Nuclear deformation in excited states studied by low-energy Coulomb excitation and lifetime measurements

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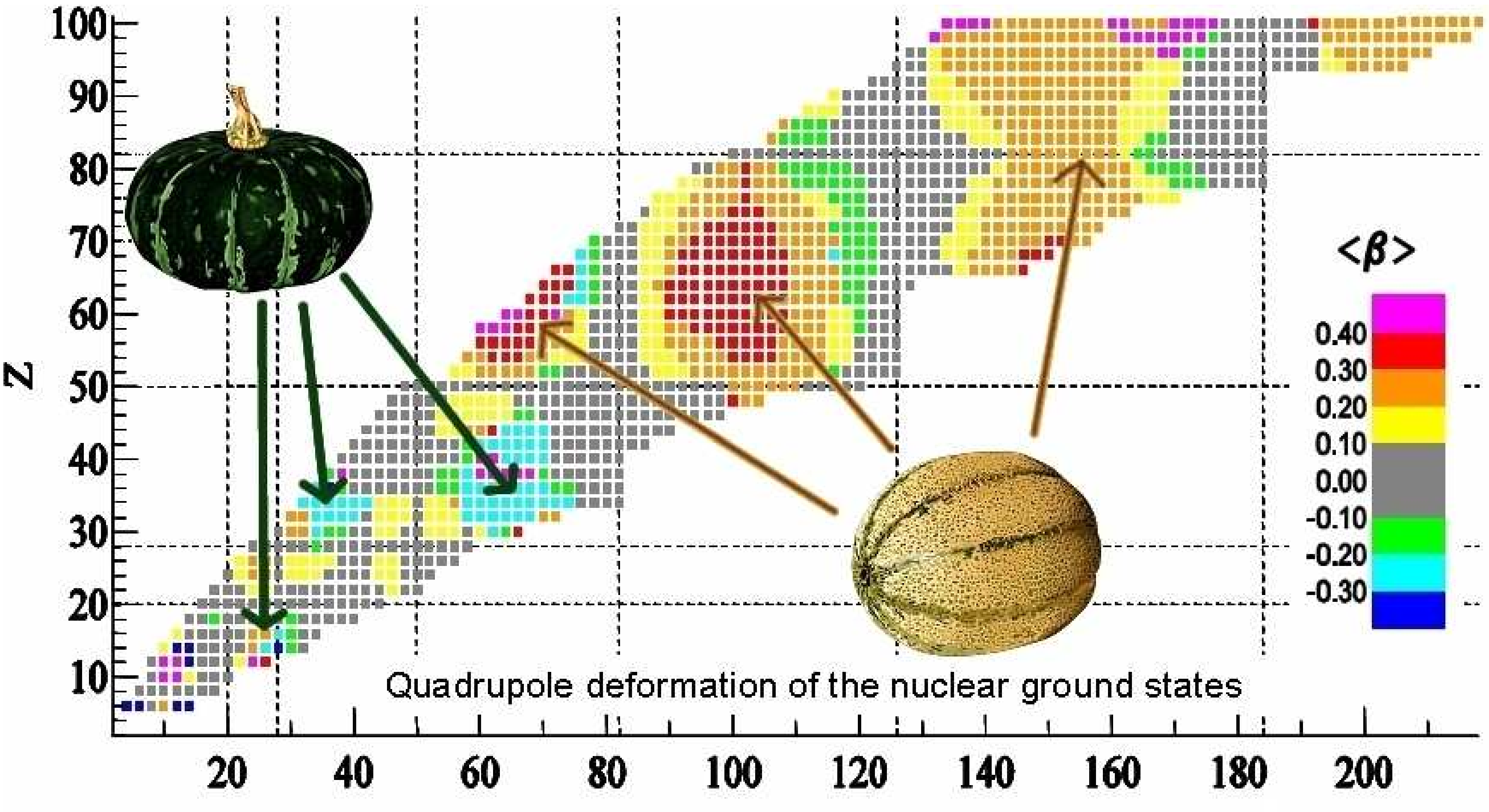
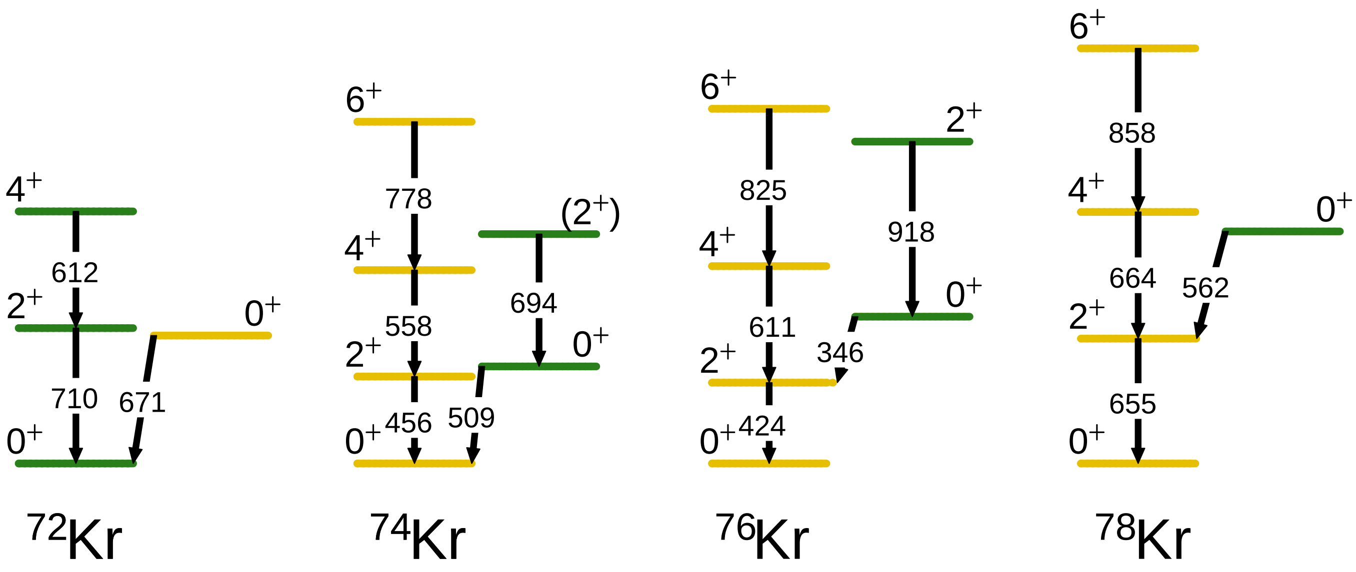
- electromagnetic structure of light krypton isotopes
- measurements in the vicinity of ^{68}Ni
- measurements in the A $\approx$ 100 region
- technical developments for future Coulex studies

Shapes of atomic nuclei



M. Girod, CEA Bruyéres-le-Châtel

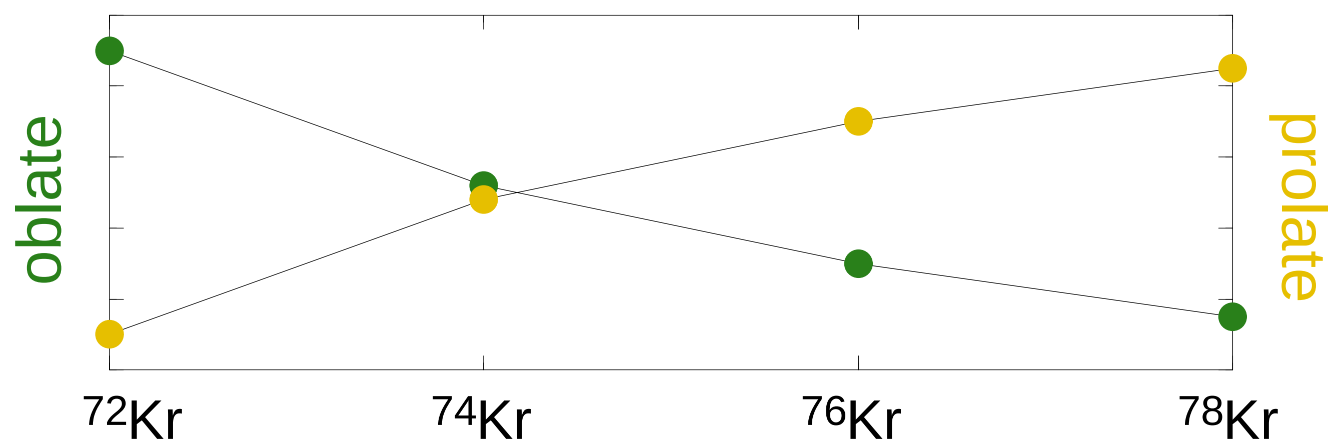
Systematics of the neutron-deficient Kr isotopes



prolate

oblate

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

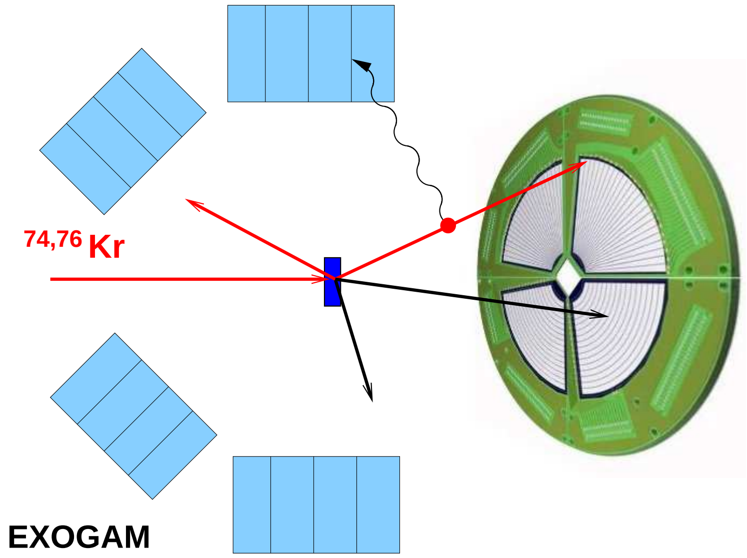


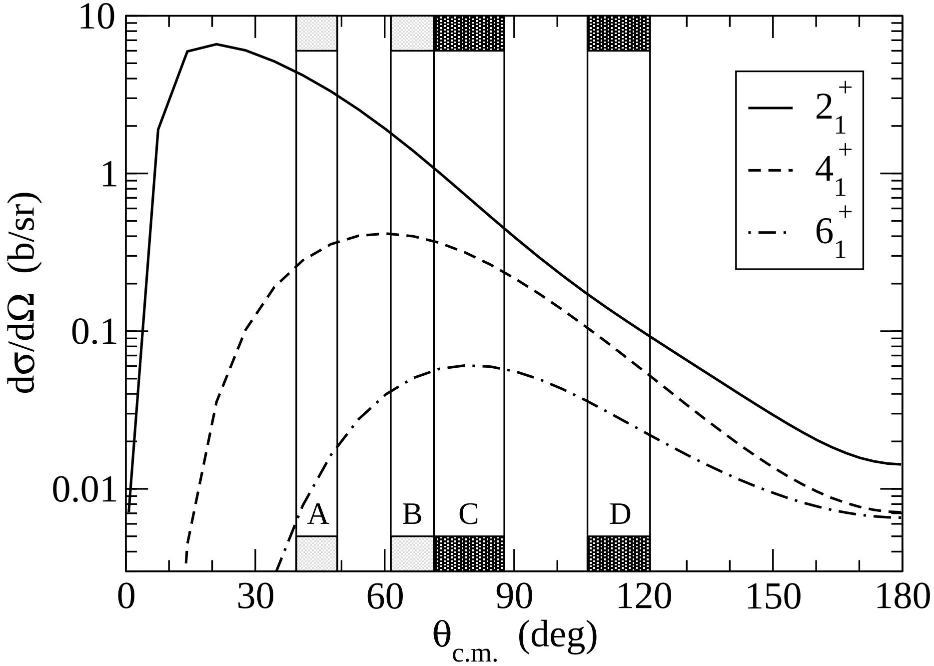
- inversion of the ground state shape for ^{72}Kr
- Coulomb excitation to determine directly the nuclear shapes

mixing of the ground state (from distortion of the rotational bands)

