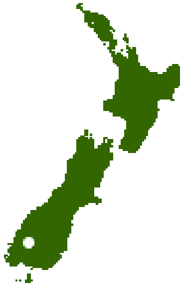
Shape coexistence in 

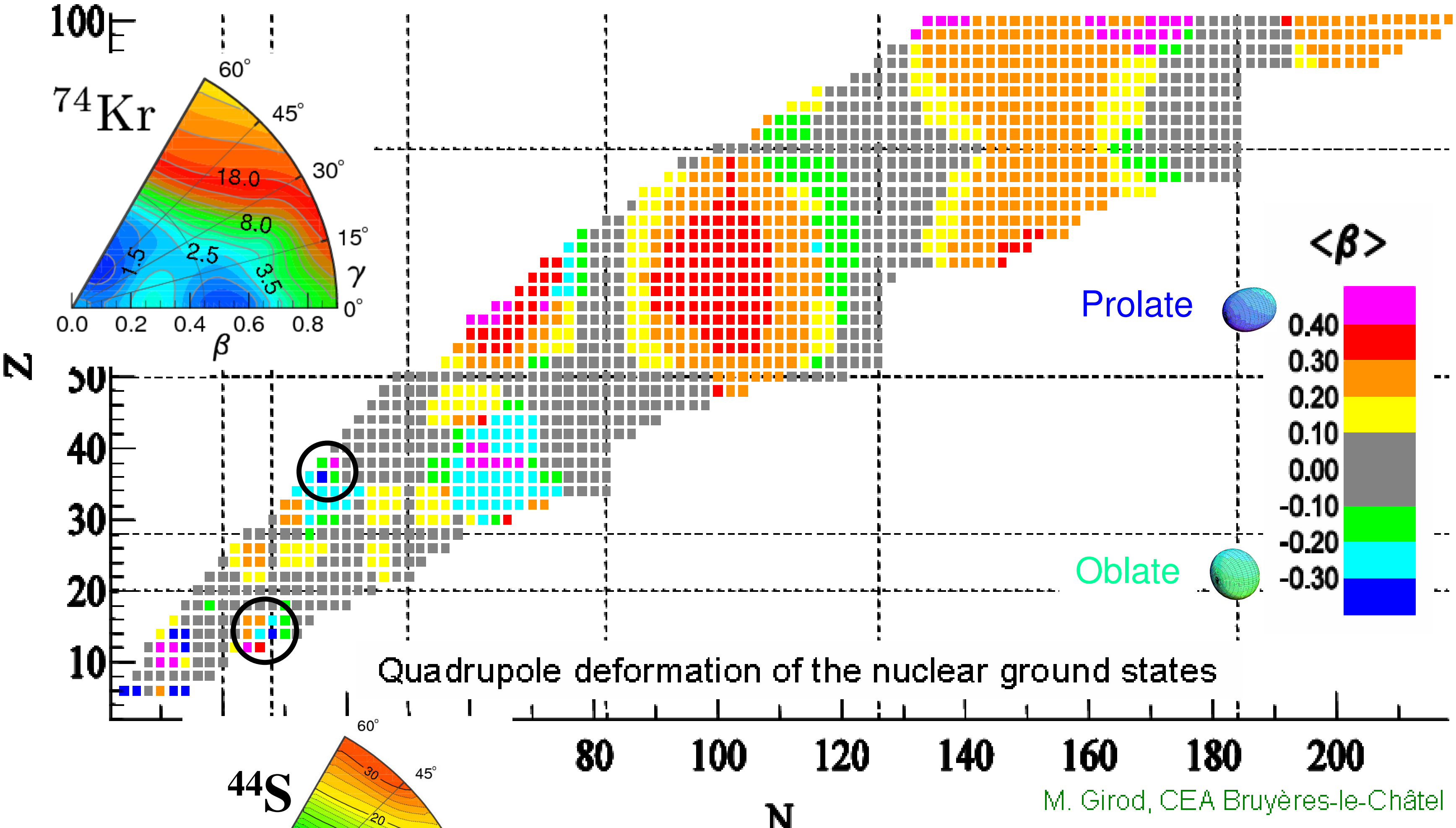
Kr and Se isotopes near N=Z

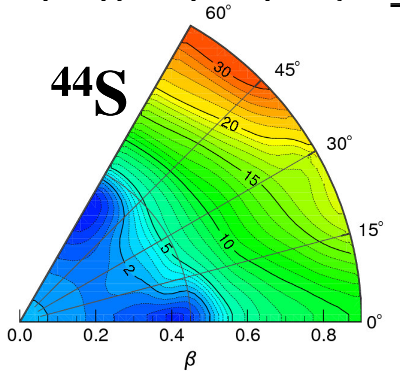
(incl. new bonus material)

Andreas Görgen

Service de Physique Nucléaire
CEA Saclay

Nuclear shapes



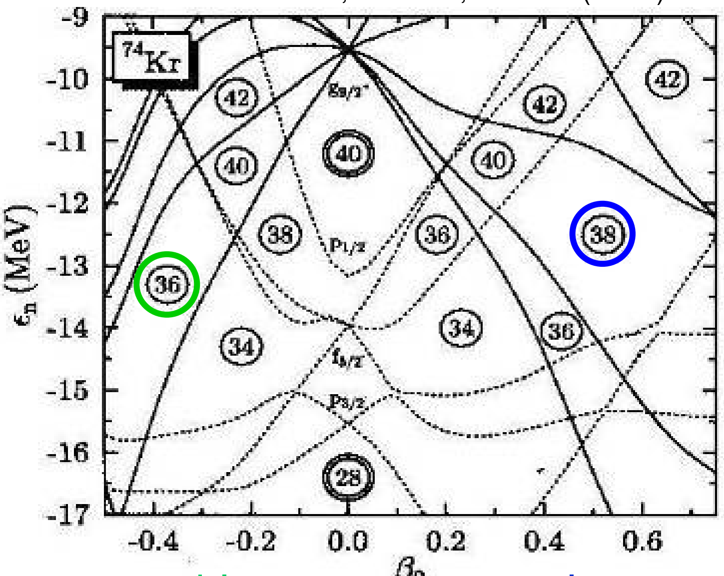


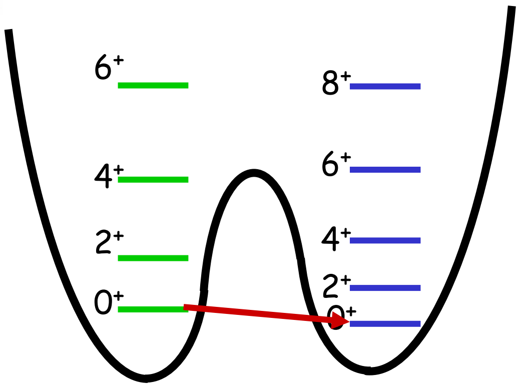
quadrupole moments of excited states, transition rates

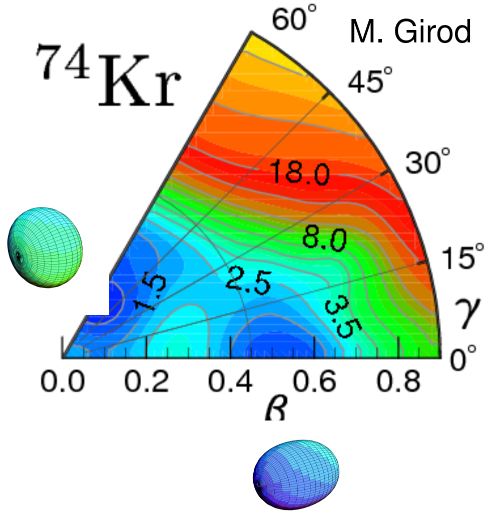
- shape coexistence
- shape evolution with N, Z, energy, spin
- evolution of shell structure far from stability
- benchmarks for nuclear structure theory

Shape coexistence

M. Bender et al., PRC 74, 024312 (2006)







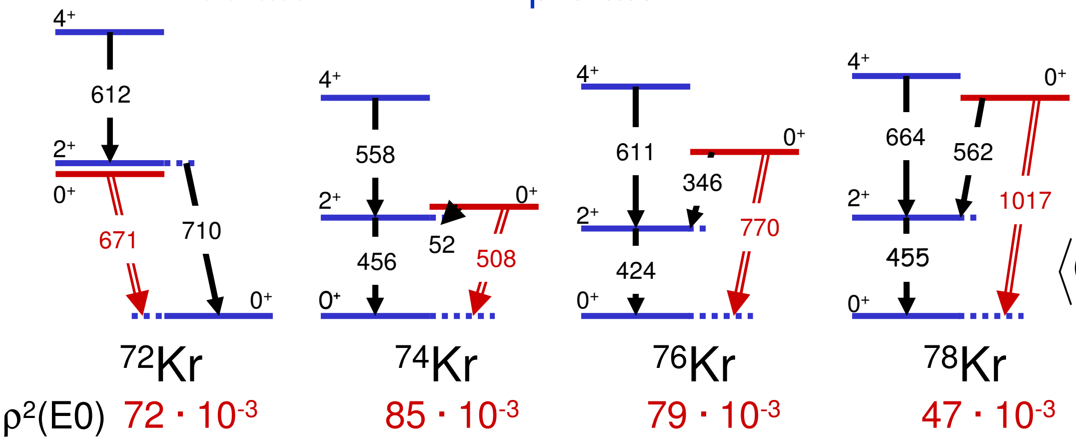
Configuration mixing:

$$\left|0_1^+\right\rangle = +\cos\eta \left|0_{\text{pro}}^+\right\rangle + \sin\eta \left|0_{\text{obl}}^+\right\rangle$$

$$\left|0_2^+\right\rangle = -\sin\eta \left|0_{\text{pro}}^+\right\rangle + \cos\eta \left|0_{\text{obl}}^+\right\rangle$$

electric monopole transition

$$\left\langle 0_2^+ \right\| \mathbf{M}(E0) \left\| 0_1^+ \right\rangle \propto \sin\eta \cos\eta \, (\beta_{\text{pro}}^2 - \beta_{\text{obl}}^2)$$

