# Shapes of exotic nuclei studied by low-energy Coulomb excitation: results from SPIRAL

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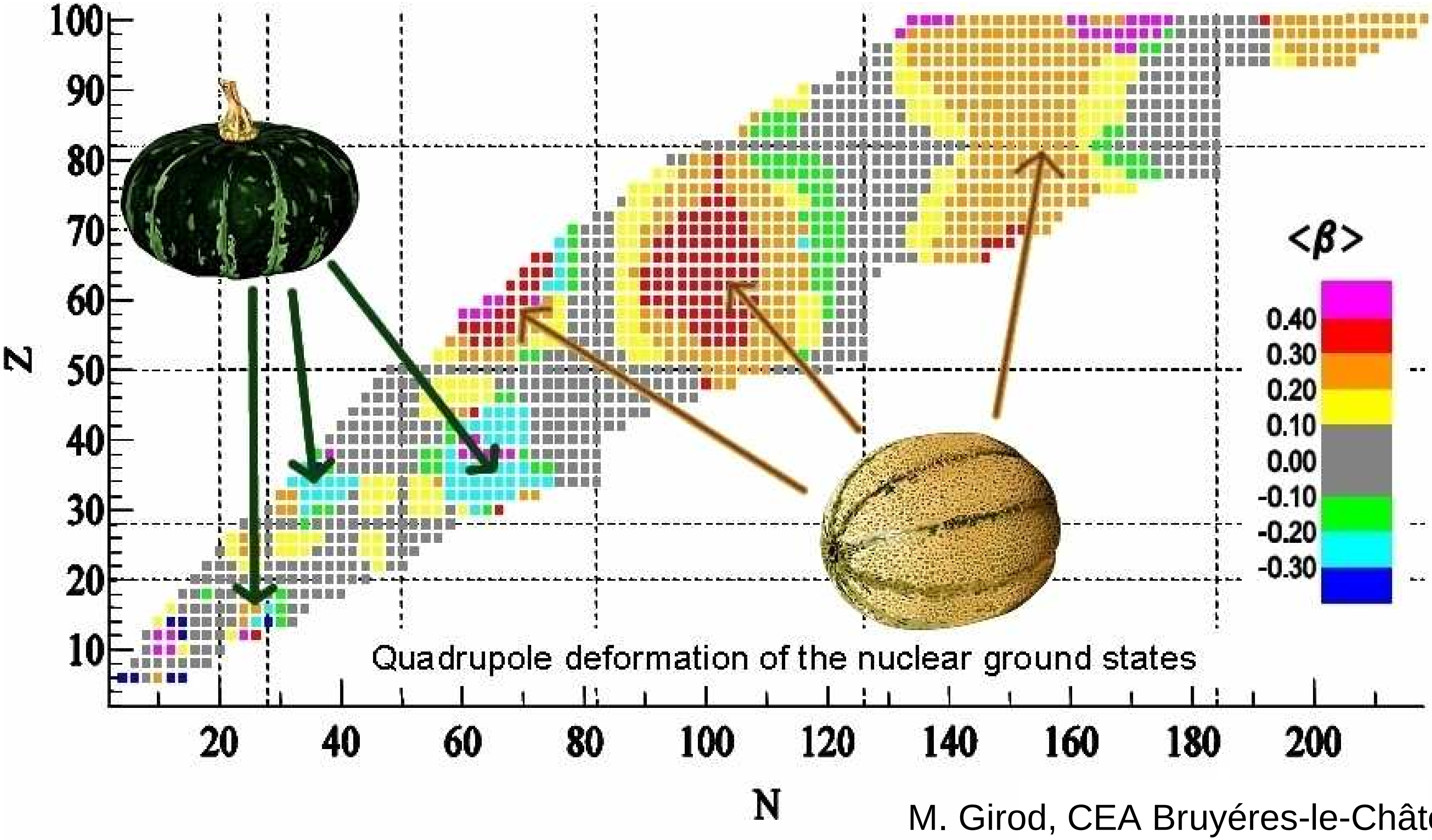
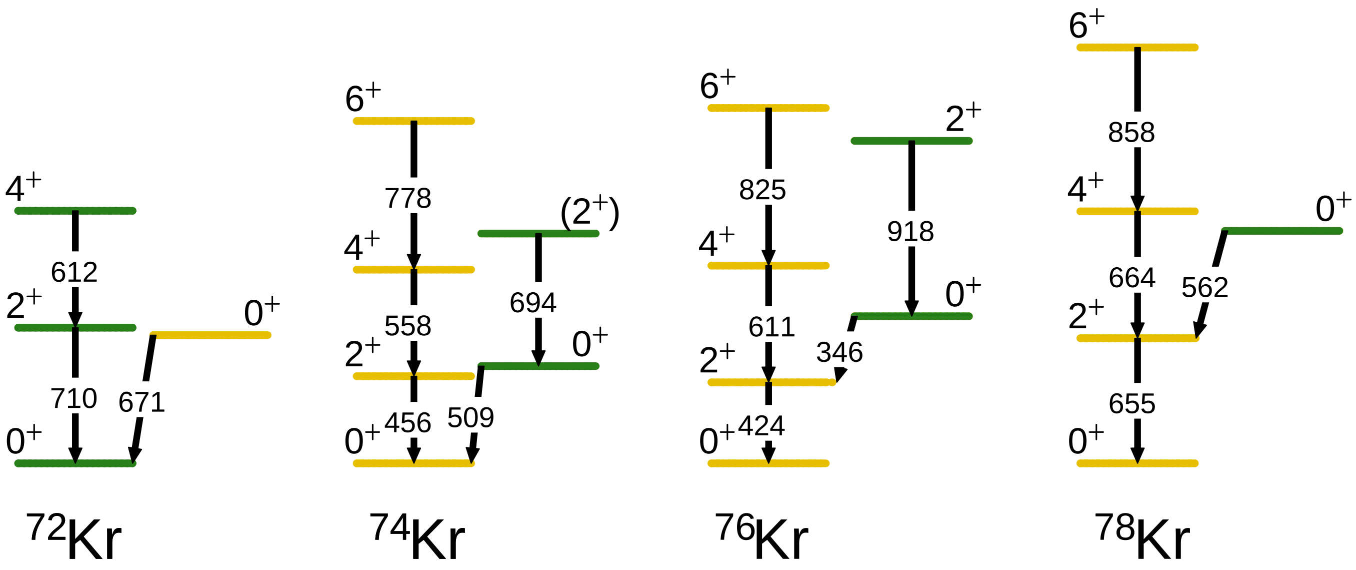
- electromagnetic structure of light krypton isotopes
  - low-energy Coulomb excitation
  - complementary lifetime measurements – see talk of E. Clément
- development of collectivity in neutron-rich argon isotopes