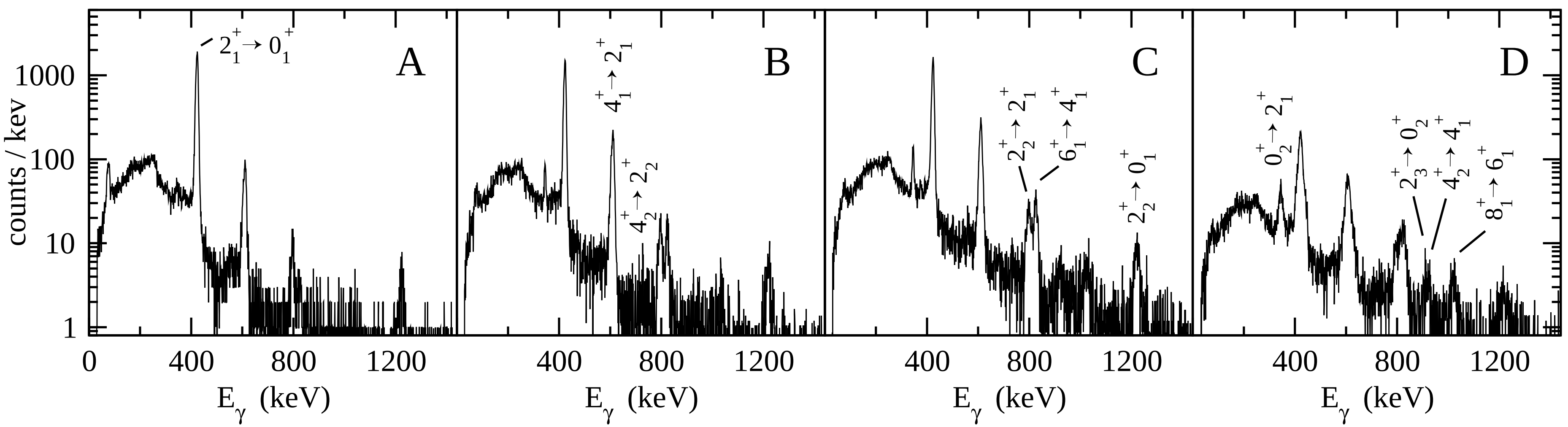
E. Bouchez *et al.* Phys. Rev. Lett. 90, 082502 (2003)

Coulomb excitation of ^{76,74}Kr

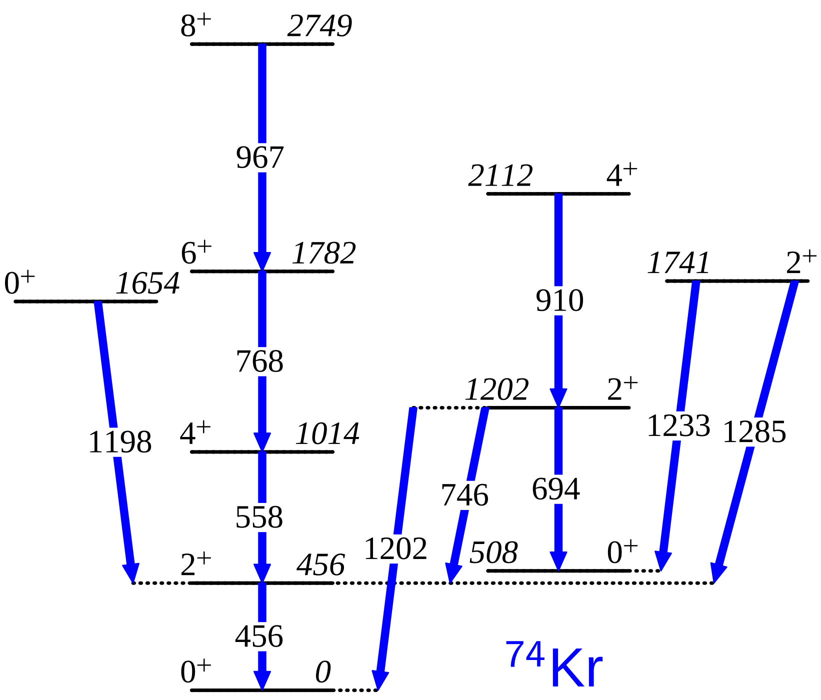




- 6 + 1 (^{76}Kr) or 7 + 4 (^{74}Kr) segmented clovers in EXOGAM
- highly segmented particle detector in forward angles: 16 sectors, 16 rings

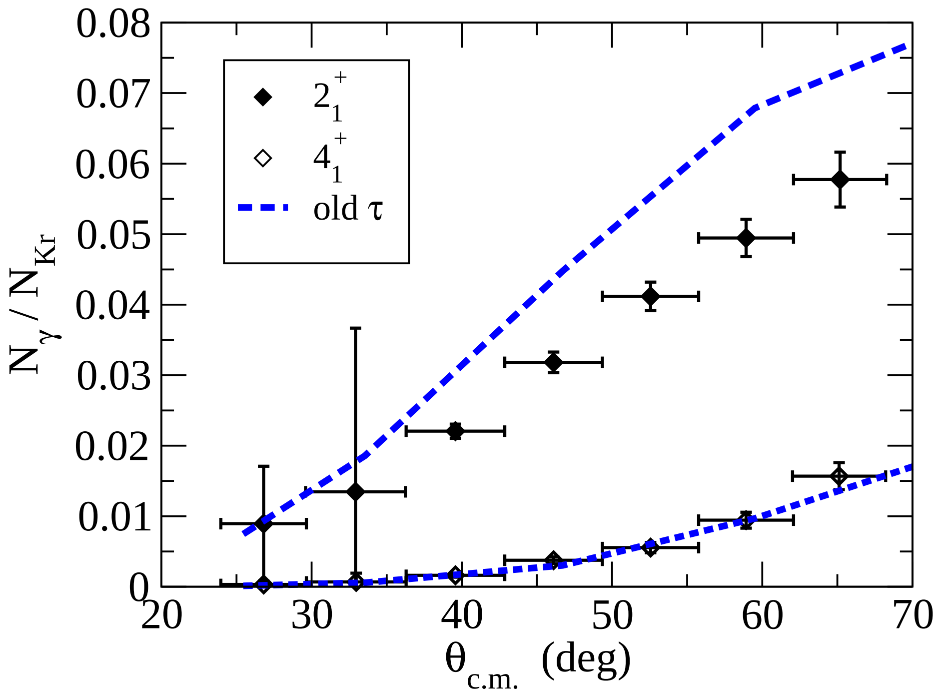


Coulomb excitation analysis



- results inconsistent with previously published lifetimes
- new RDM lifetime measurement: Köln Plunger & GASP
  ^{40}Ca (^{40}Ca,α2p) ^{74}Kr
  ^{40}Ca (^{40}Ca,4p) ^{76}Kr

- GOSIA code: D. Cline, T. Czosnyka, C.Y. Wu
  - description of experiment geometry
  - subdivision of data in several ranges of scattering angle
  - spectroscopic data (lifetimes, branching and mixing ratios)
  - least squares fit of $\sim$30 matrix elements (transitional and diagonal)



Lifetime measurement

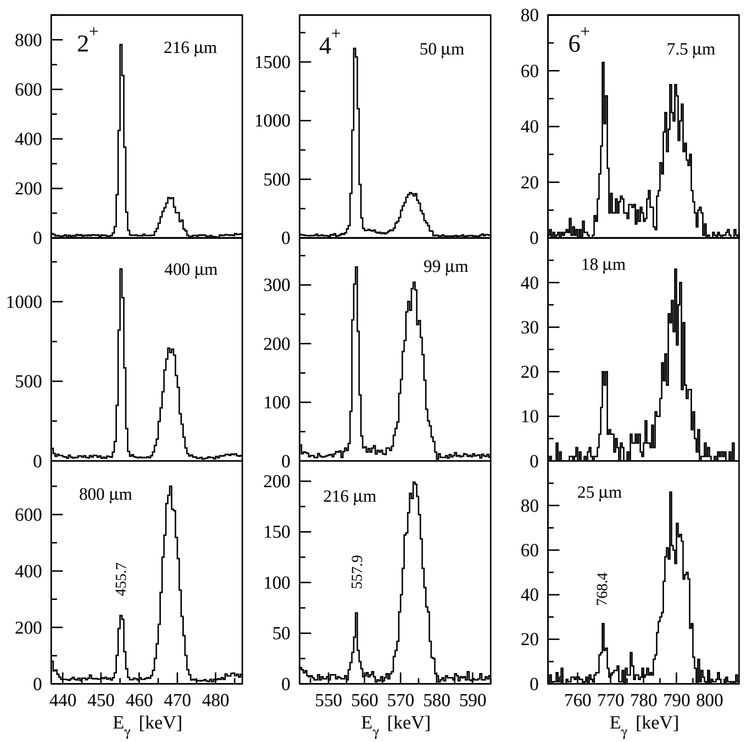
A. Görgen *et al.* EPJ A 26 153 (2005)

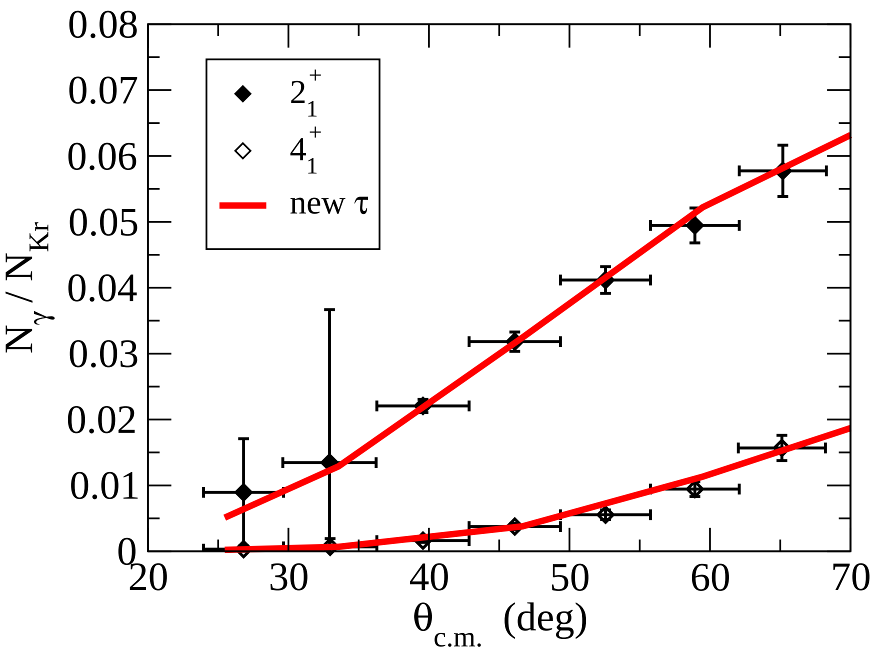
		old	new
^{76}Kr	2^+	35.3(10) ps	41.5(8) ps
	4^+	4.8(5) ps	3.87(9) ps

		old	new
^{74}Kr	2^+	28.8(57) ps	33.8(6) ps
	4^+	13.2(7) ps	5.2(2) ps

^{74}Kr, forward detectors (36°)

gated from above





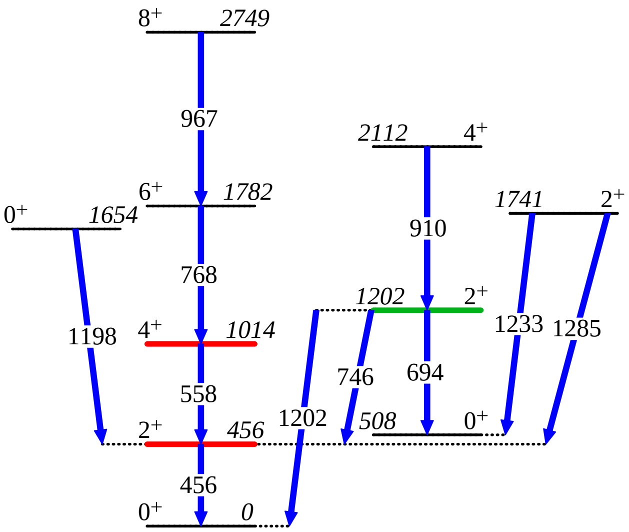
- new lifetimes in agreement with Coulex
- enhanced sensitivity for diagonal and intra-band transitional matrix elements