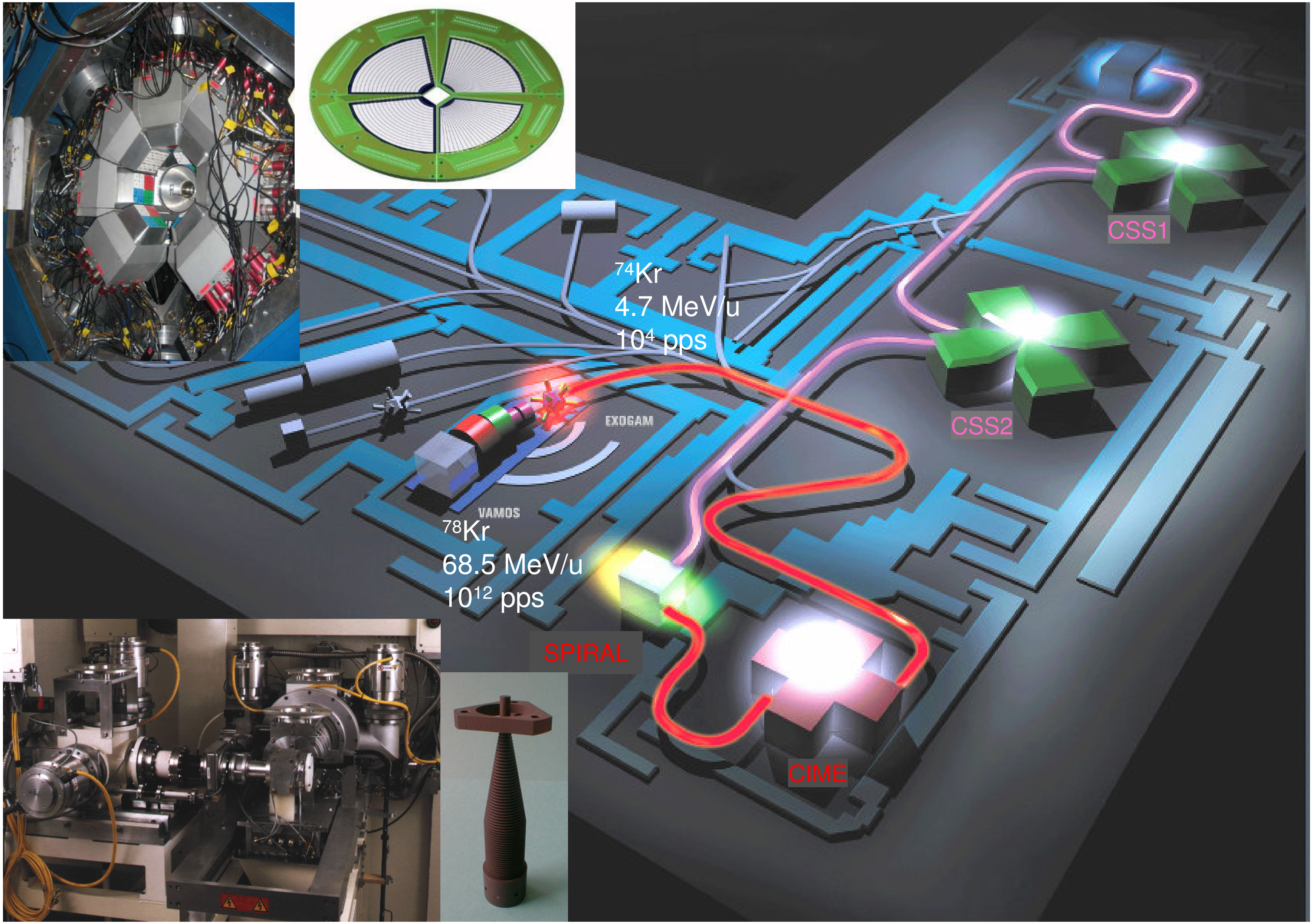


- shape isomers
- shape inversion for ^{72}Kr

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

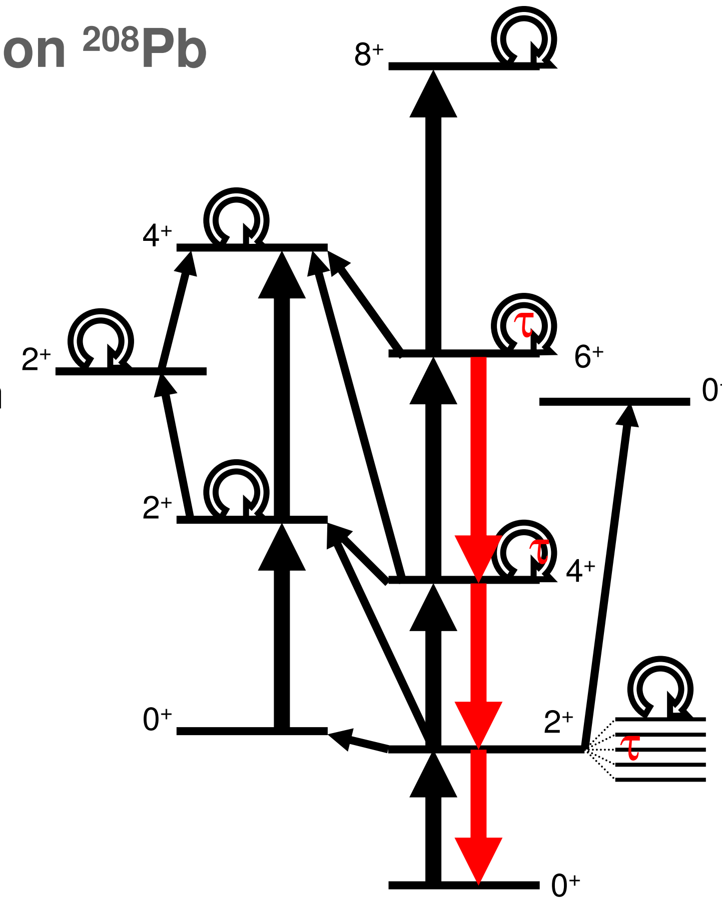
Irfu cea saclay

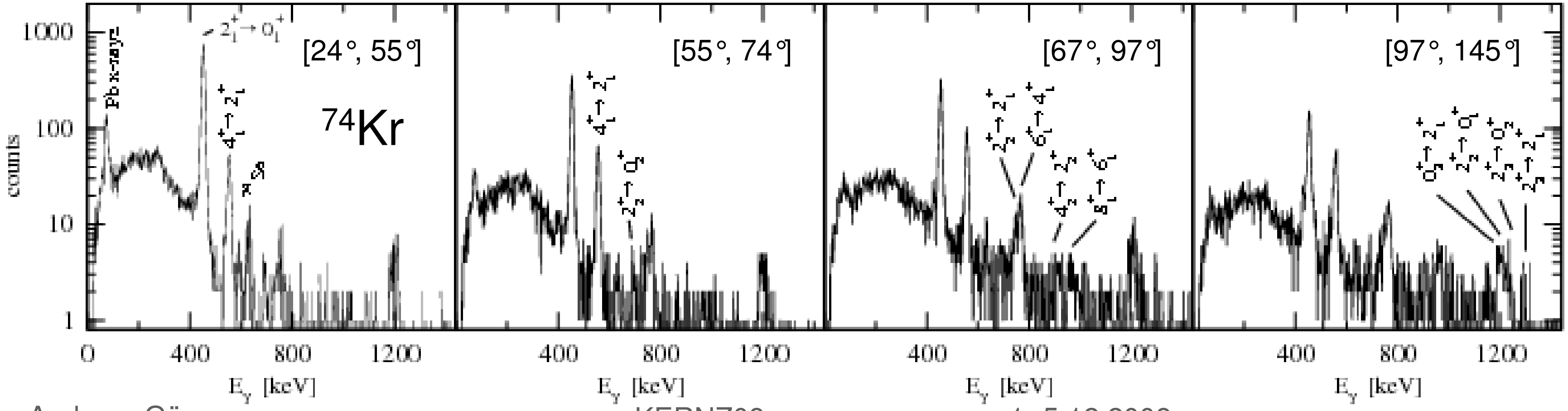
Coulomb excitation of radioactive beams from SPIRAL / GANIL



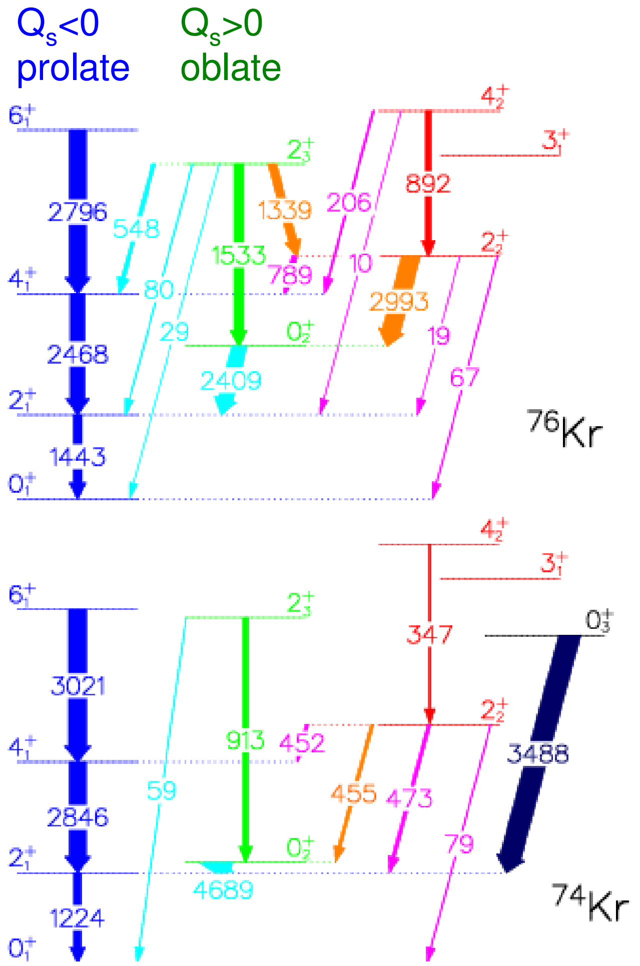
Multi-step Coulomb excitation of ^{74,76}Kr on ^{208}Pb

