaboration

E. Clément, E. Bouchez, A. Chatillon, A. Hürstel,
W. Korten, Y. Le Coz, Ch. Theisen, J.N. Wilson
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G. Sletten
NBI
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Liverpool
F. Becker, J. Gerl
GSI
W.N. Catford, C. Timis
Surrey
A. Dewald, B. Melon, O. Möller, K.O. Zell,
Köln
N. Marginean, R. Menegazzo, D. Tonev, C.A. Ur
Legnaro

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Level mixing

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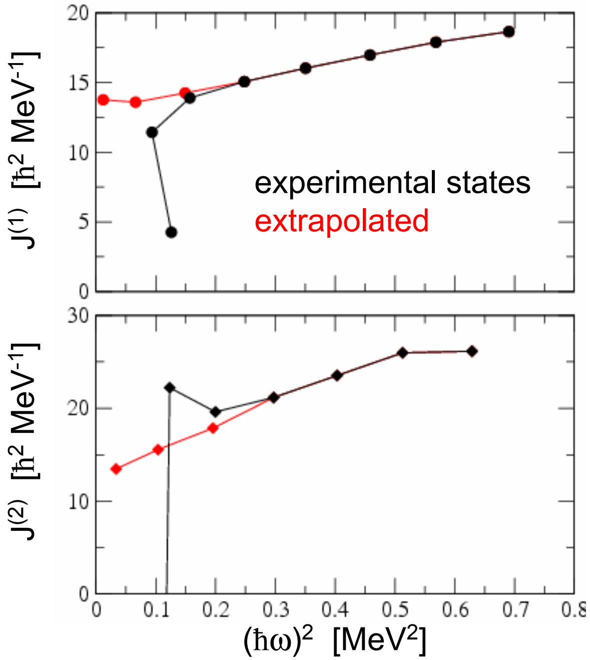
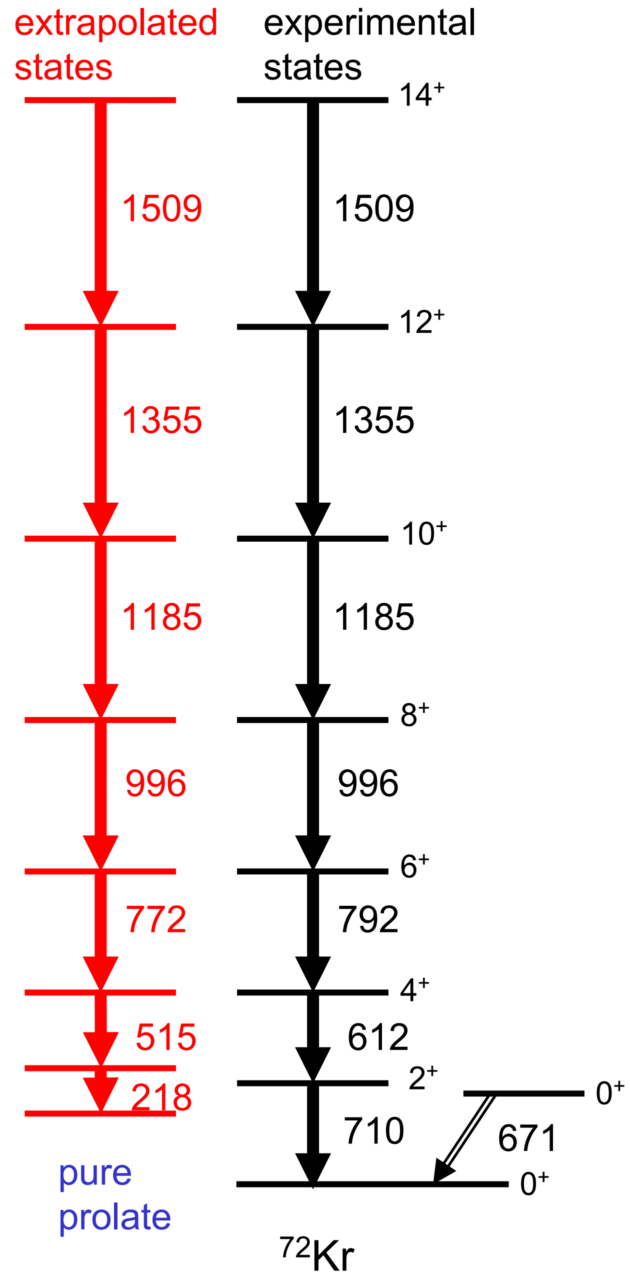
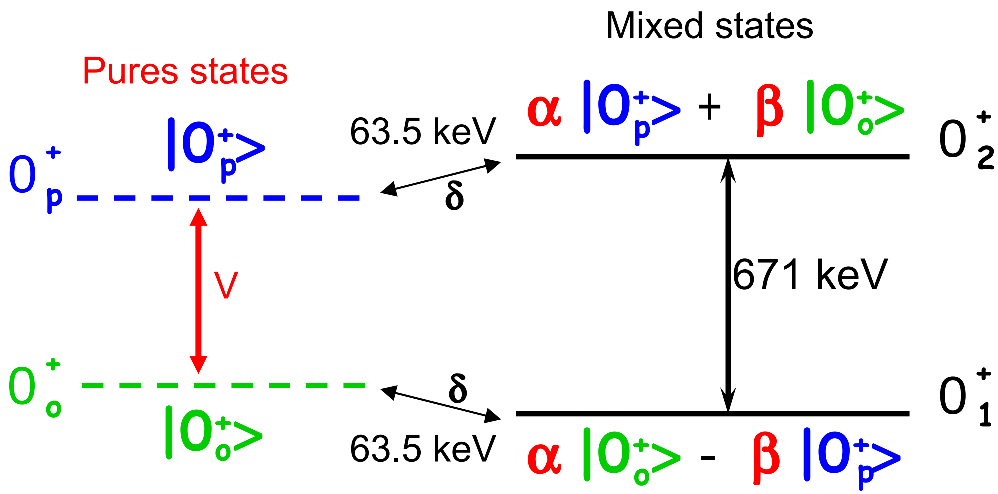