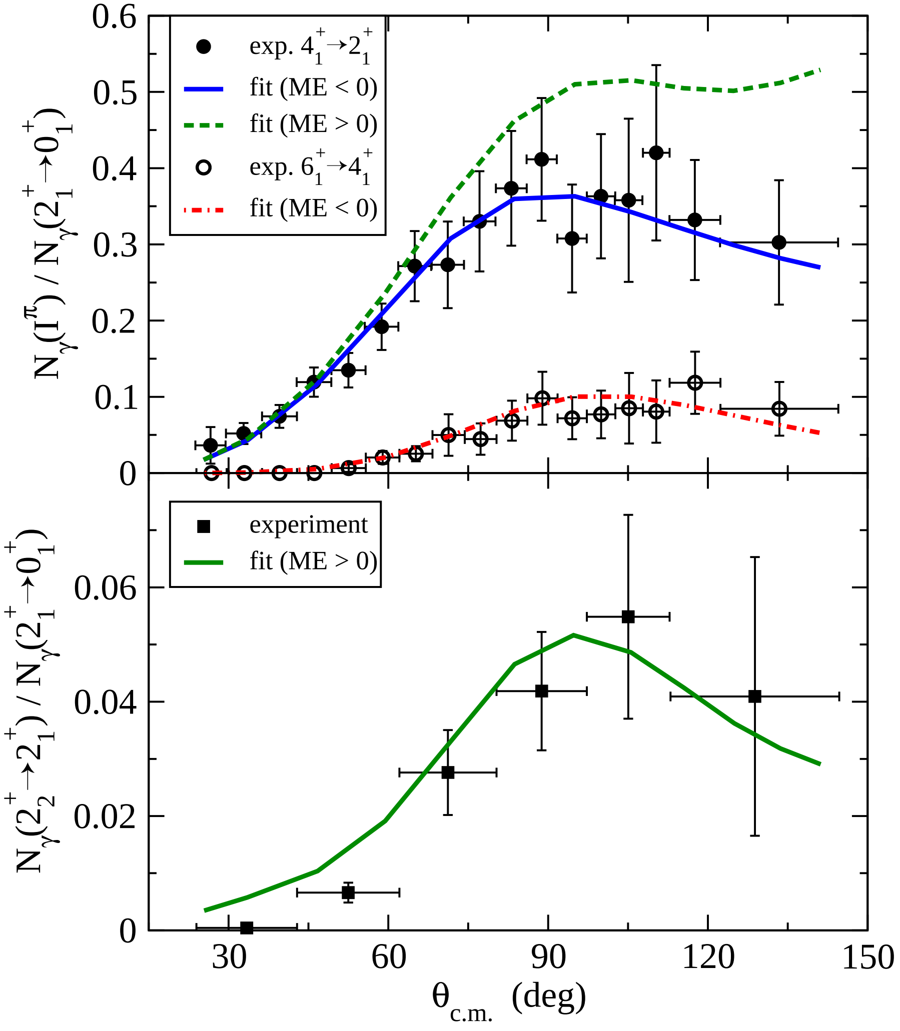
Results: shape coexistence in light Kr isotopes

^{76}Kr: 18 transitional + 5 diagonal ME
^{74}Kr: 14 transitional + 5 diagonal ME

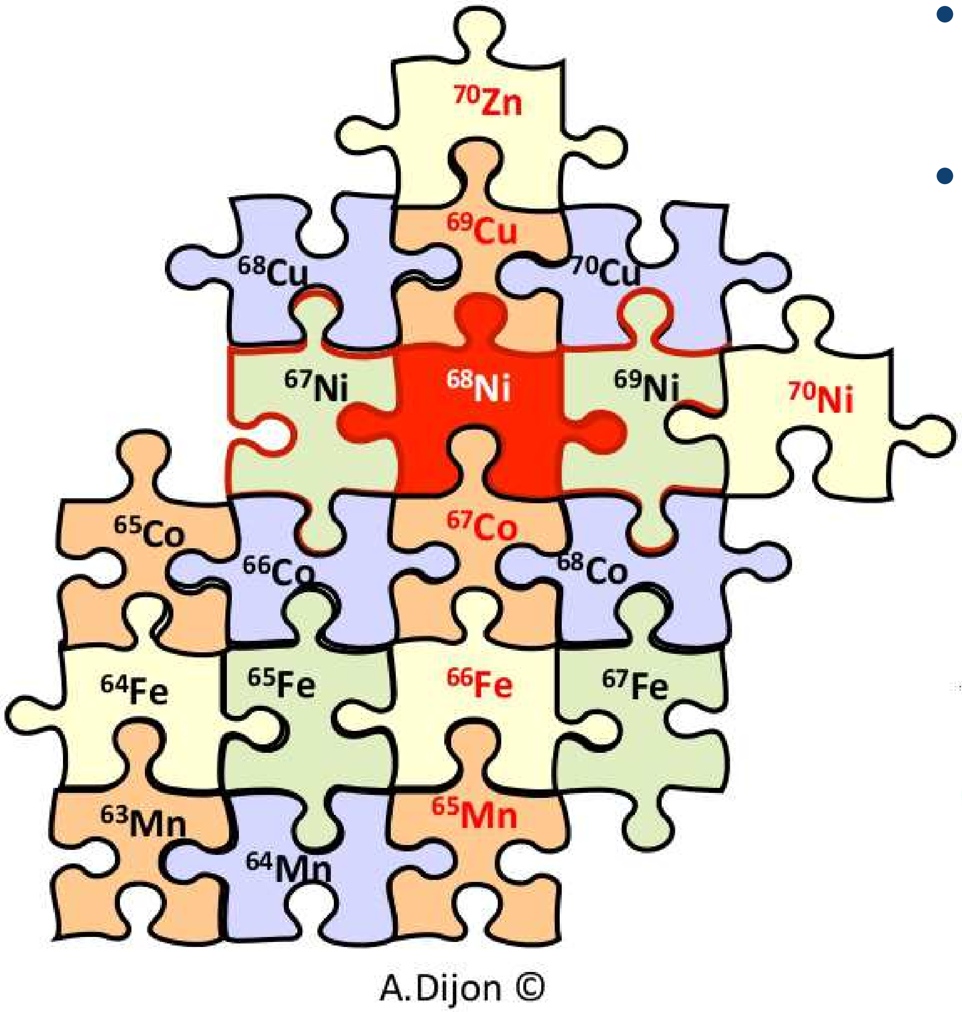
$$\langle 2_1^+ || E2 || 2_1^+ \rangle = -\,0.70^{-0.33}_{-0.30}$$
$$\langle 4_1^+ || E2 || 4_1^+ \rangle = -\,1.02^{+0.59}_{-0.21}$$

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



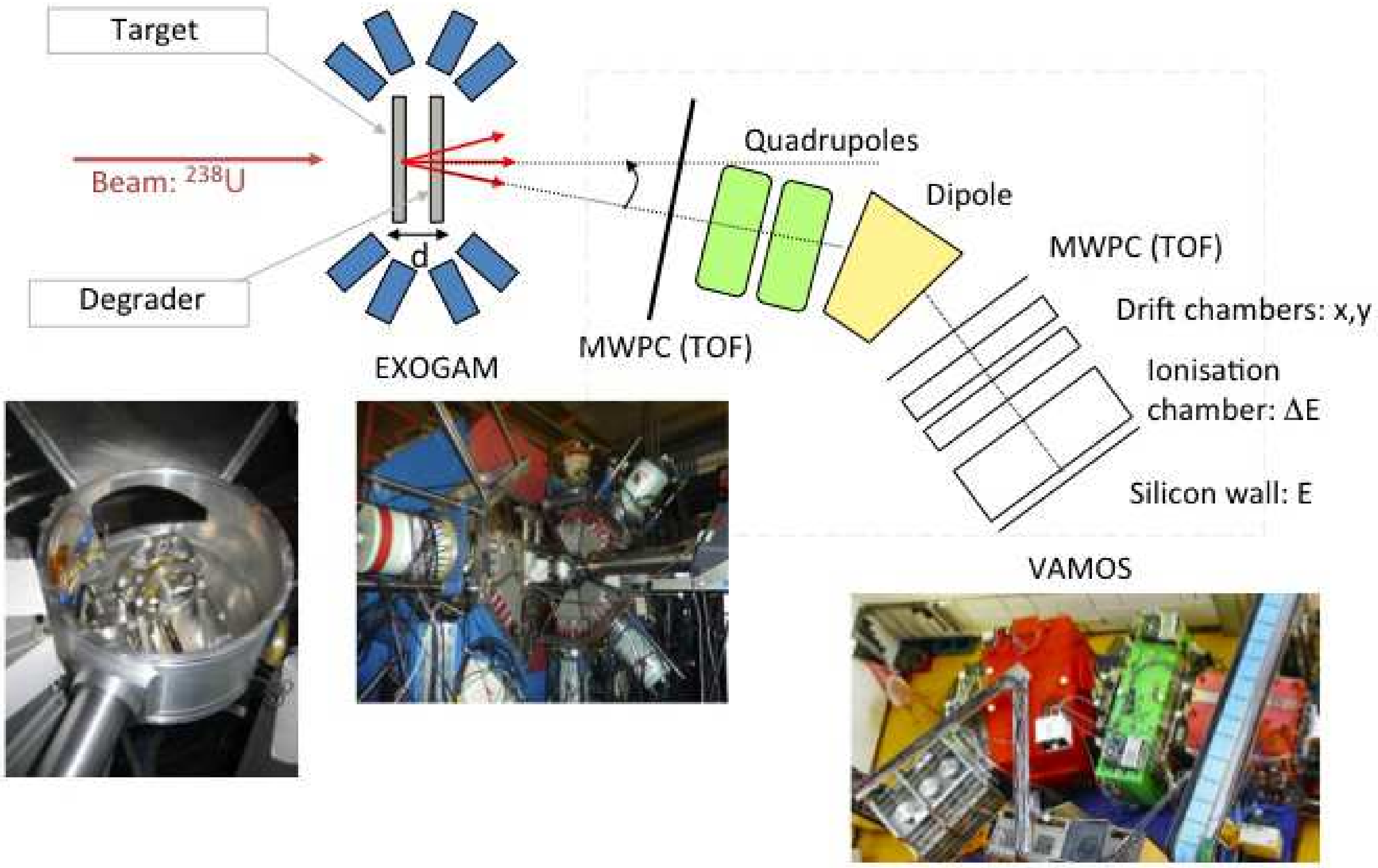


Vicinity of ^{68}Ni



- high excitation energy of the 2^+ state and low B(E2) in ^{68}Ni
- weakness of the N=40 shell gap: rapid onset of collectivity when moving away from ^{68}Ni
  - polarisation of the Z=28 proton core in ^{70}Ni (O. Perru et al., PRL 96 (2006))
  - single particle, collective and core-coupled states in Cu isotopes (I.Stefanescu et al., PRL 100 (2008))