- safe energy ⇒ purely electromagnetic excitation
- transitional matrix element ⇒ **B(E2)**
- diagonal matrix element ⇒ Q_s
- reorientation effect ⇒ sensitive to nuclear shape
- ~20 matrix elements involved in multi-step excitation
- de-excitation γ-ray yields ⇒ **dσ/dθ**
- χ^2 minimization of matrix elements to reproduce experimental γ-ray yields (code GOSIA)
- spectroscopic data (lifetimes, branching ratios) as additional data points for χ^2 fit
- lifetimes: B(E2) independent of Q_s
  RDDS measurement at Legnaro for ^{74,76}Kr
  A. Görgen et al. Eur. Phys. J. A 26, 153 (2005)





Experimental results and comparison with theory



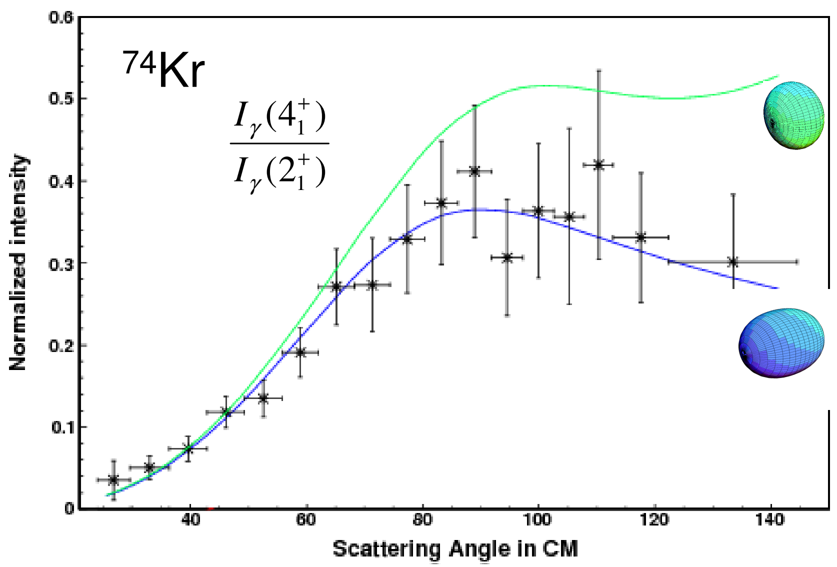
experimental B(E2;↓) [e^2fm^4]

E. Clément et al., Phys. Rev. C 75, 054313 (2007)

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

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

⇒ prolate shape



- **first reorientation measurement with radioactive beam**
- **quantitative understanding of shape coexistence and configuration mixing**

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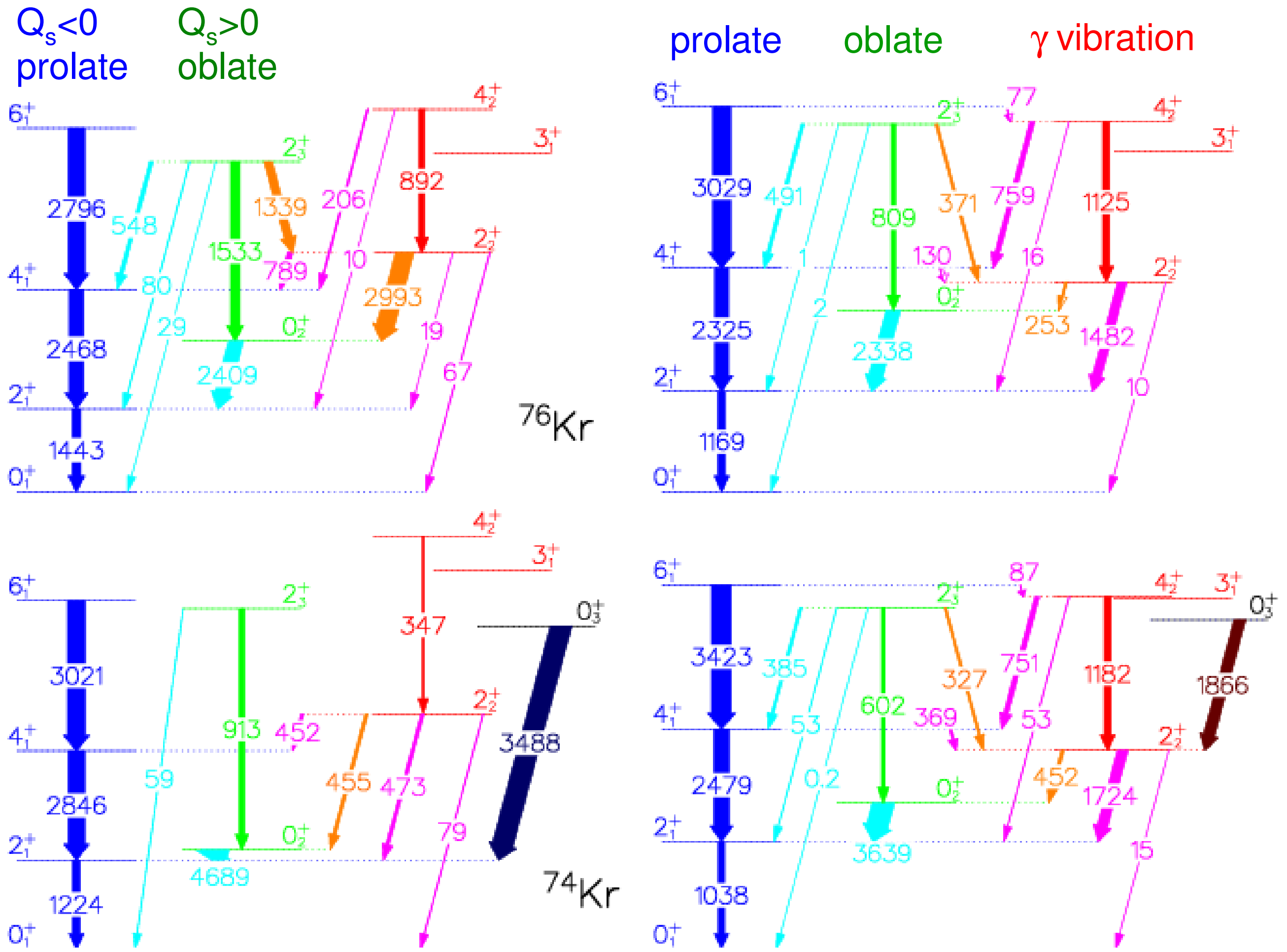
Experimental results and comparison with theory



experimental B(E2;↓) [e^2fm^4]

E. Clément et al., Phys. Rev. C 75, 054313 (2007)

theory: Gogny 5-dim GCM(GOA)
CEA Bruyères-le-Châtel

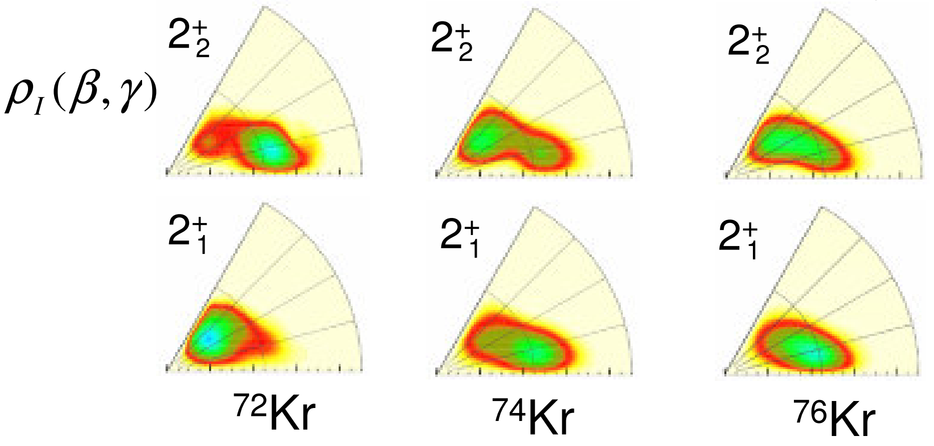
- **first reorientation measurement with radioactive beam**
- **quantitative understanding of shape coexistence and configuration mixing**

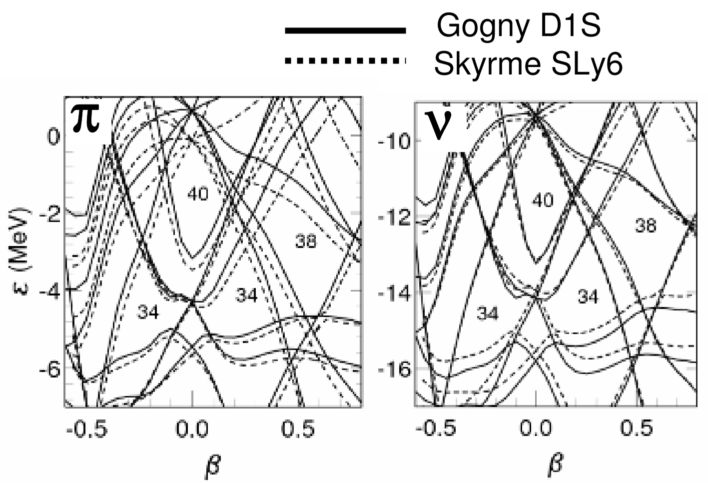
Shape transition in the light krypton isotopes