Regular rotational cascade at high spin.

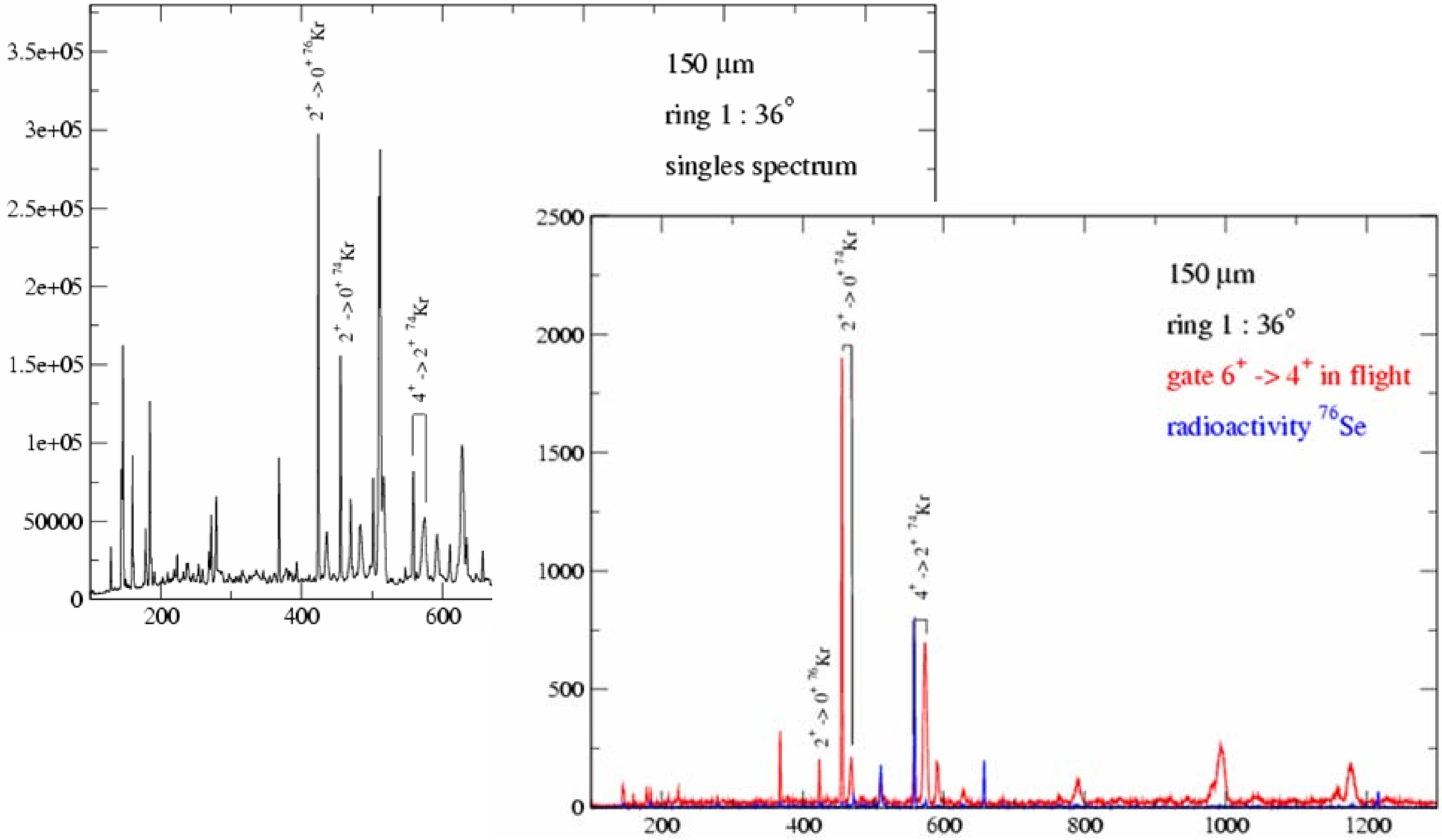
Rotational band is distorted at low spin.
⇒ influence of mixing