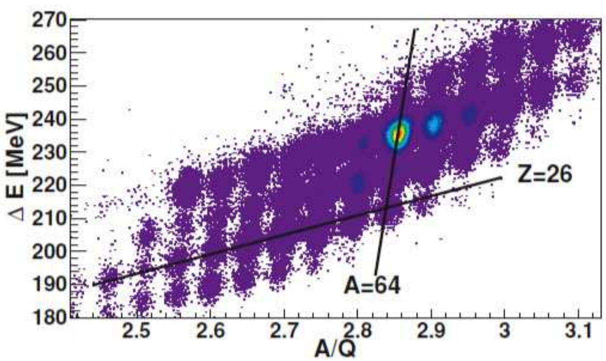
Lifetime measurements around ^{68}Ni

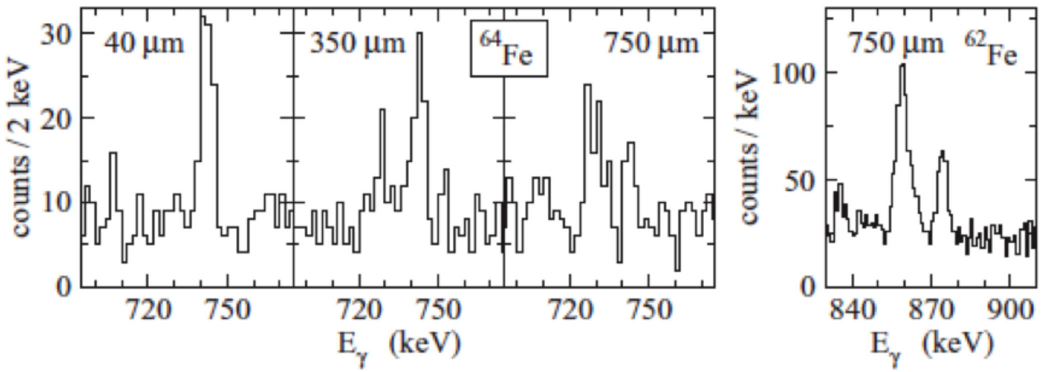


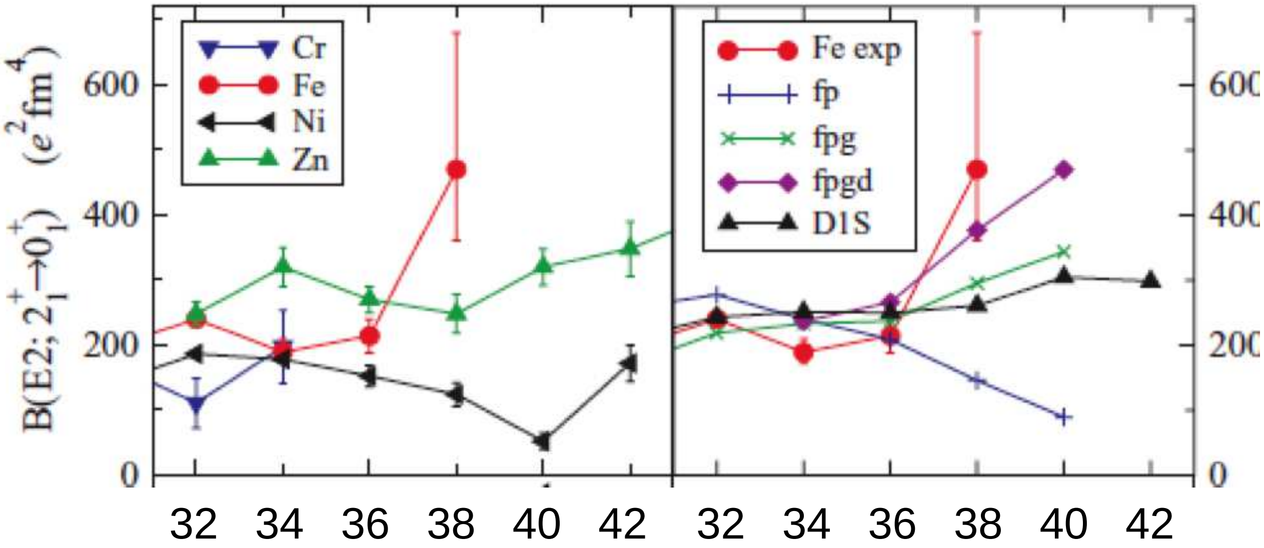
Isotopes studied	Target	VAMOS angle	Beam energy	Date
^{62,64}Fe, ^{63,65}Co	^{64}Ni	45°	6.5 MeV/A	Oct 2008
^{70,72}Zn	^{70}Zn	45°	6.7 MeV/A	Sep 2010

Lifetime measurements in ^{62,64}Fe

J.Ljungvall et al PRC 81 (2010)

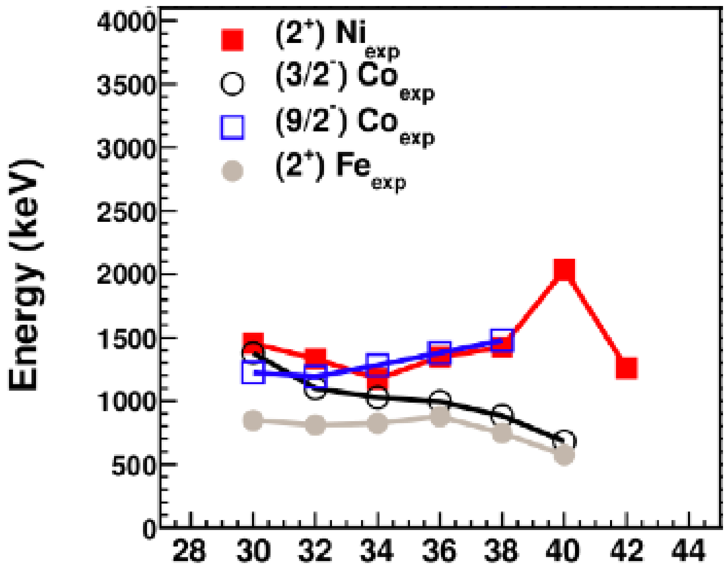






- new island of inversion: $\nu g_{9/2}$ intruder orbital necessary to explain the observed collectivity
- to reproduce measured B(E2)'s $d_{5/2}$ is mandatory
- confirmed by later measurements (W.Rother et al., PRL 106 (2011))

Core-coupled states in ^{63,65}Co



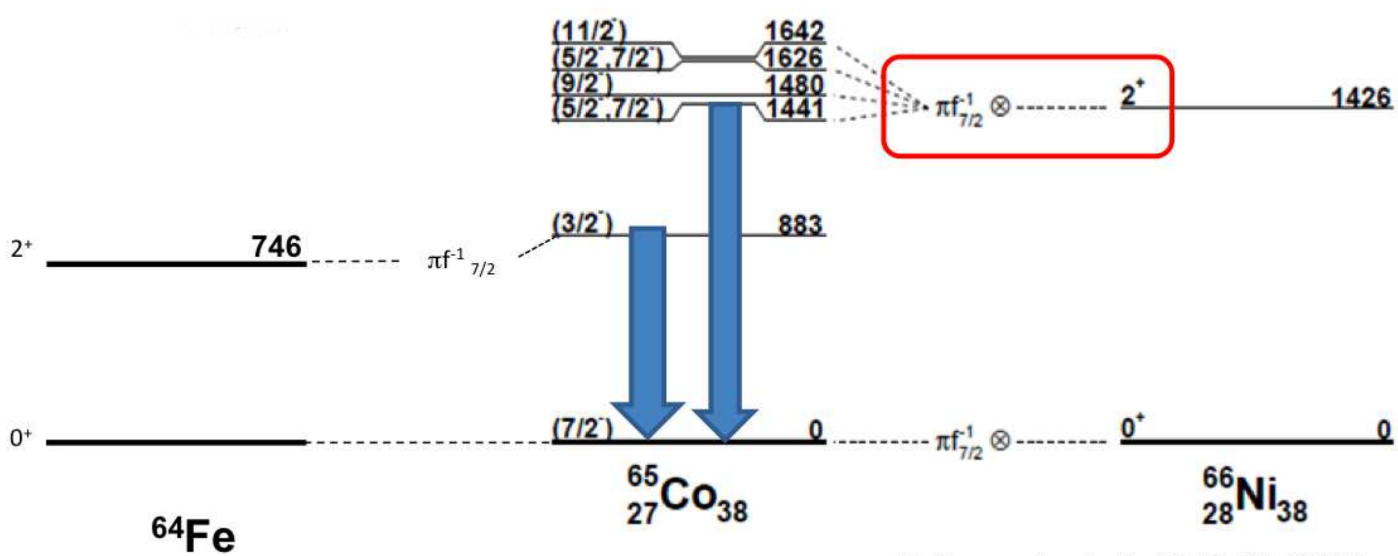
$E(2^+, \mathrm{Ni}) \approx E(9/2^-, \mathrm{Co})$

$E(2^+, \mathrm{Fe}) \approx E(3/2^-, \mathrm{Co})$

$|\, 7/2^-, \mathrm{Co} > \approx |(1\pi f_{7/2})^{-1} > \otimes |\, 0^+, \mathrm{Ni} >$

$|\, 9/2^-, \mathrm{Co} > \approx |(1\pi f_{7/2})^{-1} > \otimes \,|\, 2^+, \mathrm{Ni} >$

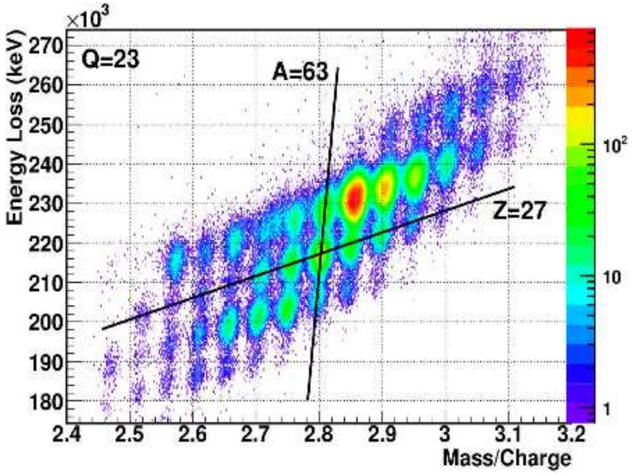
$|\, 3/2^-, \mathrm{Co} > \approx |(1\pi f_{7/2}) > \otimes \,|\, 2^+, \mathrm{Fe} >$

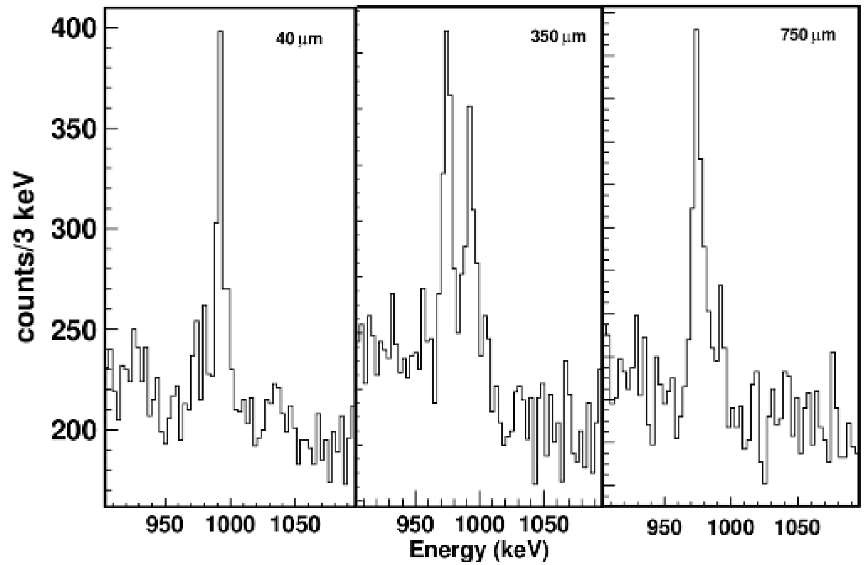


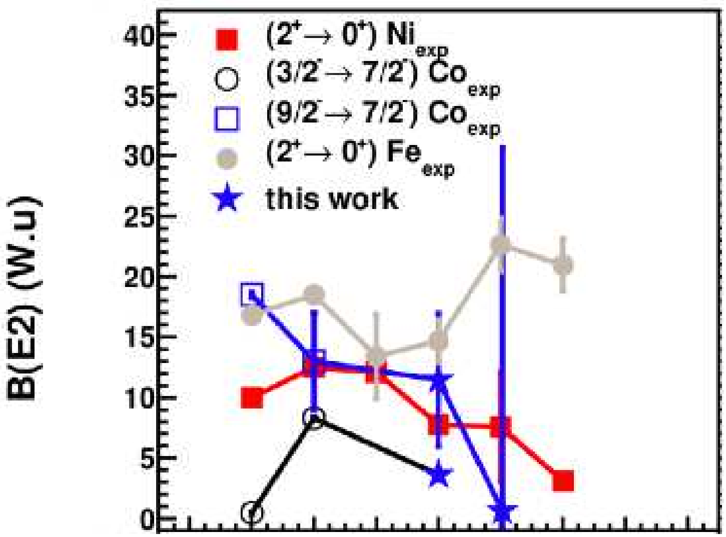
D.Pauwels et al., PRC 79, 2009

Lifetime measurements in ^{63,65}Co

A. Dijon et al PRC 83 (2011)







B(E2; $3/2^- \rightarrow 7/2^-$) in ^{63}Co « B(E2; $2^+ \rightarrow 0^+$) in ^{62}Fe