GCM(GOA) configuration mixing calculation

- 5 dimensional: q_{20}, q_{22}, Euler angles
- Gogny D1S interaction

M. Girod et al., submitted to Phys. Lett. B



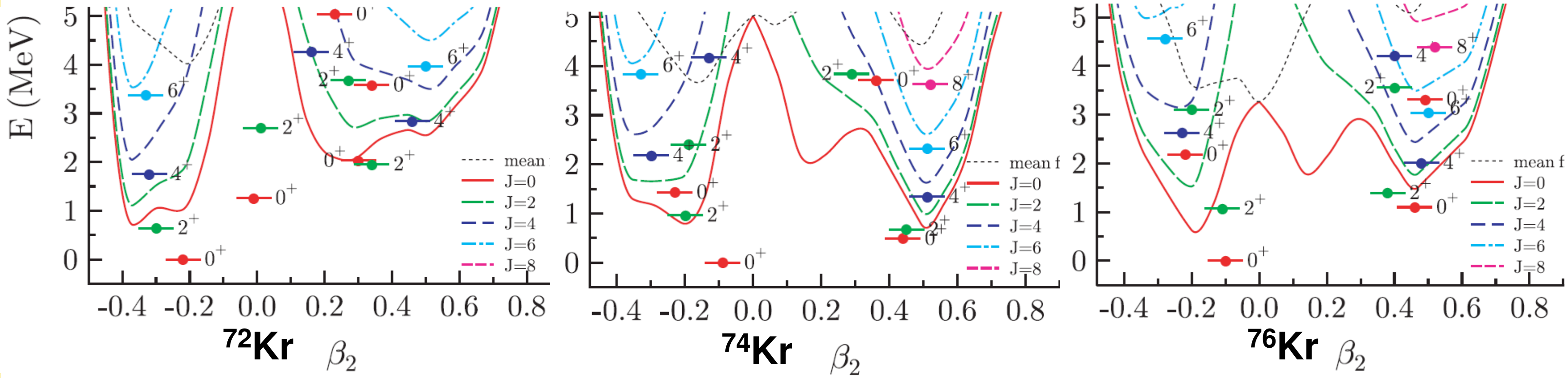


- equivalent on mean-field level
- **need to include triaxiality to describe prolate-oblate shape coexistence**

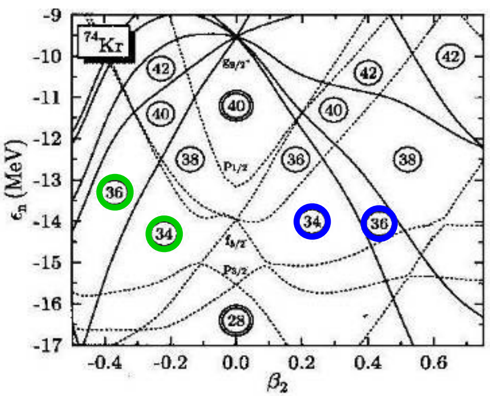
GCM configuration mixing calculation

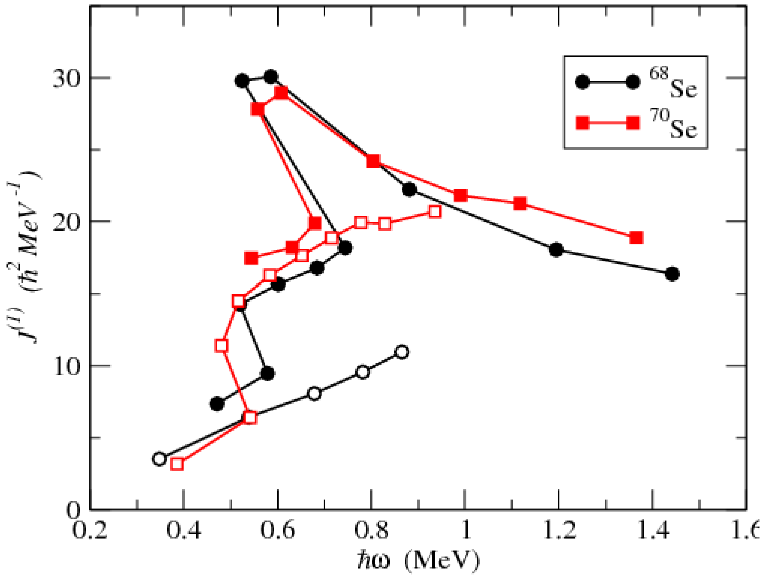
- axial deformation only: q_{20}
- Skyrme SLy6 interaction

M. Bender et al., PRC 74, 024312 (2006)



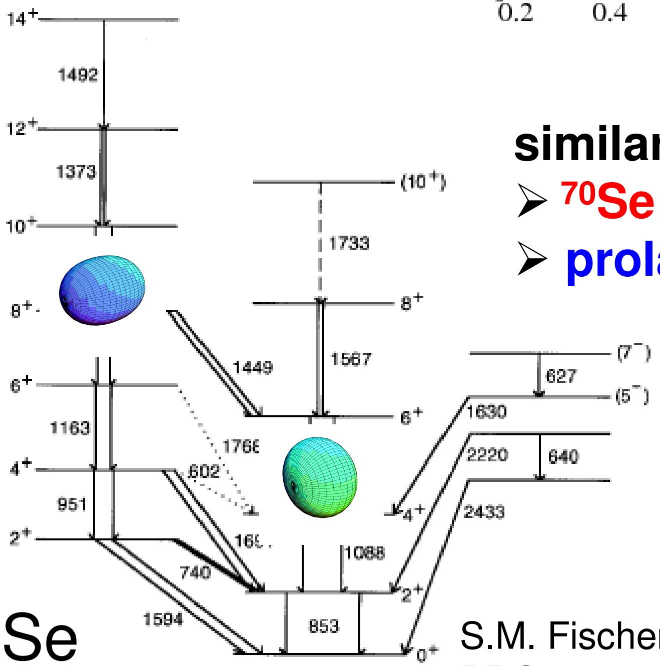
Shape coexistence in light Selenium isotopes





similar $J^{(1)}$ in ^{68}Se and ^{70}Se:

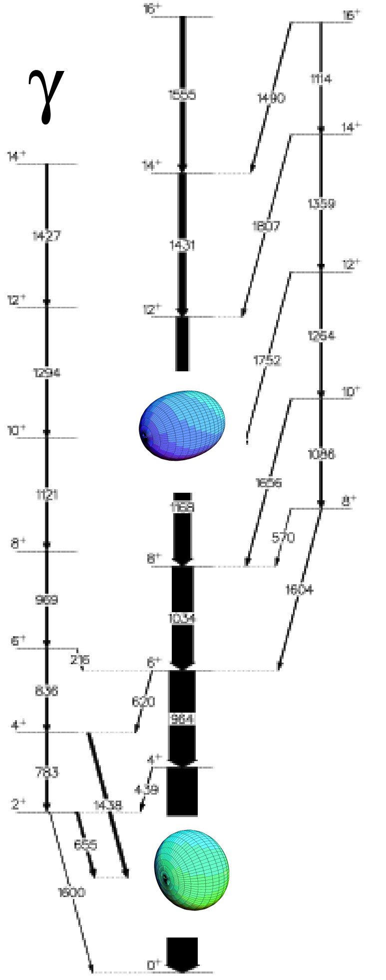
- **^{70}Se oblate near ground state**
- **prolate at higher spin**



^{68}Se

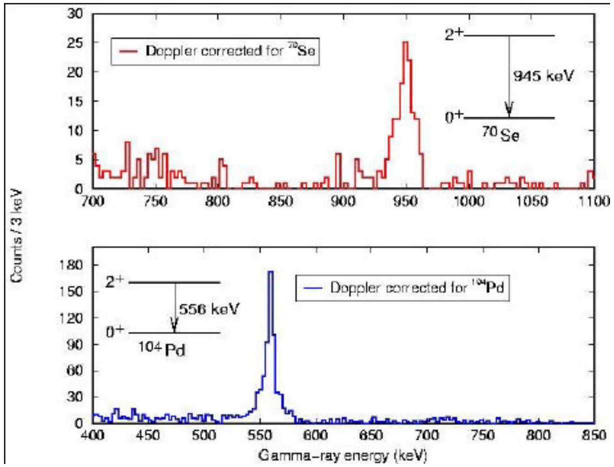
S.M. Fischer et al.,
PRC 67, 064318 (2003)

^{70}Se $\pi(g_{9/2})^2 \otimes\nu(g_{9/2})^2$



G. Rainovski et al.,
J.Phys.G 28, 2617 (2002)

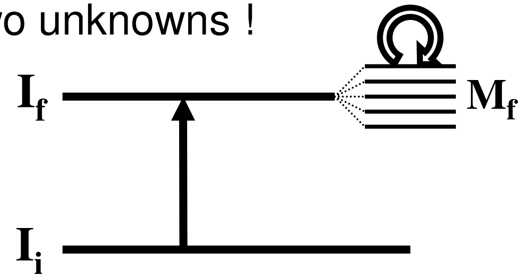
Coulomb excitation of ^{70}Se at CERN / ISOLDE