- Interaction V
- mixing amplitudes α, β

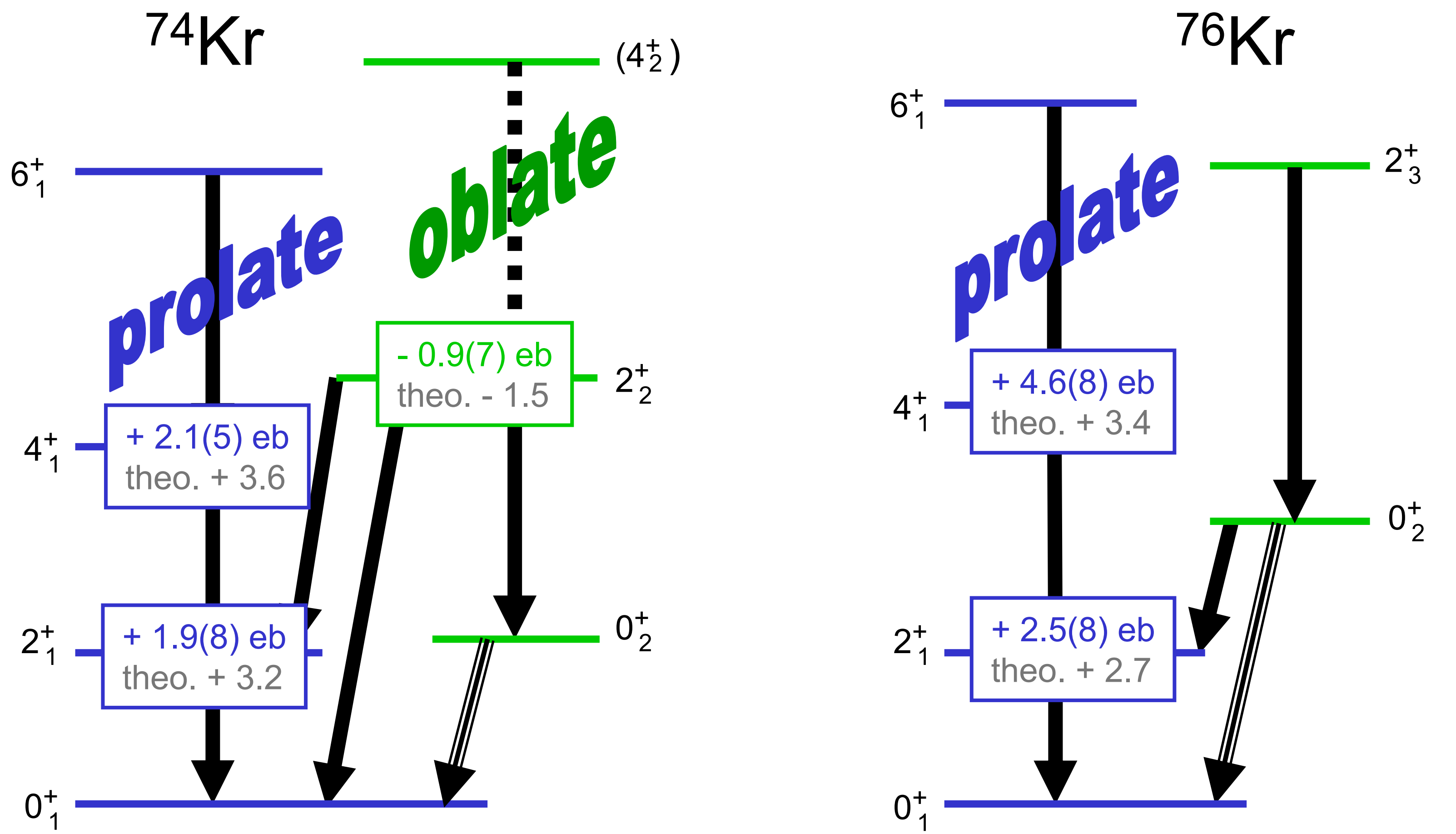




Singles vs. coincidence