→ N=40 does not collapse at Z=27 contrary to Z=26 (Fe)

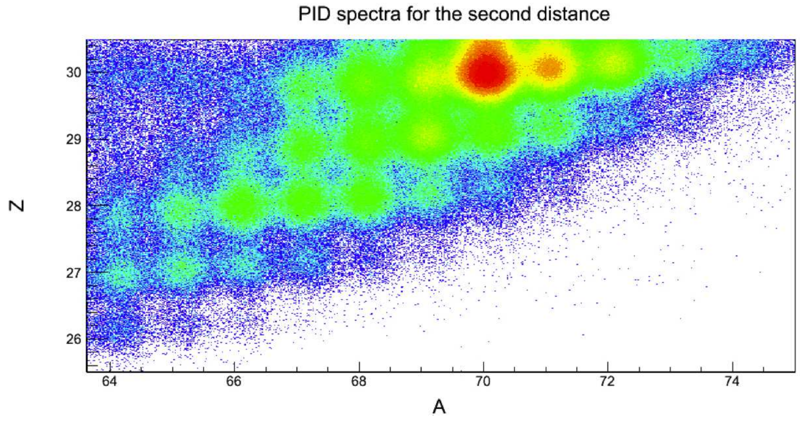
→ $3/2^-$ has a single particle character, not core-coupled

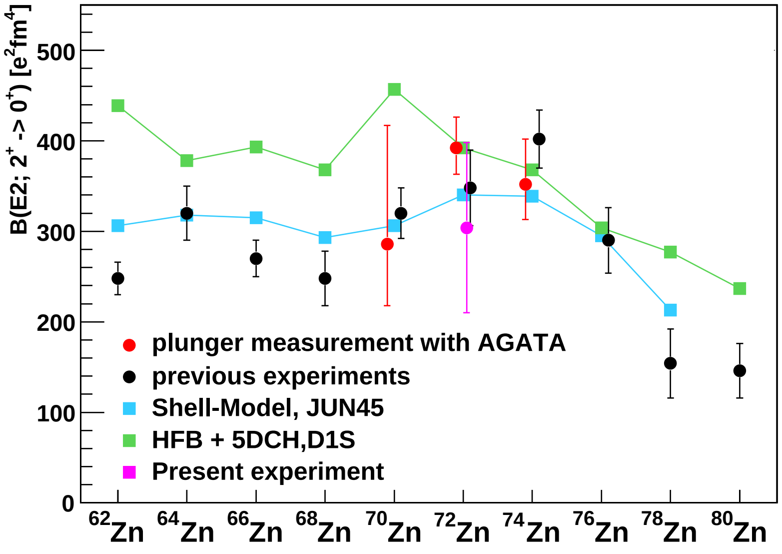
B(E2; $9/2^- \rightarrow 7/2$) in ^{63}Co compatible with B(E2; $2^+ \rightarrow 0+$) in ^{64}Ni: core coupled state

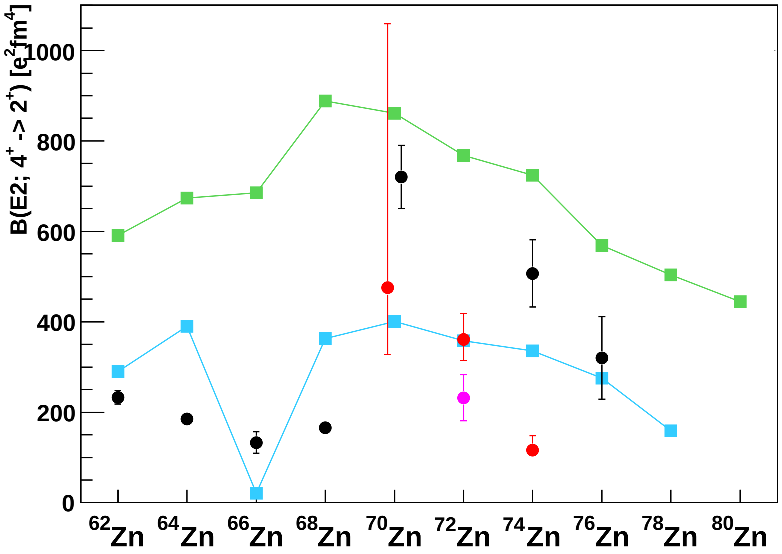
Lifetime measurements in ^{70,72}Zn

I. Celikovic, VINCA/GANIL, PhD thesis

- B(E2; $4^+ \rightarrow 2^+$) better test for theories than B(E2; $2^+ \rightarrow 0^+$)
- lower collectivity of 4^+ states ?
- discrepancy of the new lifetimes for 4^+ states with low-energy Coulex results

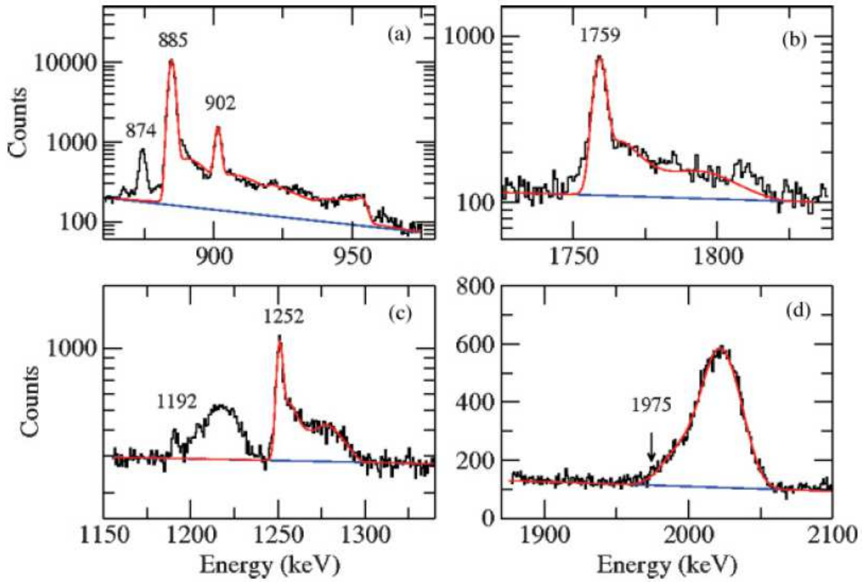






Coulomb excitation of ^{70}Zn

D. Mücher et al PRC 79 (2009)

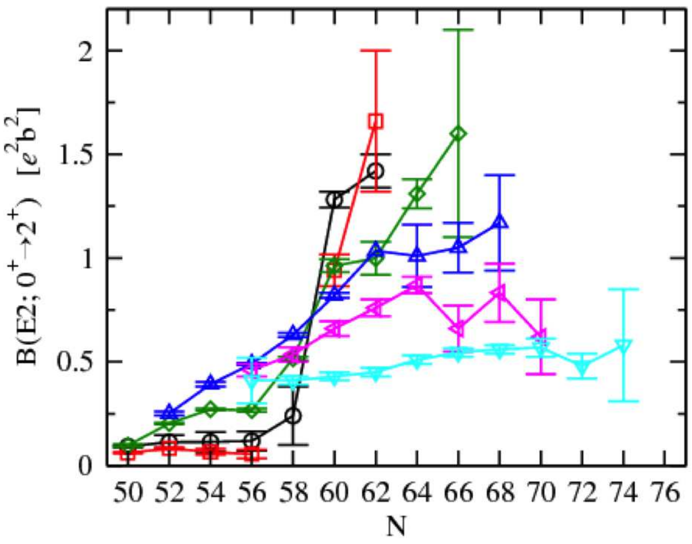


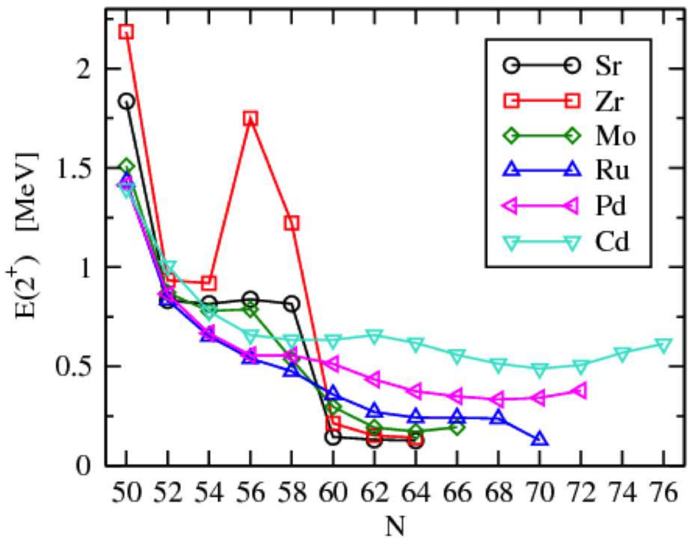
- $4^+ \rightarrow 2^+$ (901 keV) and $2^+ \rightarrow 0^+$ (885 keV) close in energy
- Coulomb excitation seems a more appropriate method to measure B(E2)'s in ^{70}Zn (no double peaks/tails)

Dedicated Coulomb excitation experiment to measure B(E2; $4^+ \rightarrow 2^+$) in ^{70}Zn to be performed in autumn 2012 at HIL Warsaw

Lifetime measurements in neutron-rich Mo, Ru, Pd isotopes

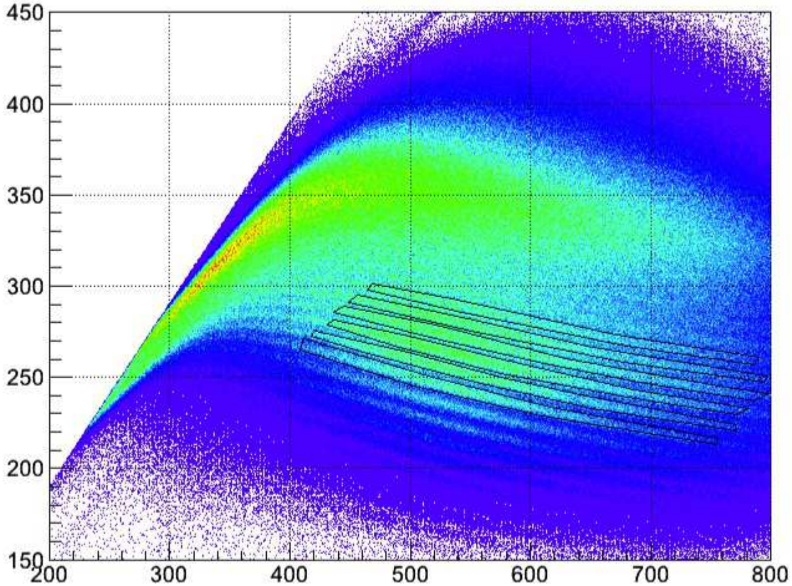
- rapid shape change at N=58
- shape coexistence: protate-oblate transitions, important role of triaxiality
- region interesting from theory point of view and not well known experimentally