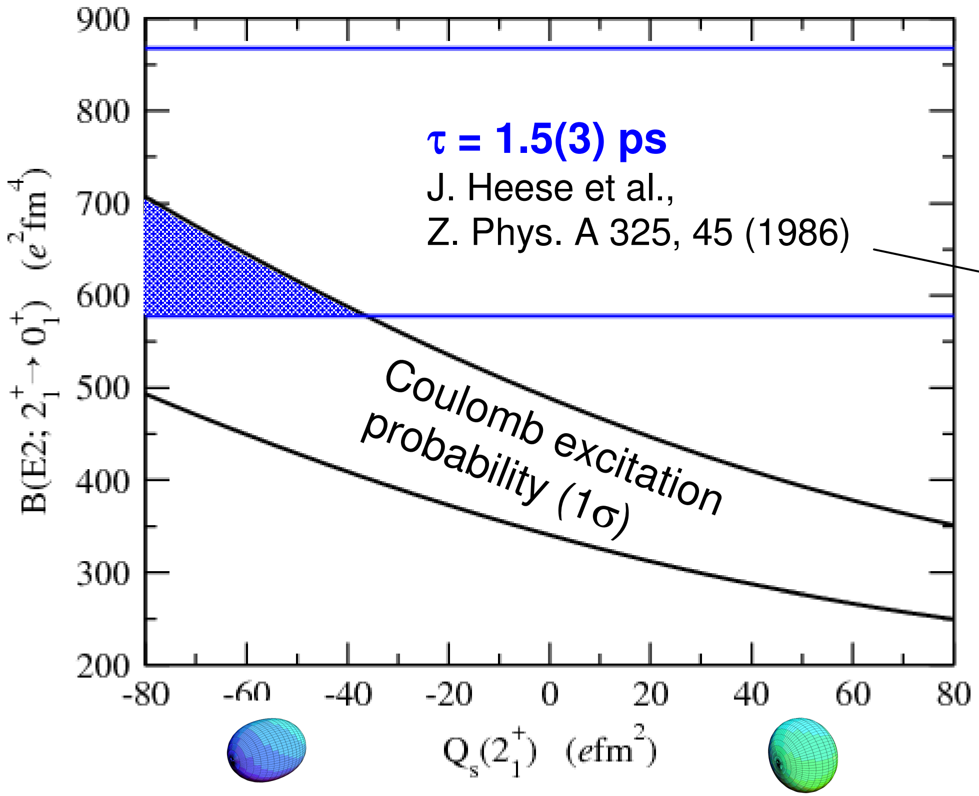


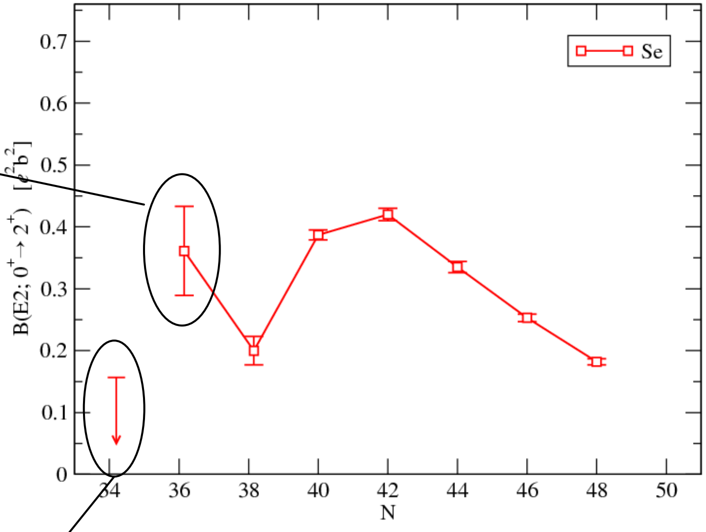
- ^{70}Se on ^{104}Pd at 2.94 MeV/u
- integral measurement
- excitation probability via normalization to target

- depends on **B(E2)** and **Q_s**
- one measurement, two unknowns !

A.M. Hurst et al.,
PRL 98, 072501 (2007)

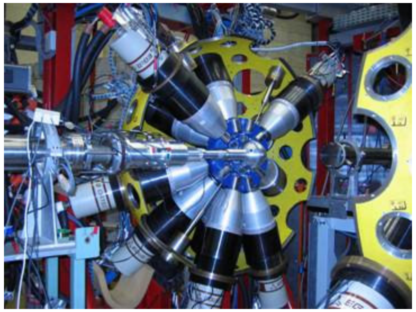




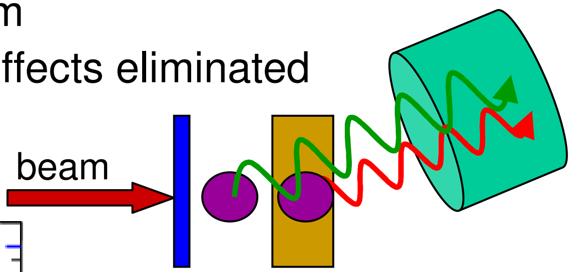


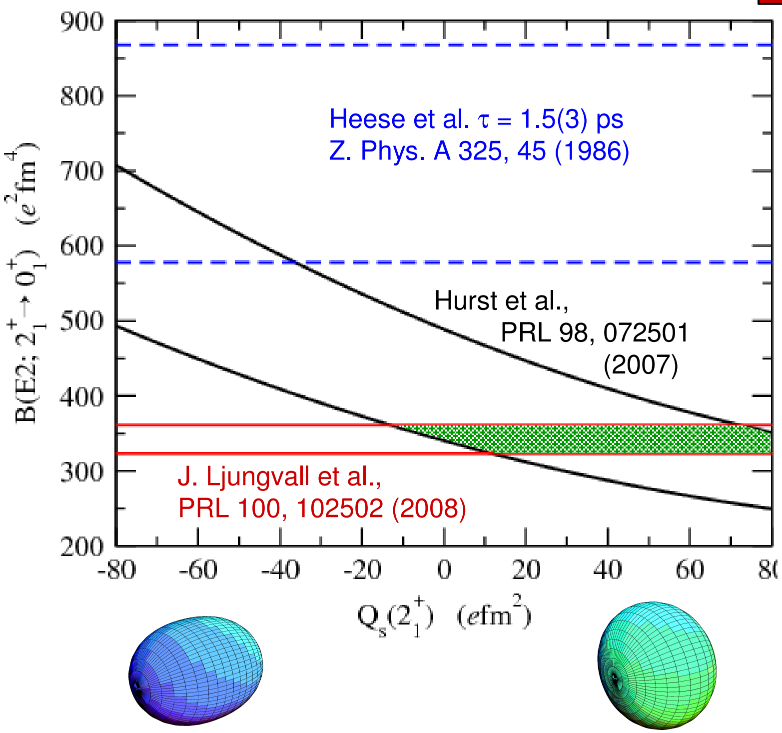
GANIL intermediate-energy Coulex ^{68}Se
E. Clément et al., NIM A 587, 292 (2008)

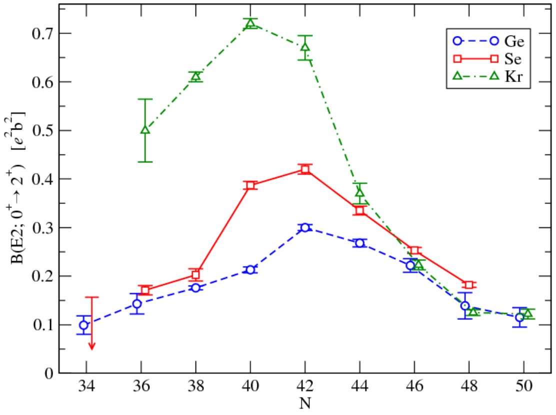
Lifetimes in ^{70}Se and ^{72}Se revisited

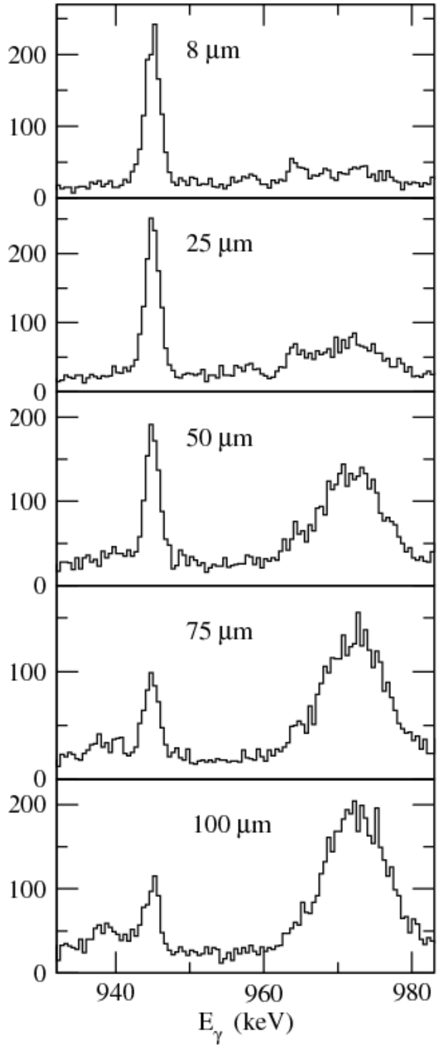


- Recoil-distance Doppler Shift
- GASP and Köln Plunger at Legnaro
- $^{40}Ca(^{36}Ar,\alpha 2p)^{70}Se$
- 12 distances between 8 and 400 μm
- gated from above ⇒ side feeding effects eliminated
- **^{70}Se, τ (2$^+$)=3.2(2) ps**