# Shapes of atomic nuclei




M. Girod, CEA Bruyéres-le-Châtel

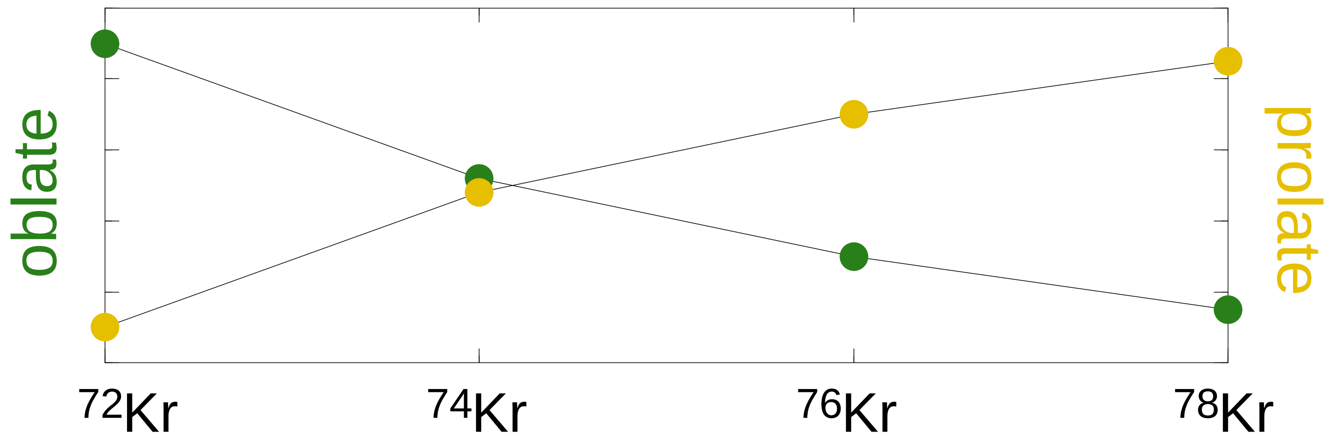
# Systematics of the neutron-deficient Kr isotopes




prolate

oblate

| $\rho^2$(E0) | $72\cdot10^{-3}$ | $85\cdot10^{-3}$ | $79\cdot10^{-3}$ | $47\cdot10^{-3}$ |
|---|---|---|---|---|