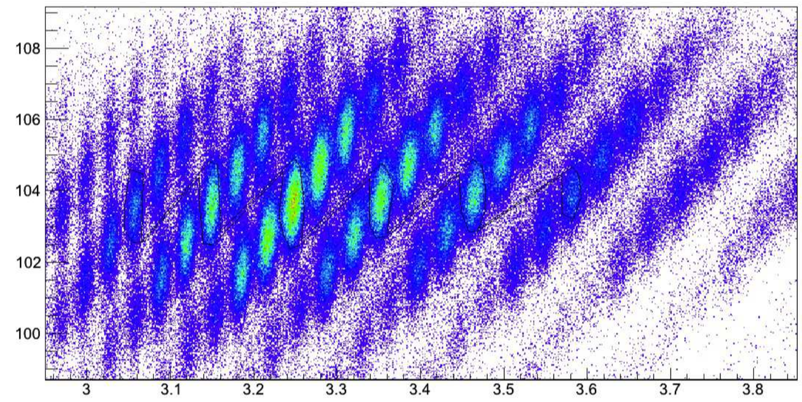


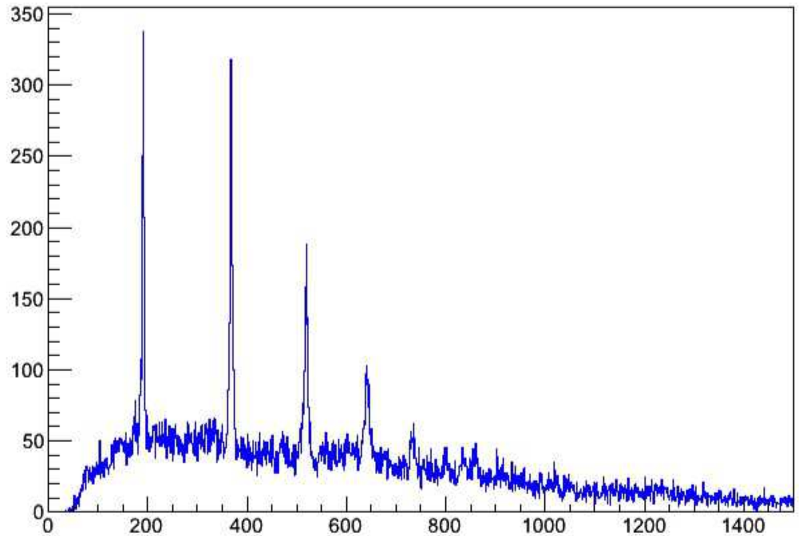


Lifetime measurements in fission products (GANIL, April 2011)

- similar experimental set-up: VAMOS + EXOGAM + plunger
- target: ^{9}Be: fusion + fission
- data under analysis



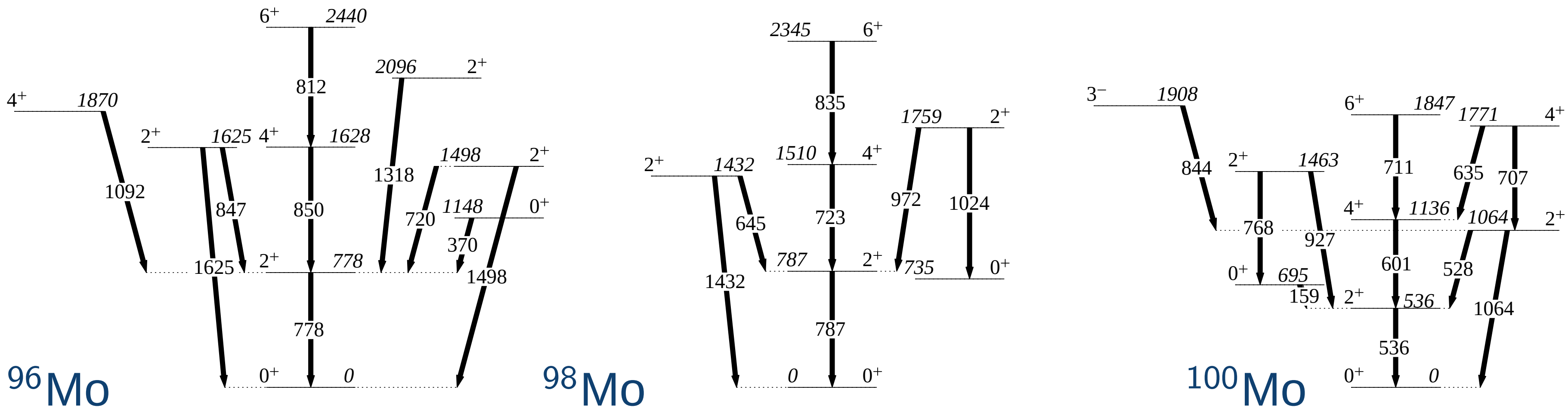




^{104}Mo

Complementary projects to study stable A $\approx$ 100 nuclei at HIL

- Coulomb excitation studies of $^{96-100}$Mo



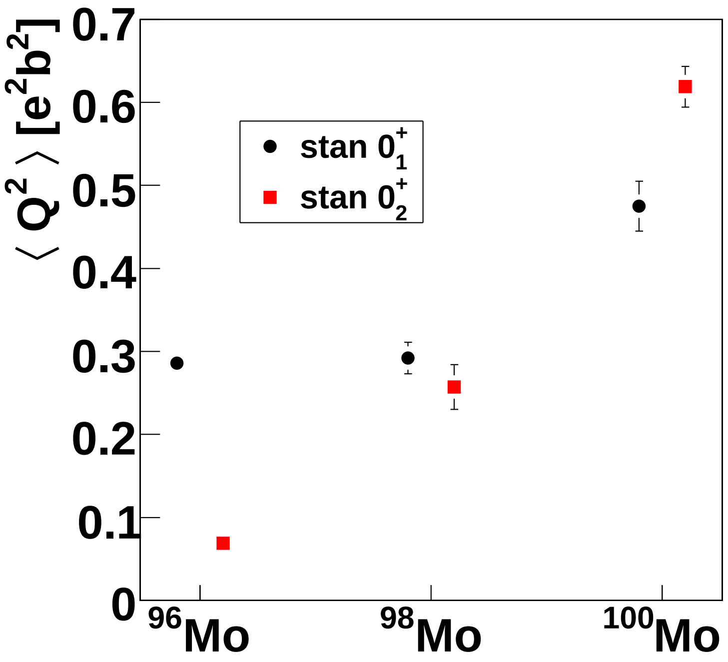
21 E2 ME's (3 diagonal) | 16 E2 ME's (3 diagonal) | 19 E2 ME's (3 diagonal)

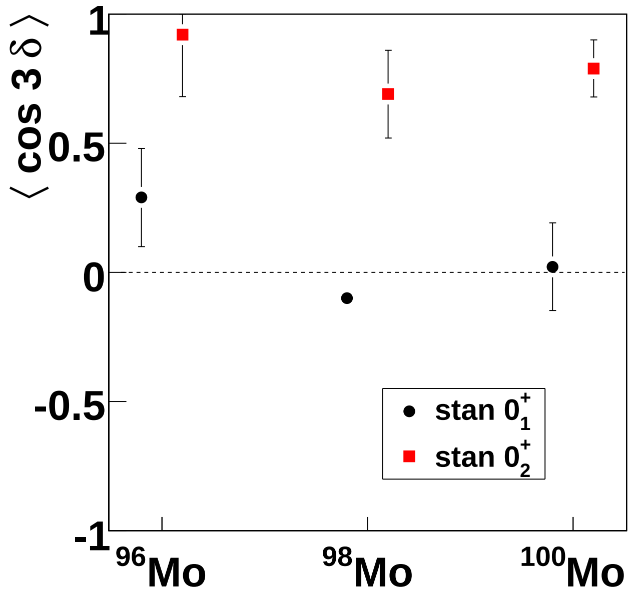
$$\frac{\langle Q^2\rangle}{\sqrt{5}} = \langle i|\left[\mathrm{E2}\times\mathrm{E2}\right]^0|i\rangle = \frac{1}{\sqrt{(2I_i+1)}}\sum_t \langle i||\mathrm{E2}||t\rangle\langle t||\mathrm{E2}||i\rangle \begin{Bmatrix} 2 & 2 & 0 \\ I_i & I_i & I_t \end{Bmatrix}$$

$$\sqrt{\frac{2}{35}}\langle \mathrm{Q}^3\cos 3\delta\rangle = \langle i|\{[\mathrm{E2}\times\mathrm{E2}]^2\times\mathrm{E2}\}^0|i\rangle$$

$$= \frac{1}{(2I_i+1)}\sum_{t,u}\langle i||\mathrm{E2}||u\rangle\langle u||\mathrm{E2}||t\rangle\langle t||\mathrm{E2}||i\rangle \begin{Bmatrix} 2 & 2 & 2 \\ I_i & I_t & I_u \end{Bmatrix}$$

Shape evolution of $^{96-100}$Mo

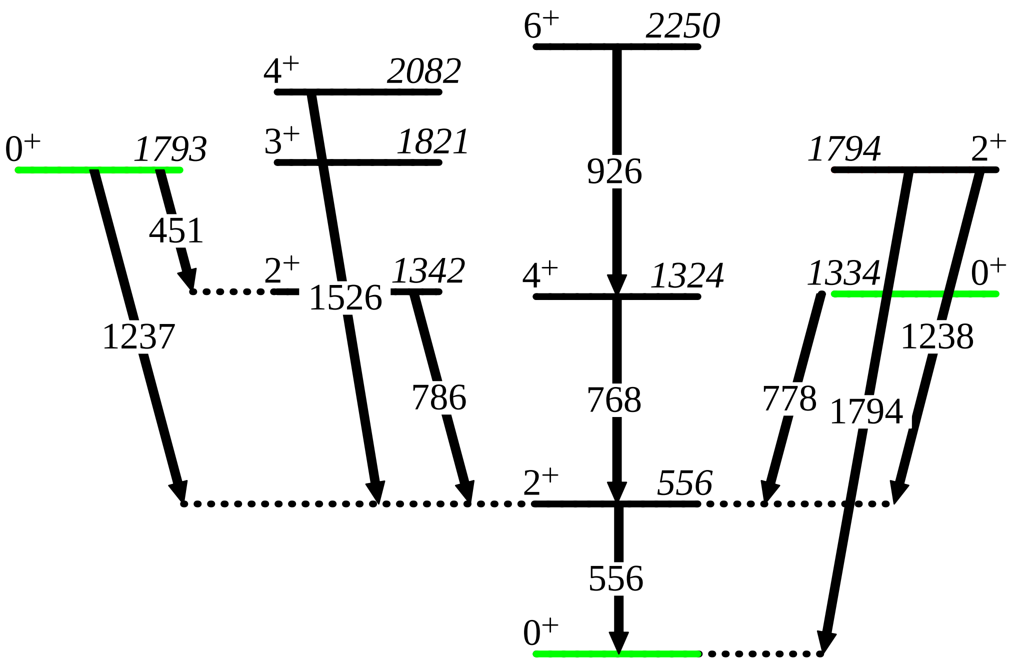




- ground states triaxial, deformation of 0_2^+ increasing with N
- ^{100}Mo: good agreement with GBH calculations (L. Próchniak et al.)
- ^{96,98}Mo: 0_2^+ band not well described