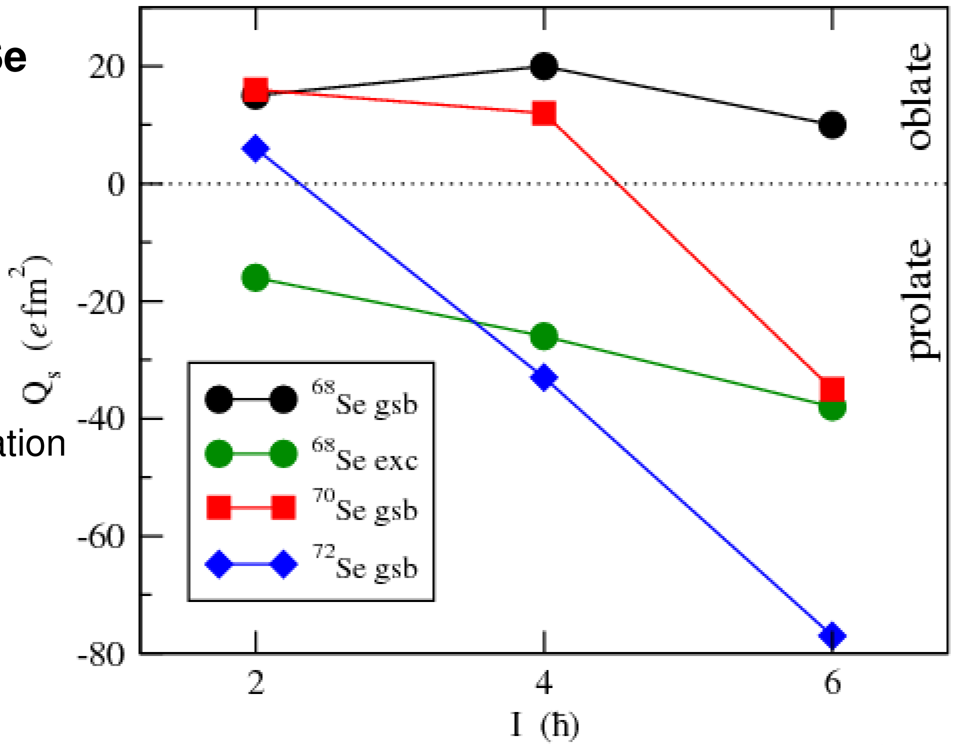




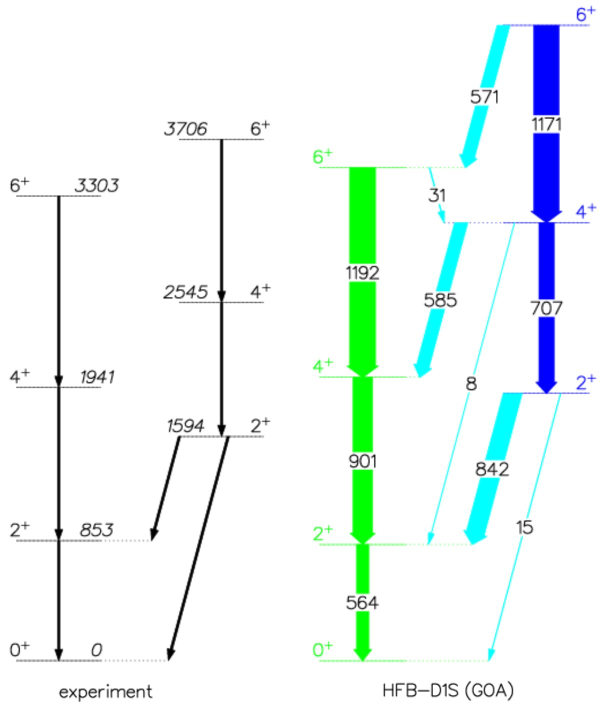


Shape evolution in the light Selenium isotopes

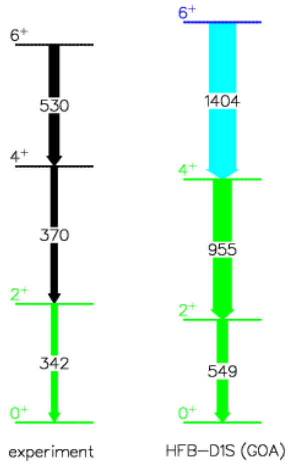
- **oblate rotation prevails only in ^{68}Se**
  ⇒ best example for shape coexistence in A=70 region
- **experimental matrix elements and quadrupole moments needed for ^{68}Se**



Q_s from Gogny configuration mixing calculation

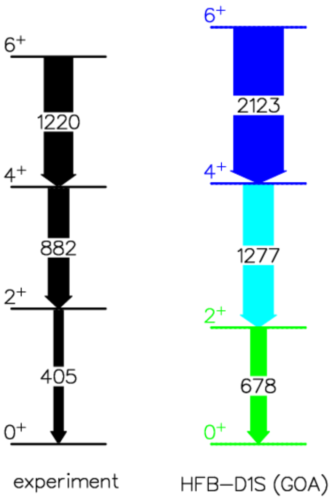


^{68}Se



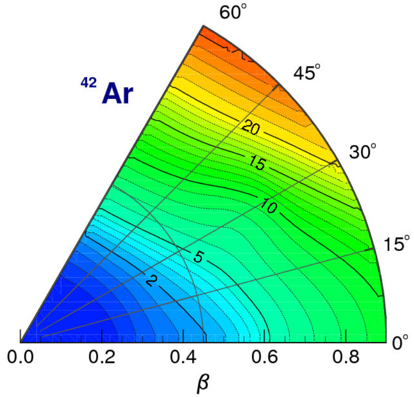
^{70}Se

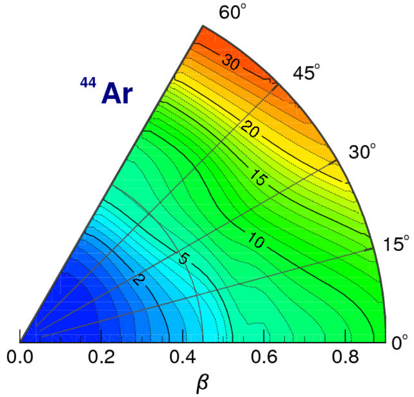
B(E2,↓) in e^2fm^4

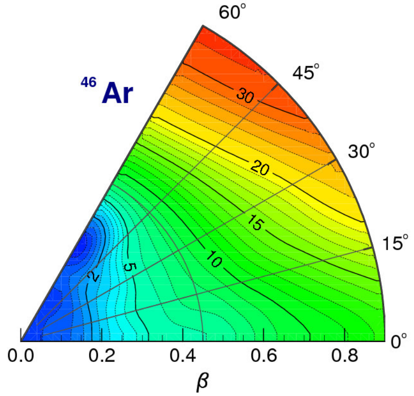


^{72}Se

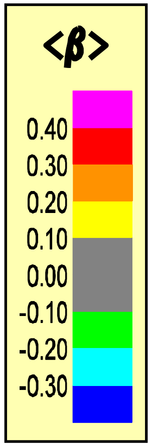
Development of deformation for N=28 below ^{48}Ca



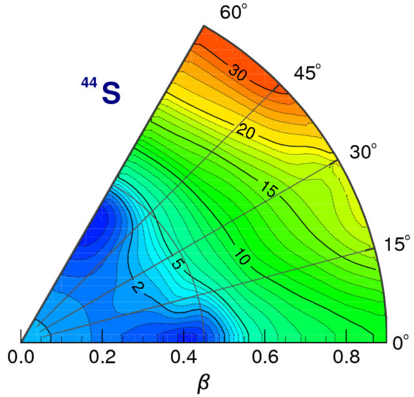


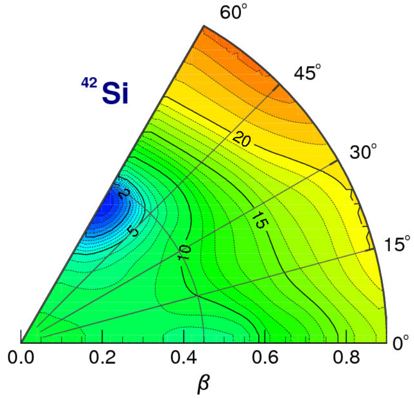


Z \ N	20	22	24	26	28	30
20	Ca 40 96.94	Ca 42 0.65	Ca 44 2.08	Ca 46 0.003	Ca 48 0.19	Ca 50 13.9 s
18	Ar 38 0.07	Ar 40 99.59	Ar 42 32.9 y	Ar 44 11.9 m	Ar 46 8.4 s	Ar 48 0.48 s
16	S 36 0.015	S 38 170 m	S 40 8.8 s	S 42 1.01 s	S 44 123 ms	S 46 50 ms
14	Si 34 2.77 s	Si 36 0.45 s	Si 38 >1 μs	Si 40 33 ms	Si 42 13 ms	Si 44 10 ms
12	Mg 32 86 ms	Mg 34 20 ms	Mg 36 3.9 ms	Mg 38 >260 ns	Mg 40 1 ms	
	20	22	24	26	**28**	30