measurement



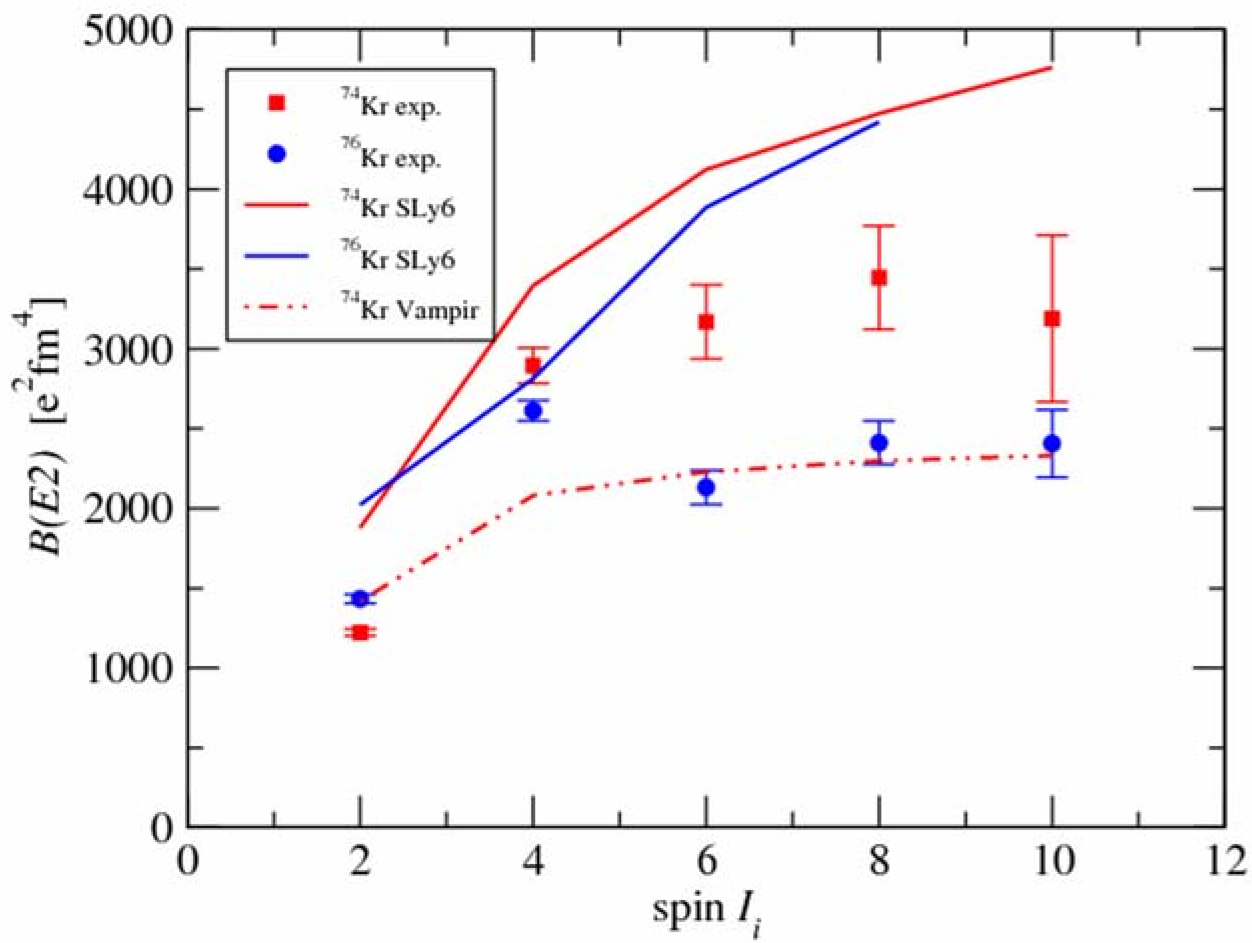
Quadrupole moments in ^{74}Kr and ^{76}Kr