Shape evolution in ^{104}Pd

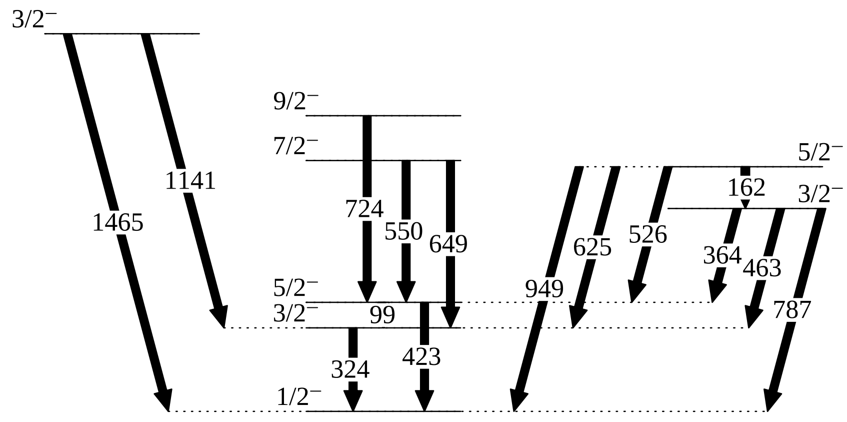
Spokesperson: M. Zielińska

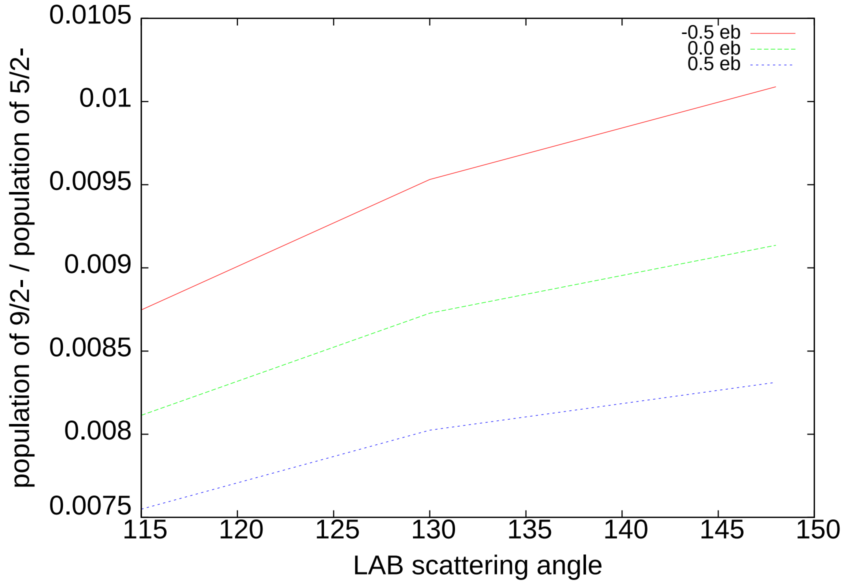


- Quasi-vibrational level scheme, transition probabilities for heavier Pd not in agreement with this picture
- Considerable beta and gamma softness predicted
- What is the nature of low-lying 0^+ states? Collective or intruder?

Quadrupole moments in ^{107}Ag

Spokespersons: K. Wrzosek-Lipska, KU Leuven / M. Zielińska



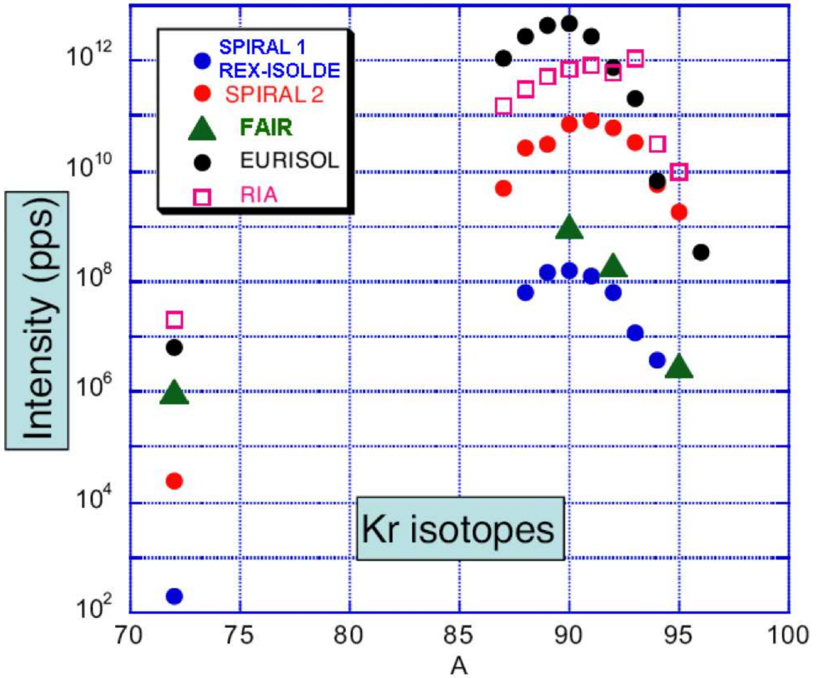


- predictions of various model very different
- strong dependence on triaxiality
- important to normalise data from Coulex of exotic Hg isotopes

Coulomb excitation of exotic beams: future

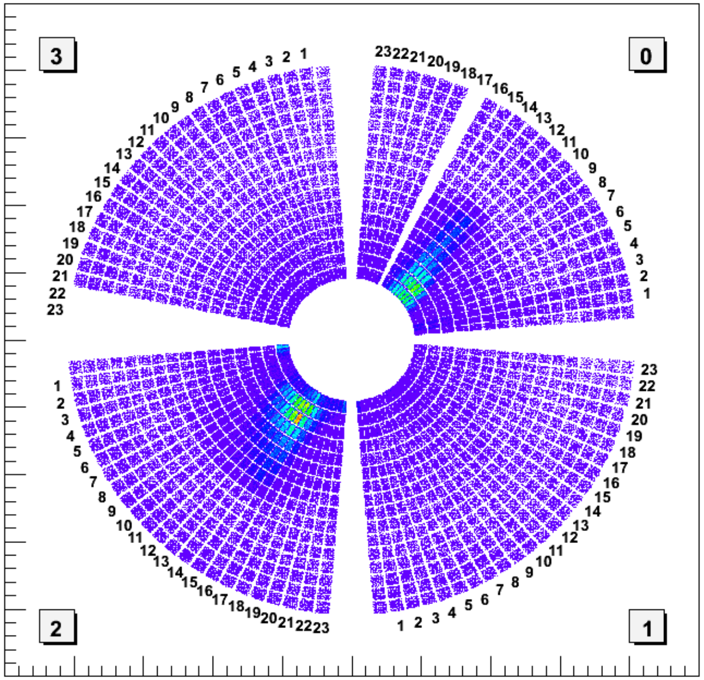
- Coulex one of the most important methods to measure transition probabilities, especially on the neutron-rich side
- increase in RIB intensities (and energies)
- multi-step excitation experiments will become common
- Si detectors at forward angles no longer an option:

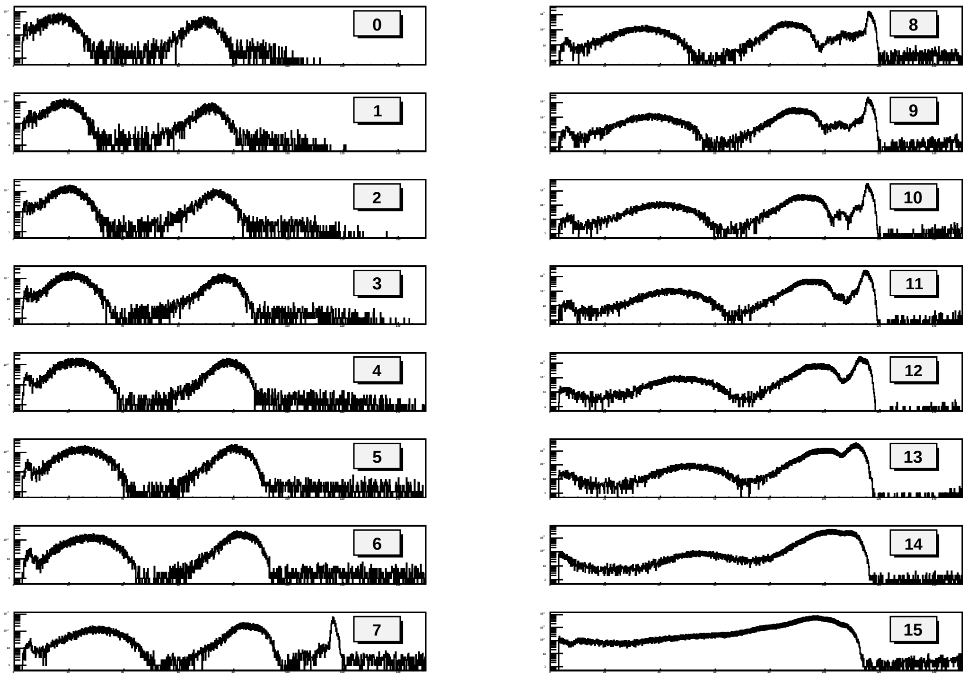
need for novel particle detectors



Si detectors for high-intensity RIB Coulex?

Coulomb excitation of ^{44}Ar

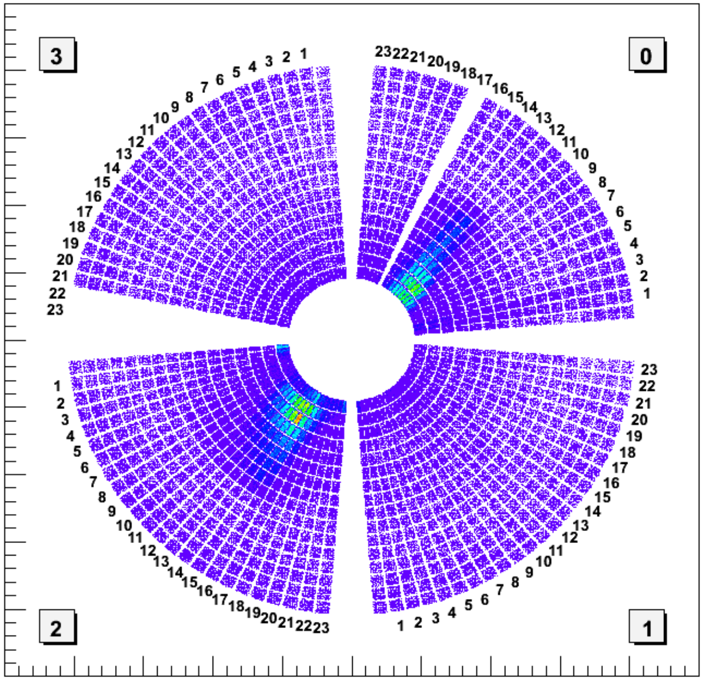


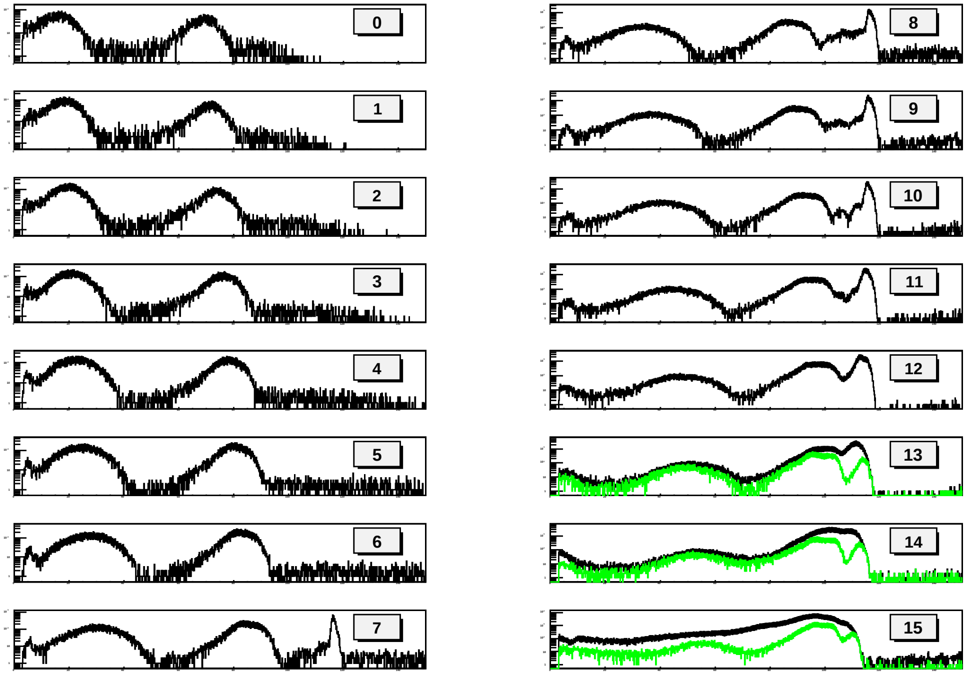


Direct beam of intensity 10^3 pps hitting 5-10% of detector area

Si detectors for high-intensity RIB Coulex?