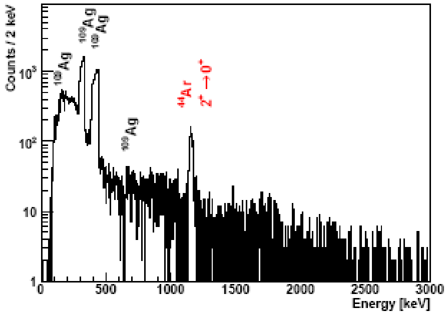
M. Girod
Bruyères-le-Châtel



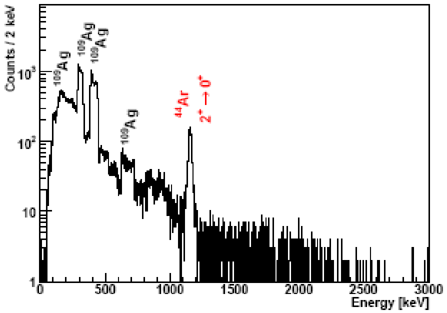


Coulomb excitation of ^{44}Ar at SPIRAL

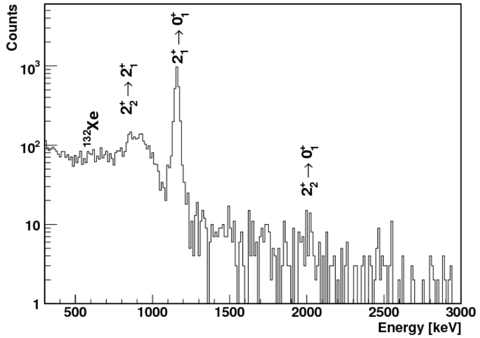
^{109}Ag target, 35°<θ_{cm}<70°



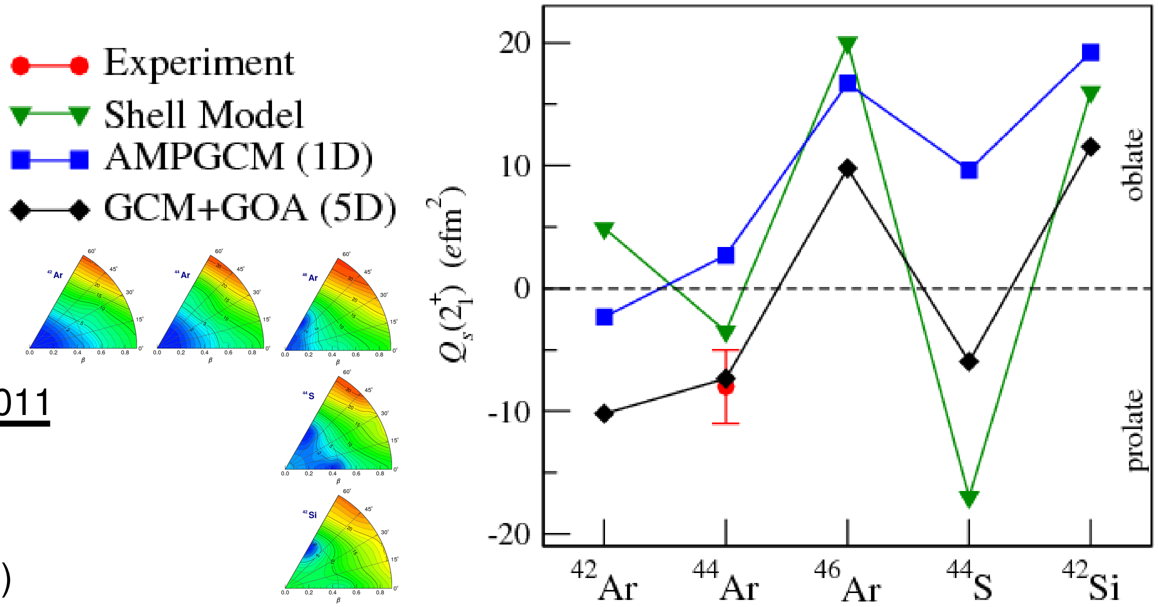
^{109}Ag target, 70°<θ_{cm}<130°

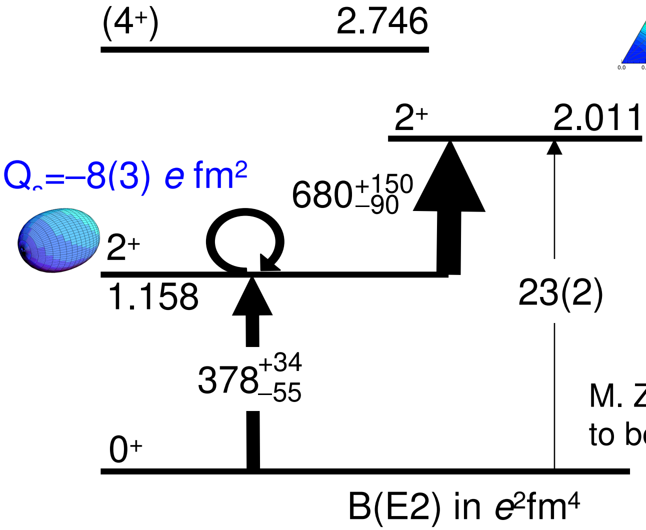


^{208}Pb target, 30°<θ_{cm}<130°



- EXOGAM + DSSD
- SPIRAL beam ^{44}Ar
- $3\cdot10^5$ pps
- 2.7·A MeV on ^{109}Ag
- 3.7·A MeV on ^{208}Pb





M. Zielińska et al.
to be published

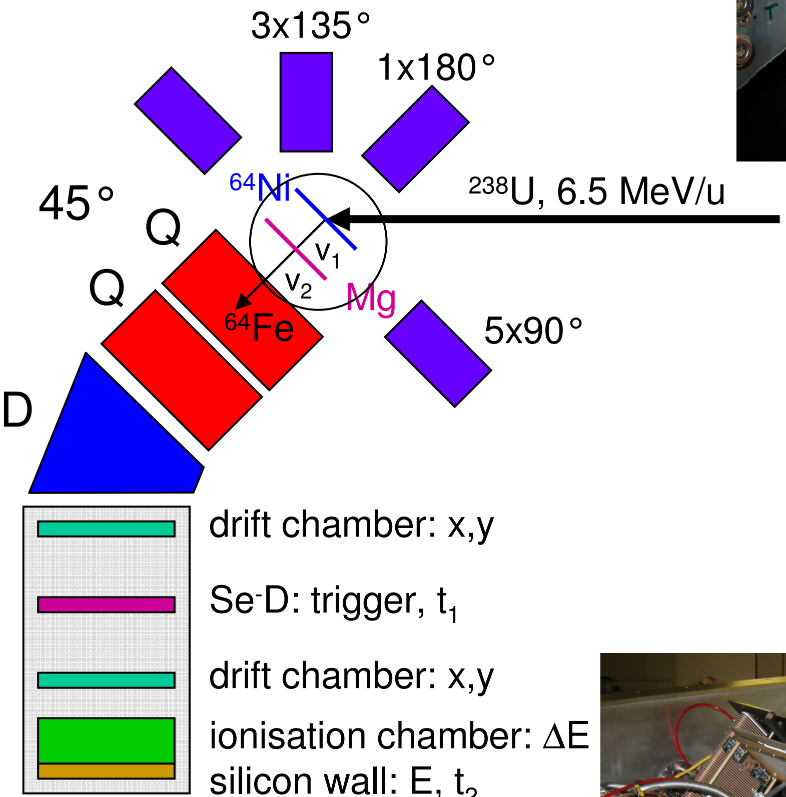
SM : Retamosa et al. PRC 55, 1266 (1997)
Caurier et al. Nucl. Phys. A 742, 14 (2004)

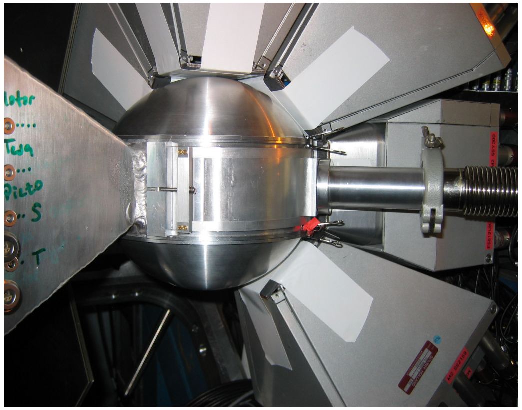
AMPGCM: R. Rodríguez-Guzmán et al. PRC 65, 024304 (2002)

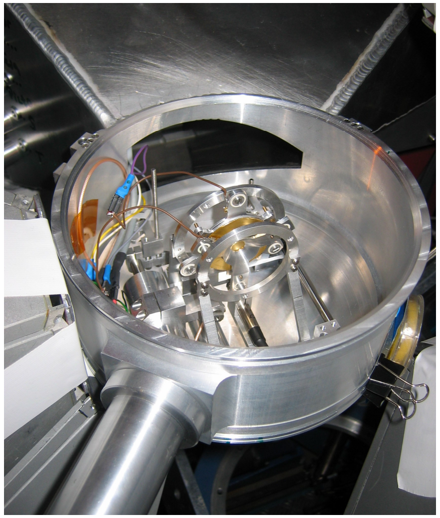
GCM(GOA)-5D: M. Girod

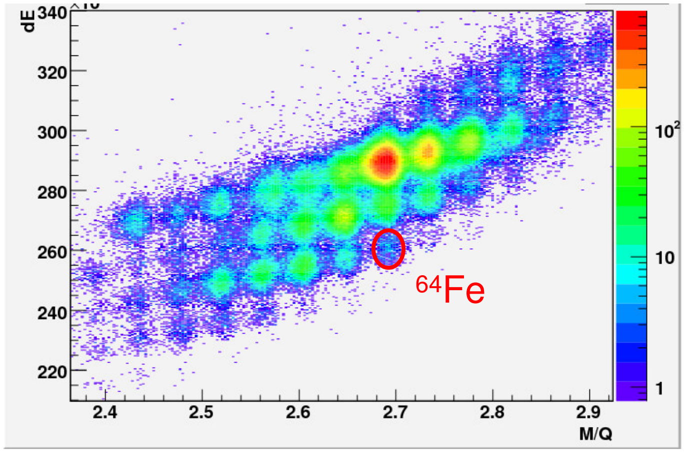
Picosecond lifetimes in neutron-rich nuclei?