E. Clément et al., to be published

direct confirmation of the prolate – oblate shape coexistence

Transition strengths : B(E2)

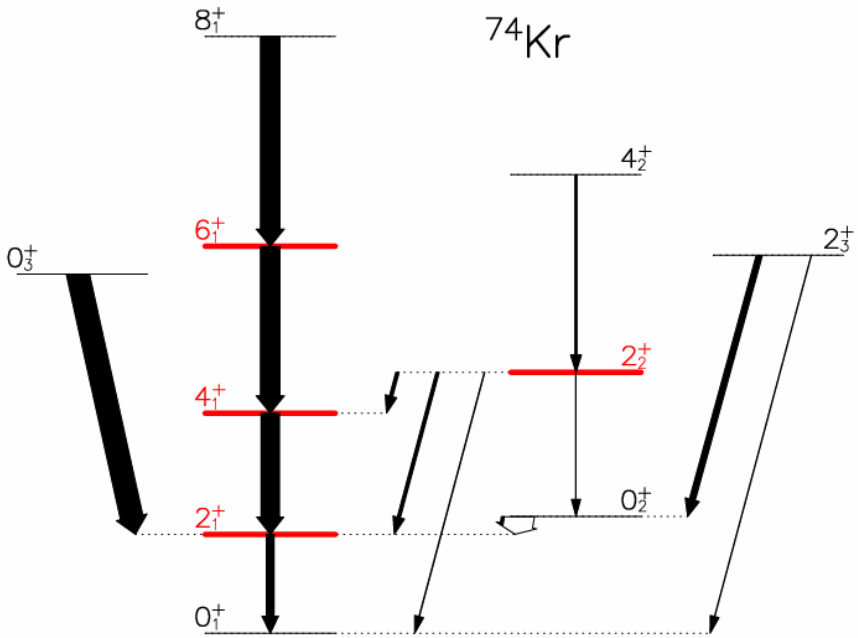


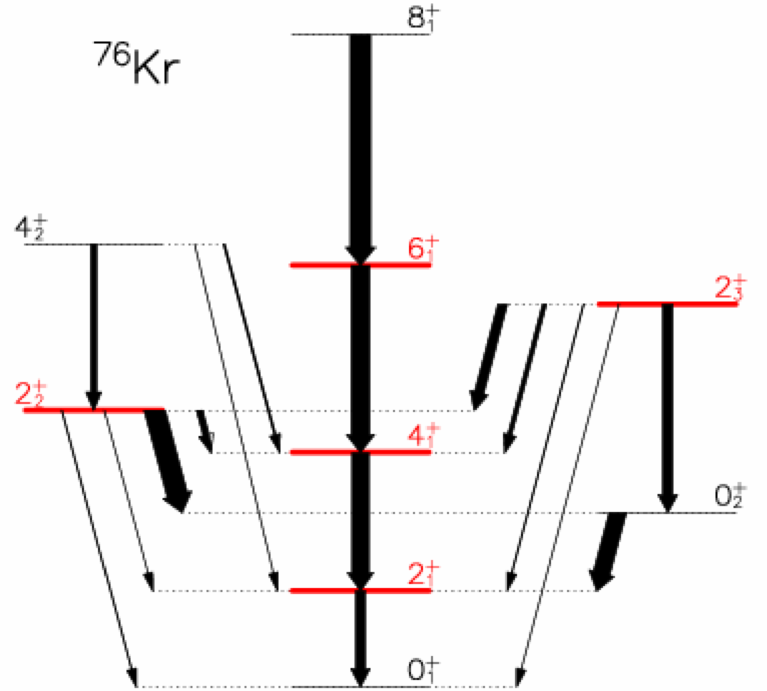
Theory:
HFB+BCS-LN+AMPGCM
M. Bender, P.H. Heenen
priv. comm.