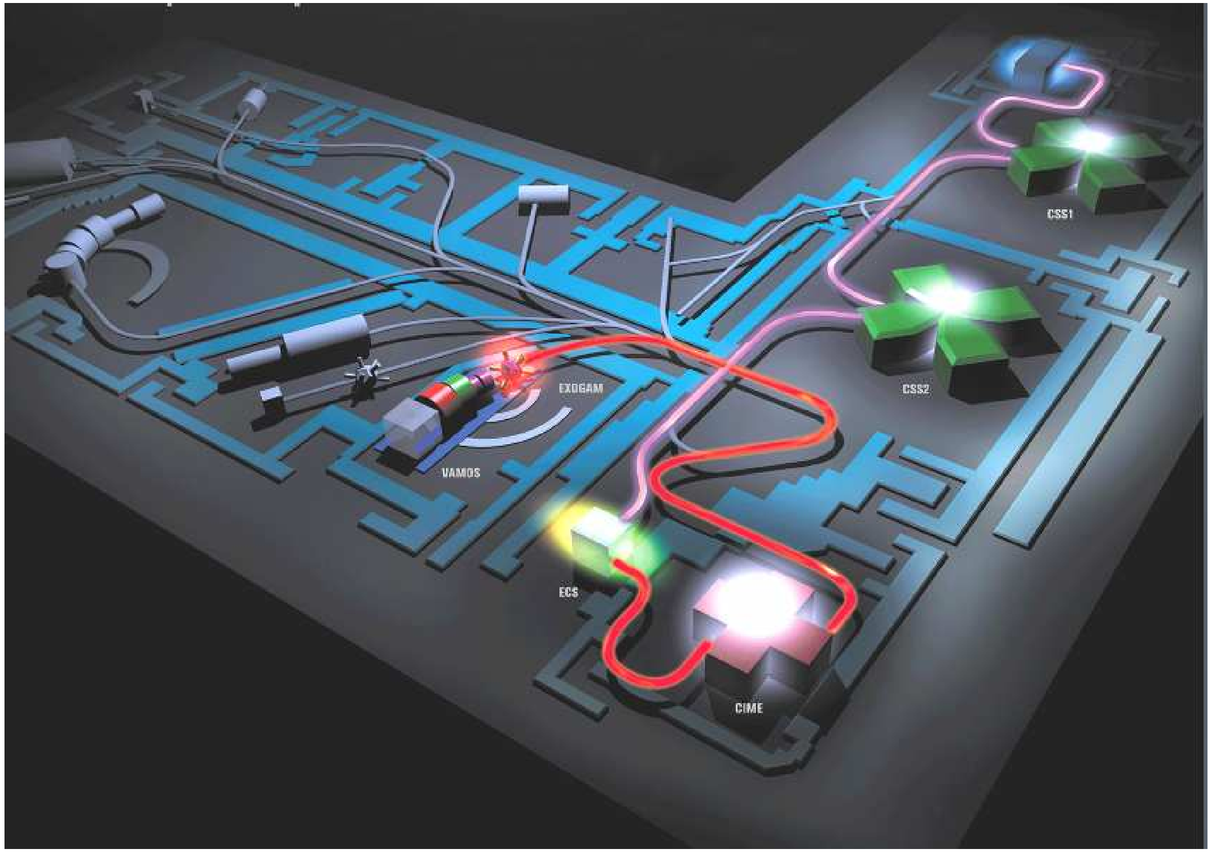



- inversion of the ground state shape for $^{72}$Kr
- Coulomb excitation to determine directly the nuclear shapes