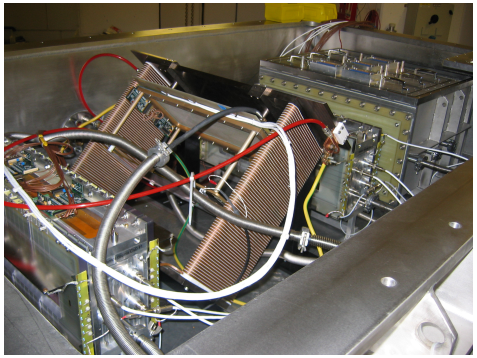
Multi-nucleon transfer $^{238}U + ^{64}Ni$
EXOGAM
VAMOS
differential RDDS Plunger









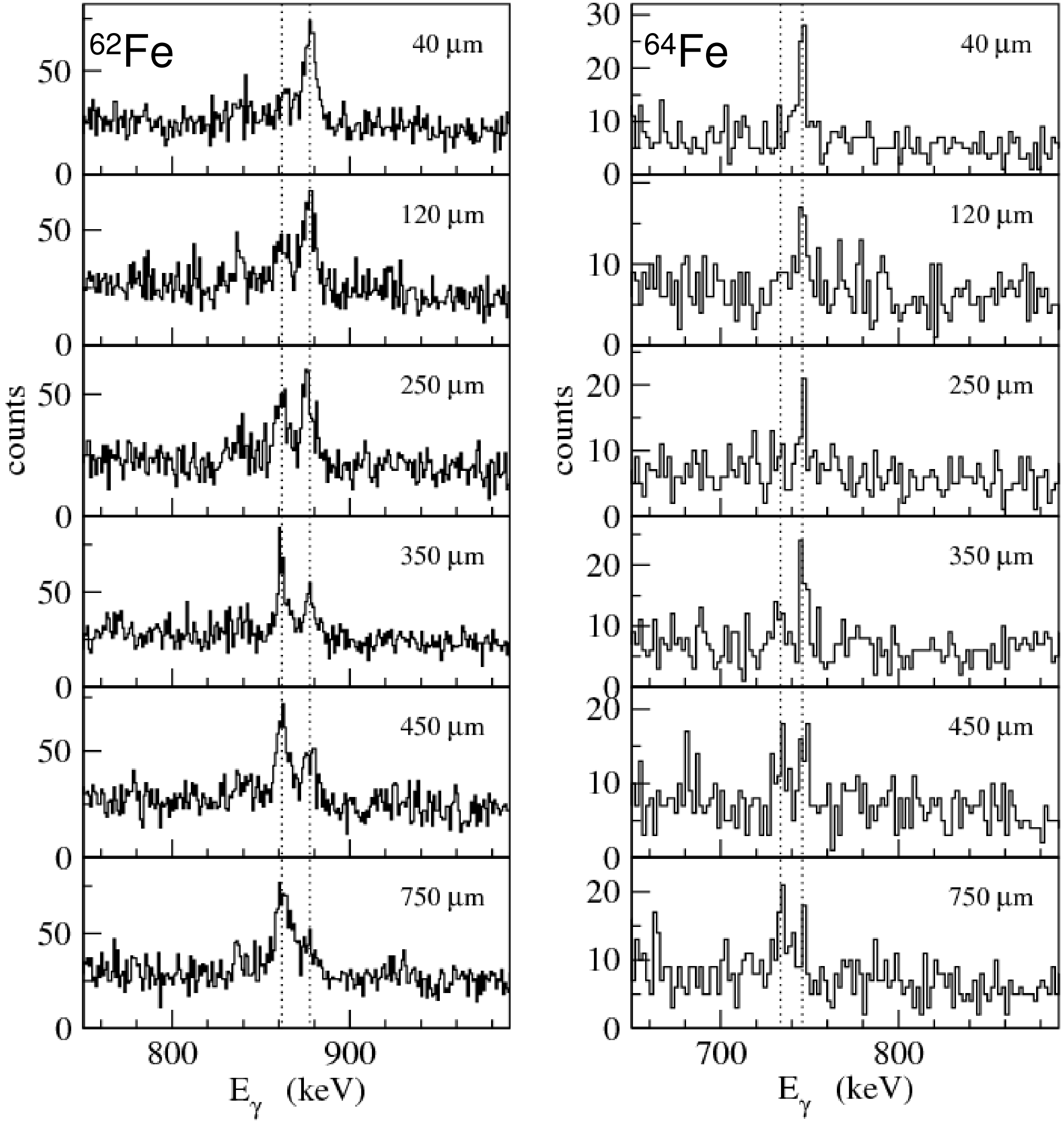


RDDS lifetimes in ^{62}Fe et ^{64}Fe

- beam: ^{238}U at 1547 MeV
- target: ^{64}Ni, 1.5 mg/cm^2
- degrader: ^{nat}Mg, 5 mg/cm^2
- 6 distances 40 – 750 µm

- new technique to measure picosecond lifetimes in neutron-rich nuclei

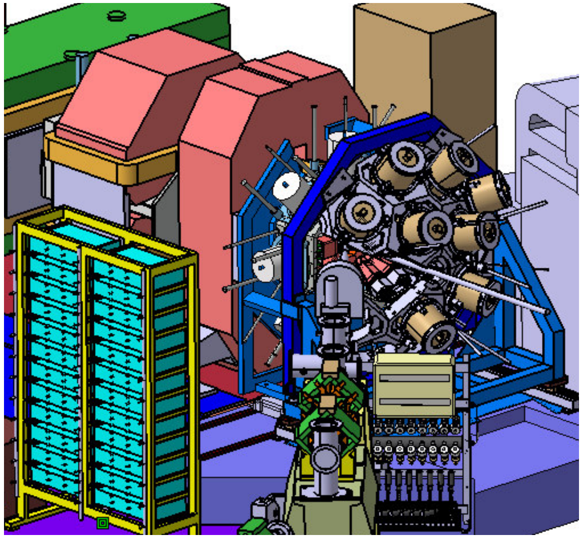
- many more neutron-rich nuclides produced
- many more lifetimes to be measured



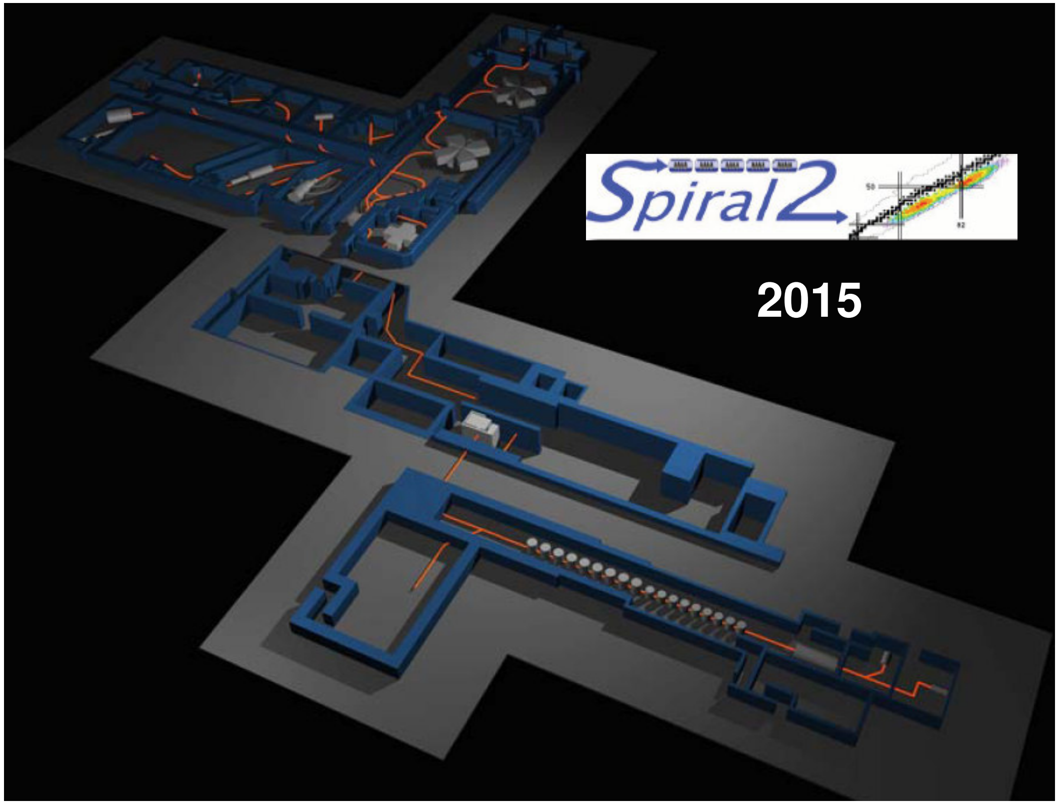
Conclusions and Perspectives

- shape coexistence and evolution in Kr and Se near N=Z
- onset of deformation and shape coexistence near N=28
- nuclear shapes very sensitive to underlying nuclear structure
- quadrupole moments and transition rates as benchmarks for theory
- importance of triaxiality for GCM calculations
- complementary techniques
  - low-energy Coulomb excitation with RIB
  - RDDS lifetime measurements (fusion evaporation, multi-nucleon transfer)

2010



AGATA + EXOGAM + VAMOS



Collaboration

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

Saclay: E. Clément, A. Görgen, W. Korten, E. Bouchez, A. Chatillon, A. Hürstel, Y. Le Coz, A. Obertelli, Ch. Theisen, J.N. Wilson, M. Zielińska
Liverpool: C. Andreoiu, P.A. Butler, R.-D. Herzberg, D.G. Jenkins, G.D. Jones
GSI: F. Becker, J. Gerl
GANIL: J. M. Casandjian, G. de France
Surrey: W. N. Catford, C.N. Timis
Warsaw: T. Czosnyka, J. Iwanicki, P. Napiorkowski
NBI: G. Sletten

Lifetime measurement ^{74}Kr and ^{76}Kr

Saclay: A. Görgen, E. Clément, A. Chatillon, W. Korten, Y. Le Coz, Ch. Theisen
IKP Köln: A. Dewald, B. Melon, O. Möller, K.O. Zell
Legnaro: N. Marginean, R. Menegazzo, D. Tonev, C.A. Ur

Lifetime measurement ^{70}Se and ^{72}Se

Saclay: J. Ljungvall, A. Görgen, C. Dossat, W. Korten, A. Obertelli, Ch. Theisen, M. Zielińska
IKP Köln: A. Dewald, B. Melon, T. Pissulla, K.O. Zell
Legnaro: R. Menegazzo, R. Orlandi, R.P. Singh, C.A. Ur, J.J. Valiente-Dobón
Oslo: S. Siem
Warsaw: J. Srebrny

Coulomb excitation ^{44}Ar

Saclay: M. Zielińska, A. Görgen, E. Clément, W. Korten, A. Bürger, C. Dossat, J. Ljungvall, A. Obertelli, Ch. Theisen
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Warsaw: J. Iwanicki, P. J. Napiorkowski, D. Pietak, J. Srebrny, K. Wrzosek
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Lifetime measurement ^{62}Fe and ^{64}Fe

Saclay: J. Ljungvall, A. Obertelli, A. Görgen, W. Korten
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