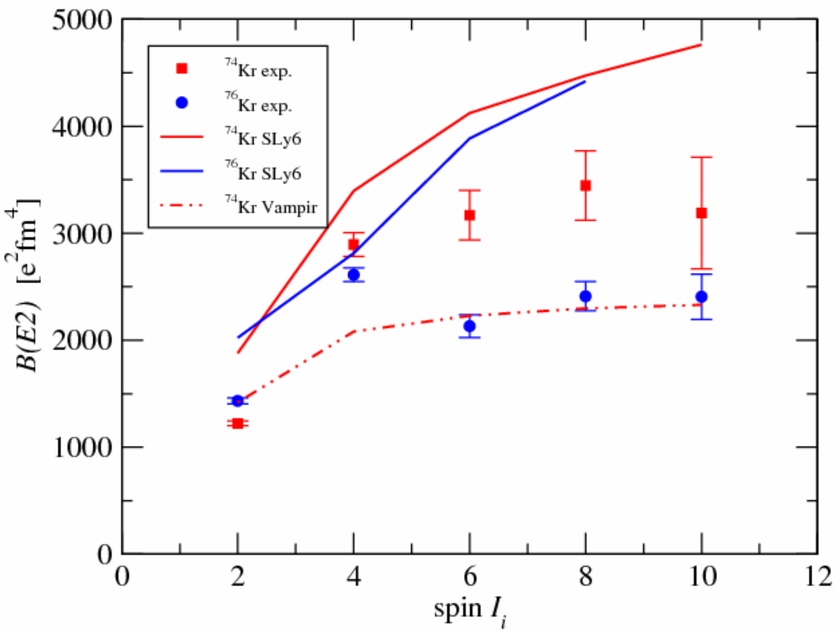
Vampir
A. Petrovici et al.,
Nucl. Phys. A 665, 333 (00)

- B(E2) reduced for $2^+ \rightarrow 0^+$ transitions $\Rightarrow$ influence of mixing
- theory describes trend, but not absolute values

Transition strengths: B(E2)