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

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

# Radioactive beams: SPIRAL at GANIL

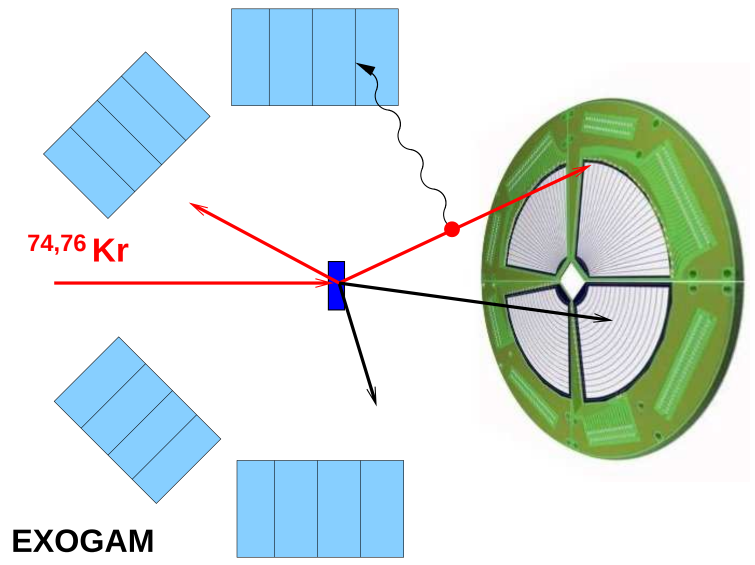


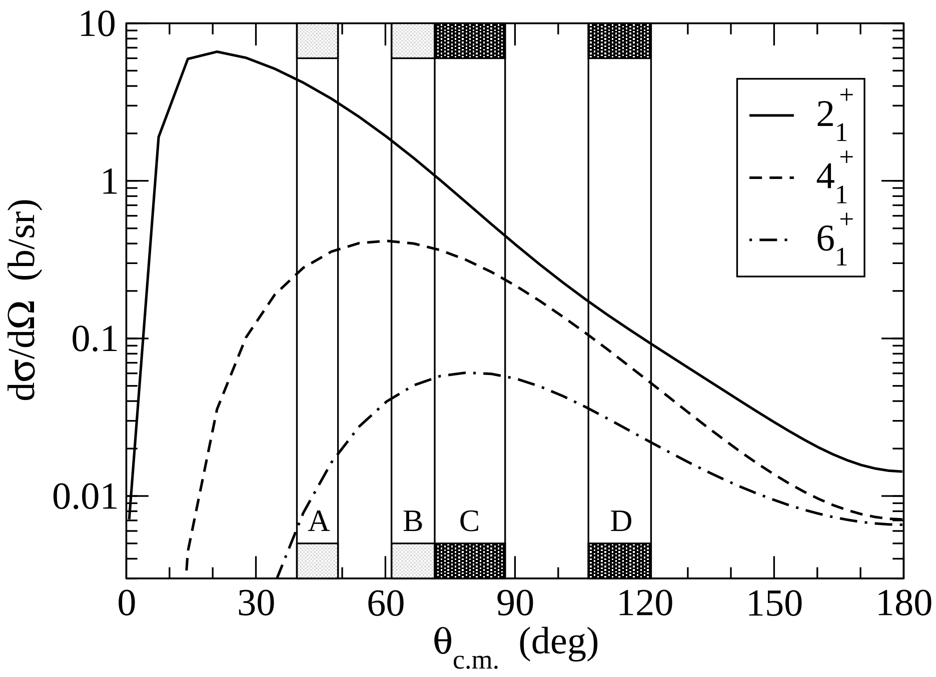

- Primary beam: $^{78}$Kr 68.5 MeV/A, $10^{12}$ pps

- Secondary beams: $^{76}$Kr, $^{74}$Kr

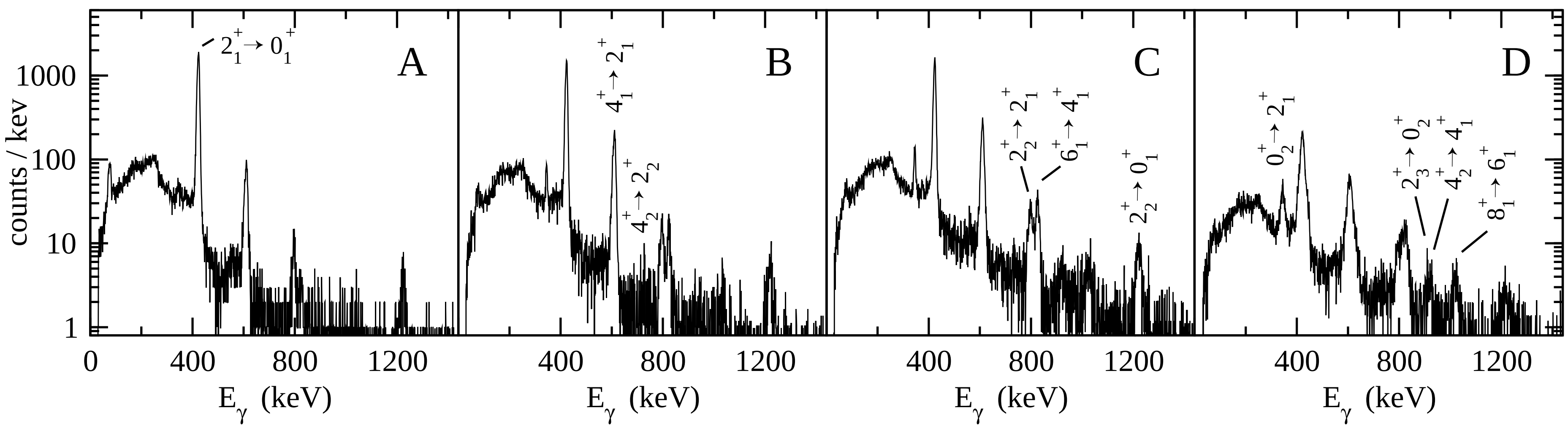
| Beam | Energy | Intensity | Target | Duration |
|---|---|---|---|---|
| $^{76}$Kr | 4.4 MeV/A | $5{\cdot}10^5$ pps | $^{208}$Pb,1 mg/cm$^2$ | 50 h |
| $^{74}$Kr | 4.7 MeV/A | $1{\cdot}10^4$ pps | $^{208}$Pb,0.9 mg/cm$^2$ | 150 h |