Coulomb excitation of ^{44}Ar





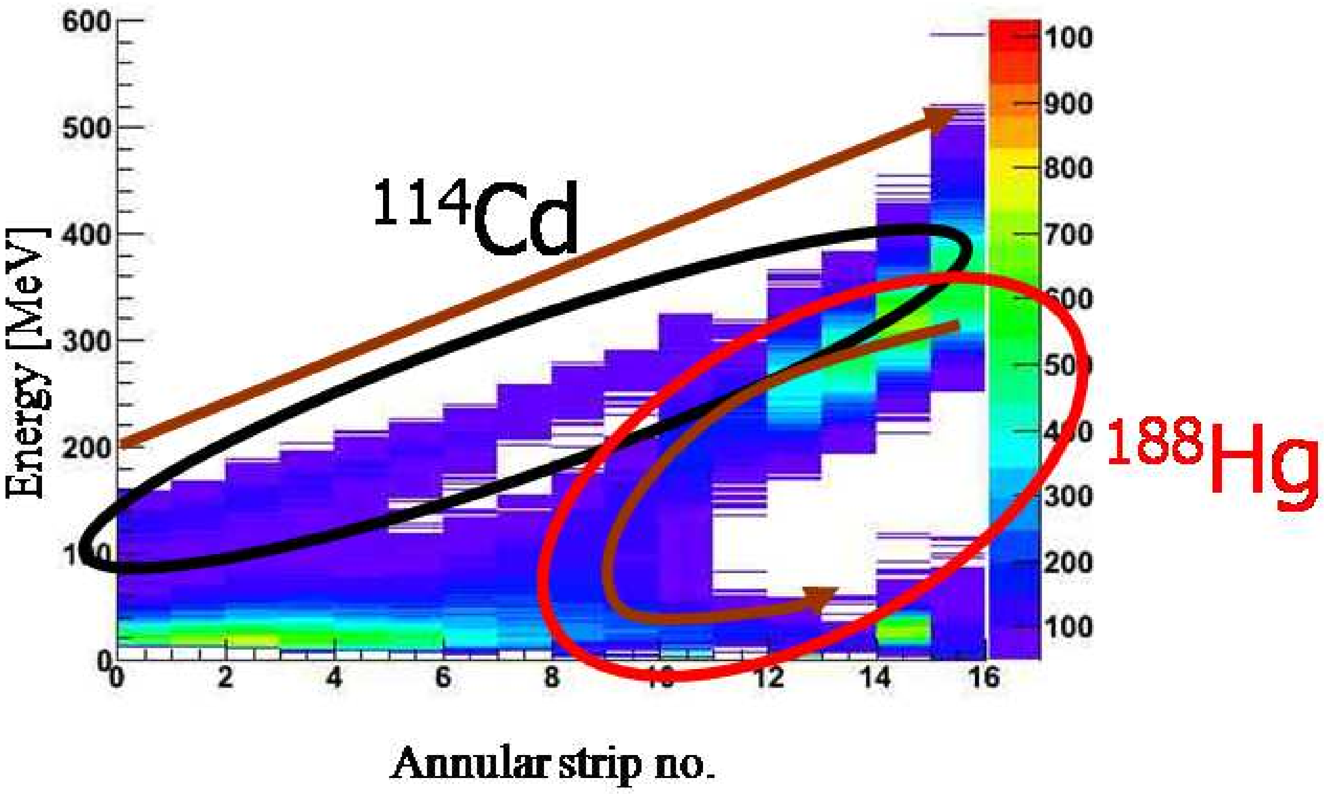
Direct beam of intensity 10^3 pps hitting 5-10% of detector area

Rate equivalent to Rutherford scattering of 10^8 pps beam at $15^\circ < \theta < 25^\circ$

Identification ejectile-recoil: energy

- for Si detectors and targets of 1-2 mg/cm^2: ejectile and recoil should differ in mass by roughly a factor of two

- this limits observed excitation for mass > 100 (heavy targets like Pt or Pb cannot be used)



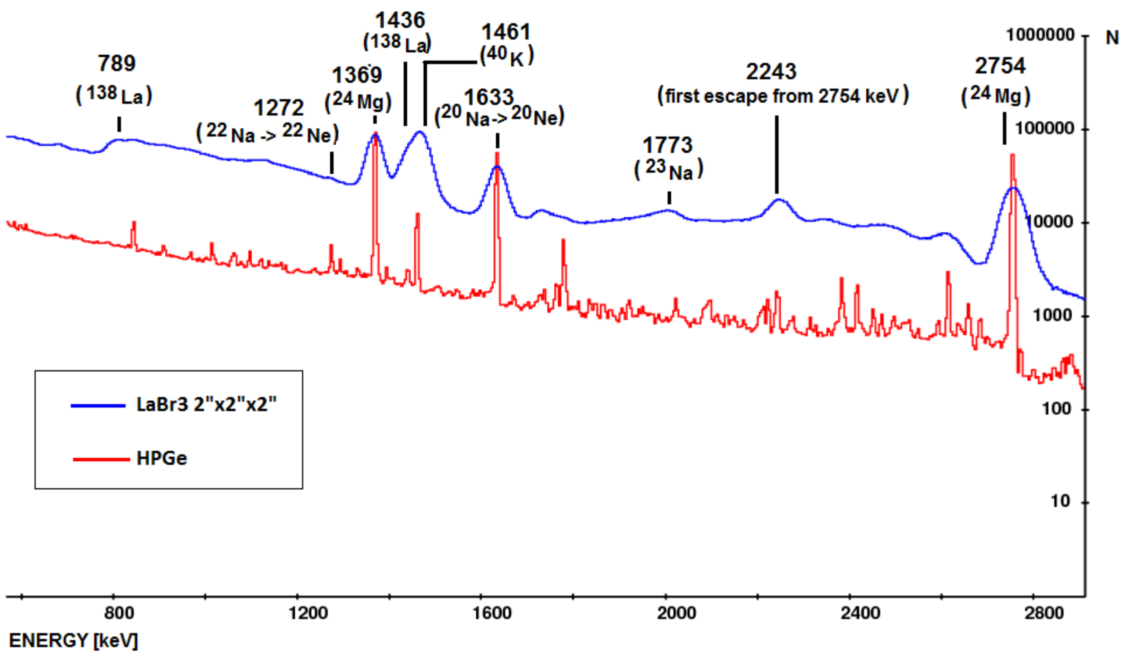
Diamond CVD detectors

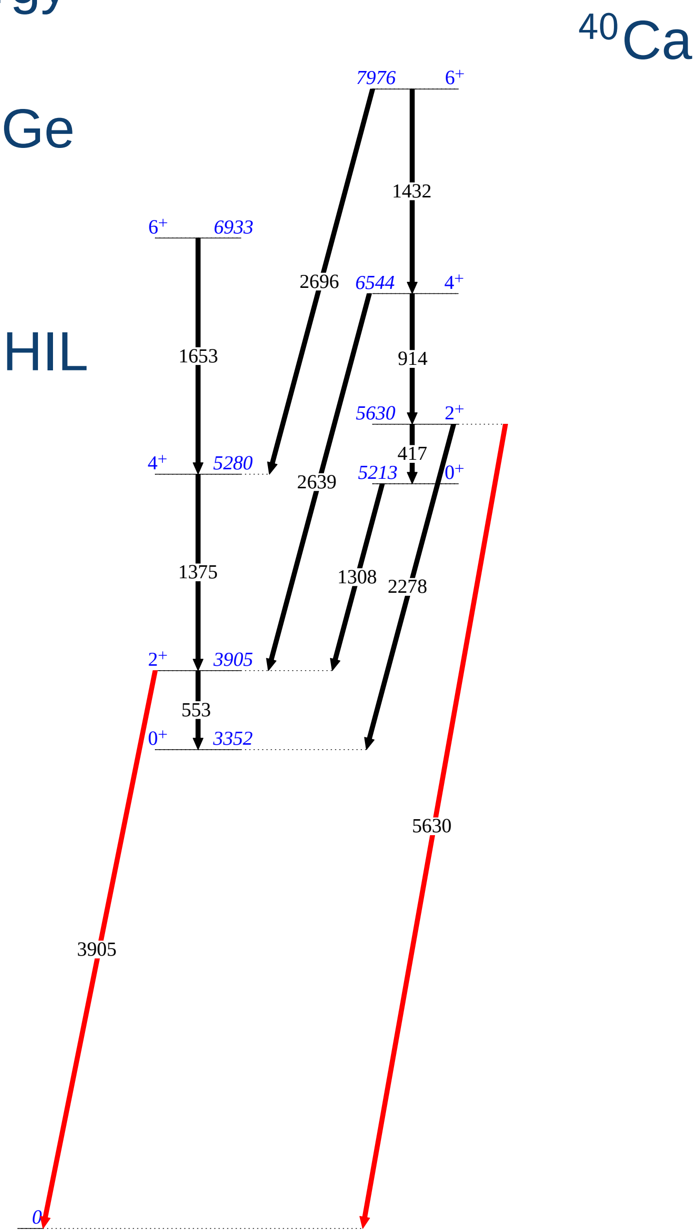
- promising detector material for harsh environment
- high $E_g \longrightarrow$ negligible leakage current at the room temperature
- low dielectric constant $\longrightarrow$ low capacitance $\longrightarrow$ low noise
- high carrier mobility $\longrightarrow$ fast signal collection $\longrightarrow$ excellent timing properties
- used for beam monitoring in high-energy physics (CERN, HADES...)
- conflicting information on radiation hardness of SC CVD detectors

test of CVD detectors as possible particle detectors for Coulex to be performed at HIL Warsaw in 2012

LaBr$_3$ detectors for Coulex of SD bands (PARIS physics case)

- SD bands in A$\approx$ 40 nuclei decay by high-energy gamma rays
- LaBr$_3$ detectors may be used to complement Ge arrays in such studies
- in-beam test of LaBr$_3$ detectors performed at HIL Warsaw in 2009 ($^{12}C(^{14}N,2p)^{24}Na$ reaction)





Genetic Algorithm in Coulex data analysis: the JACOB code

Pawel Napiorkowski, HIL Warsaw

Coulex data analysis: multi-dimensional fit of ME's to measured γ-ray intensities

- GOSIA:
  - standard Coulex analysis code
  - often trapped in a local minimum
  - various starting points have to be carefully checked (combinations of signs and magnitudes)
- JACOB:
  - automated, user-friendly way to find global minima in a GOSIA fit
  - scan of the χ^2 surface, "promising" minima localised
  - real, "physical" solutions identified by the user
  - alternative method for error estimation (in development)

Collaboration

Polish side:

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M. Dudeło
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