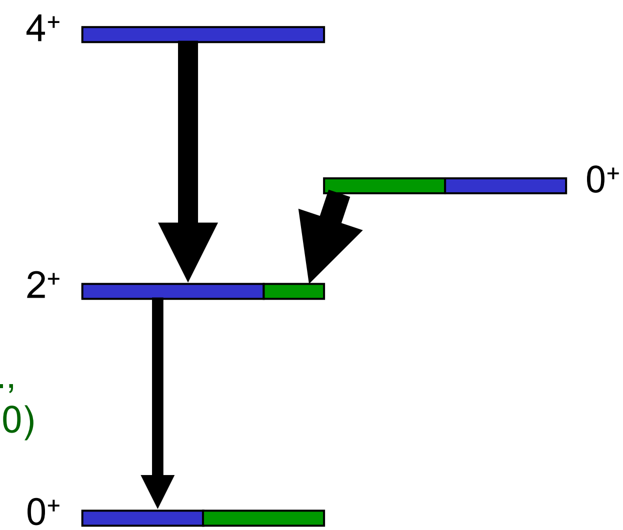




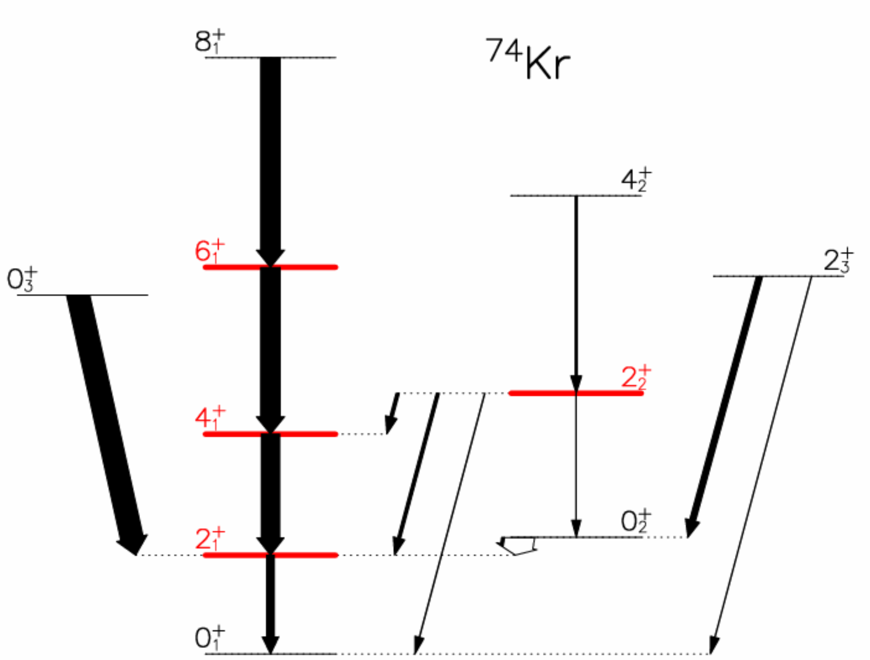


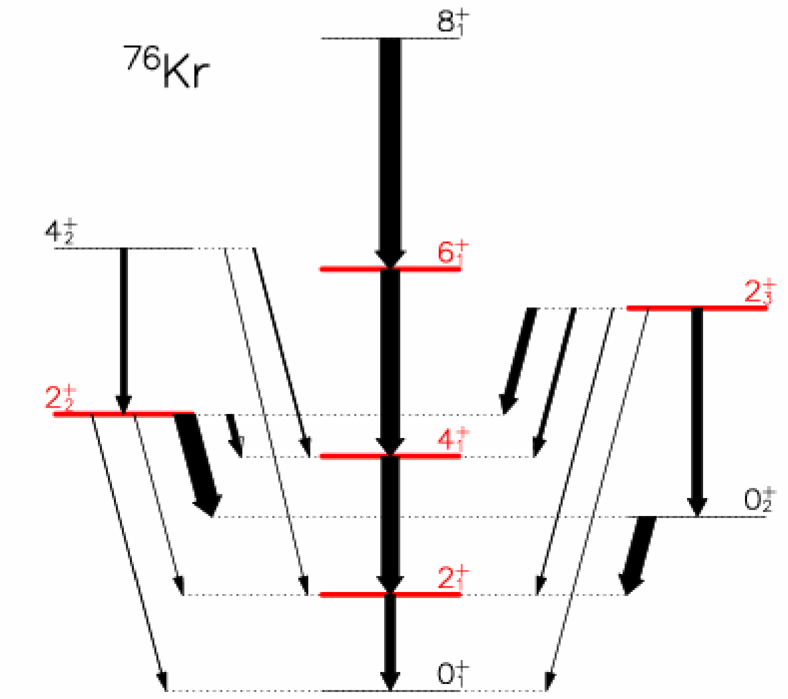
HFB+AMPGCM
M. Bender,
P.H. Heenen
priv. comm.

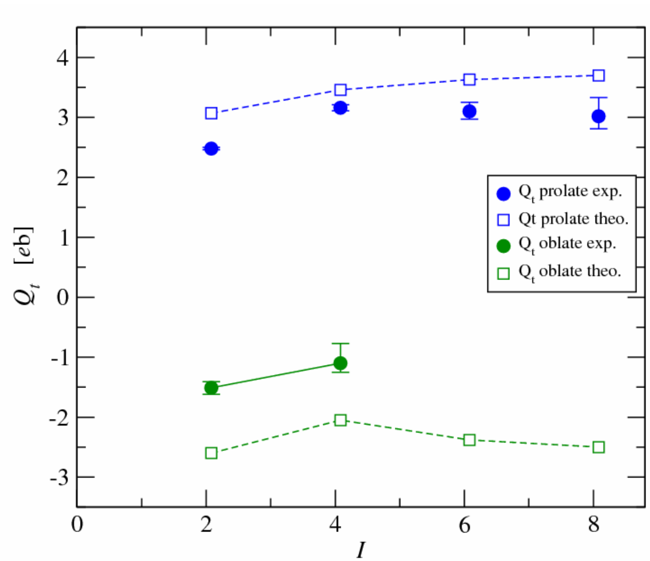
Vampir
A. Petrovici et al.,
NPA 665, 333 (00)



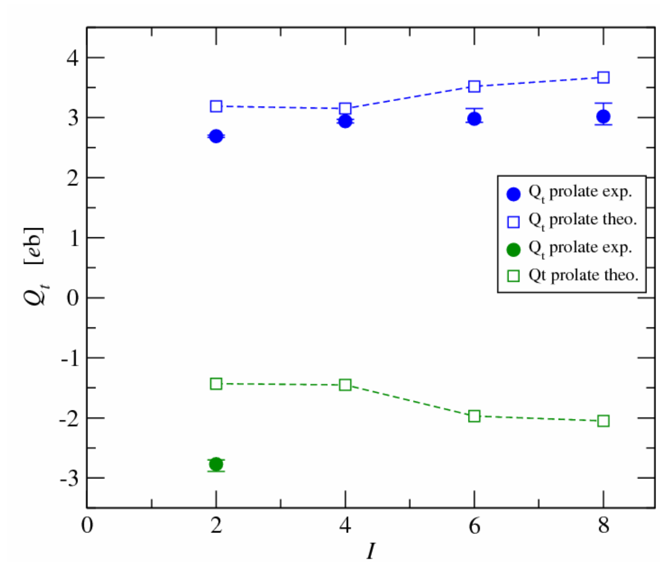
Transition strengths: B(E2)