# Coulomb excitation of $^{76,74}$Kr

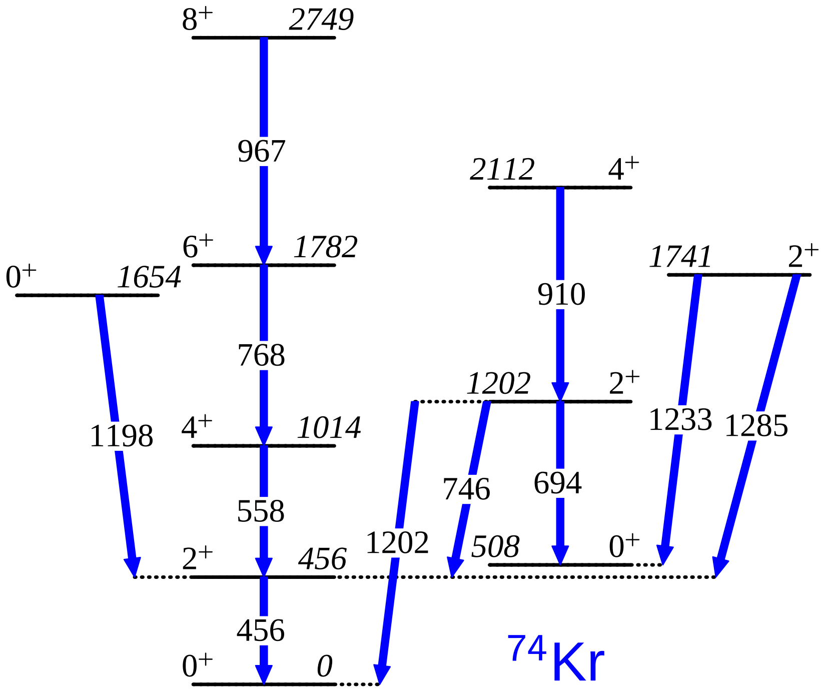



- 6 + 1 ($^{76}$Kr) or 7 + 4 ($^{74}$Kr) segmented clovers in EXOGAM
- highly segmented particle detector in forward angles: 16 sectors, 16 rings

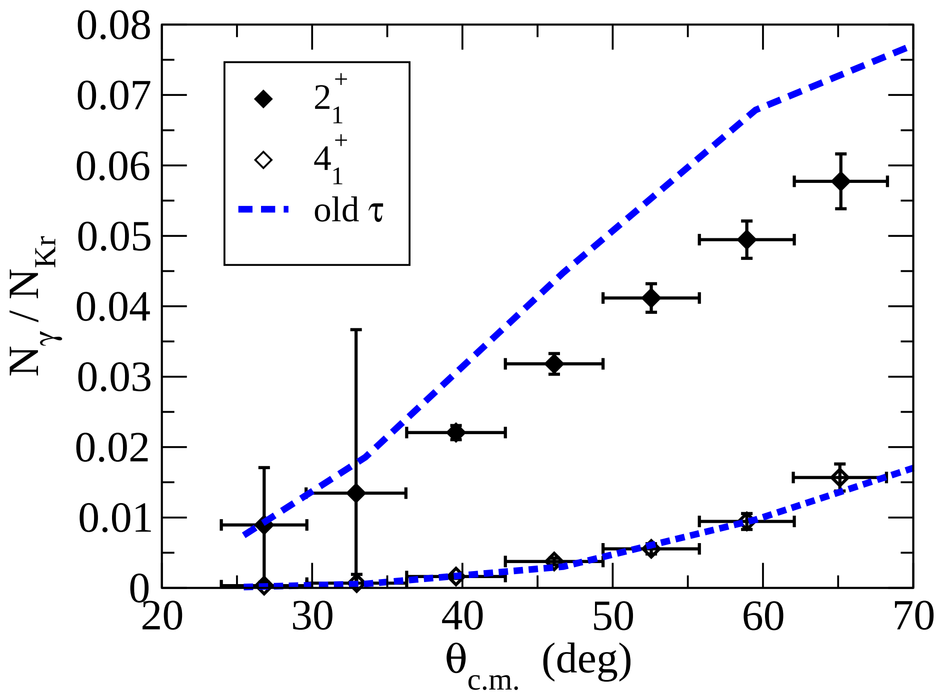


## Coulomb excitation analysis




- results inconsistent with previously published lifetimes
- new RDM lifetime measurement: Köln Plunger & GASP
  $^{40}$Ca ($^{40}$Ca,$\alpha$2p) $^{74}$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 ∼30 matrix elements (transitional and diagonal)