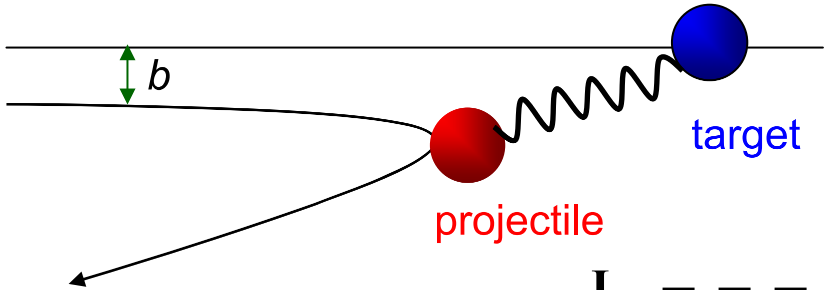




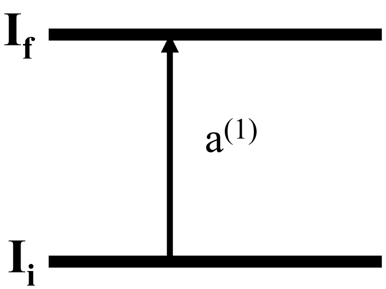
HFB+GCM
M. Bender,
P.H. Heenen
priv. comm.



Coulomb excitation

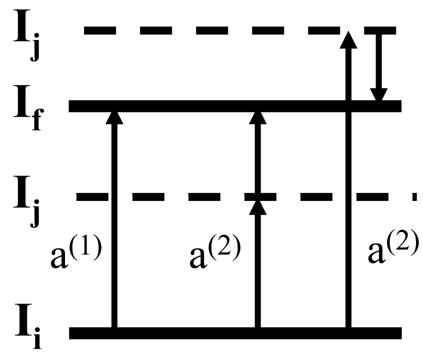


- safe energy: $r_d > 1.25\,(A_T^{\frac{1}{3}} + A_P^{\frac{1}{3}}) + 5\ \text{fm}$
- purely electromagnetic process
- excitatitation cross section is a direct measure of the *E*λ matrix elements.



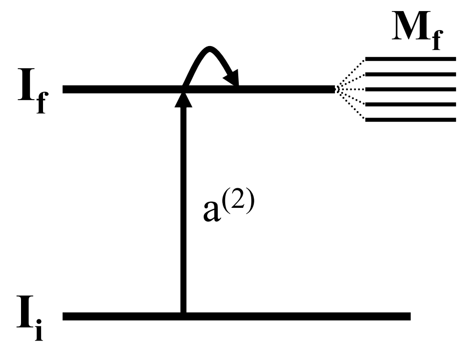
1st order:

$$a^{(1)} \propto \langle I_f \| \mathrm{M}(E2) \| I_i \rangle$$



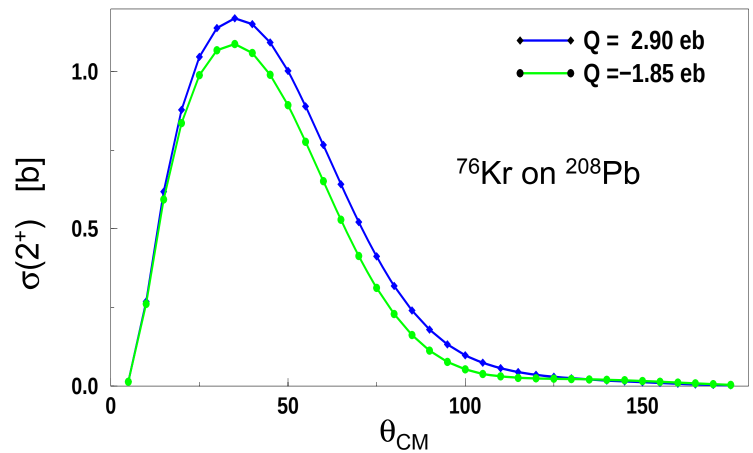
2nd order:

$$a^{(2)} \propto \sum_j \langle I_f \| \mathrm{M}(E2) \| I_j \rangle \langle I_j \| \mathrm{M}(E2) \| I_i \rangle$$



reorientation effect:

$$a^{(2)} \propto \langle I_f \| \mathrm{M}(E2) \| I_f \rangle \langle I_f \| \mathrm{M}(E2) \| I_i \rangle$$



sensitive to diagonal matrix elements
⇒ intrinsic properties of final state:
quadrupole moment including sign