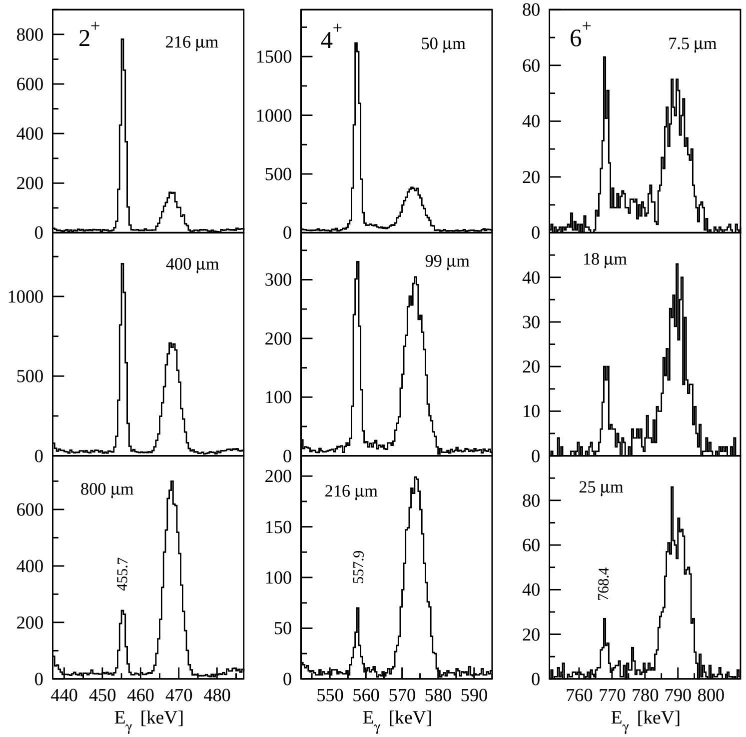
# Lifetime measurement

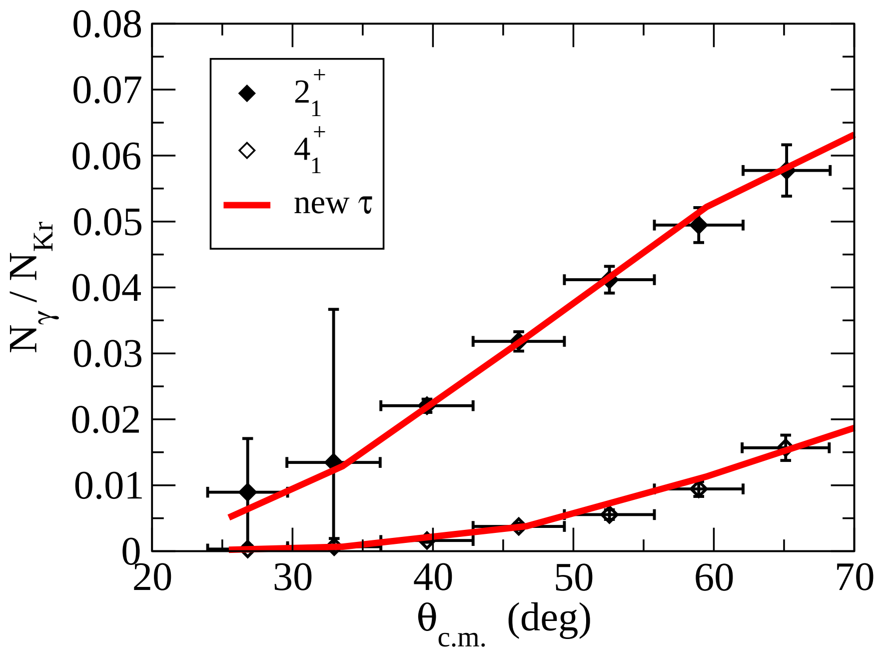
A. Görgen *et al.* EPJ A 26 153 (2005)

| | | 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



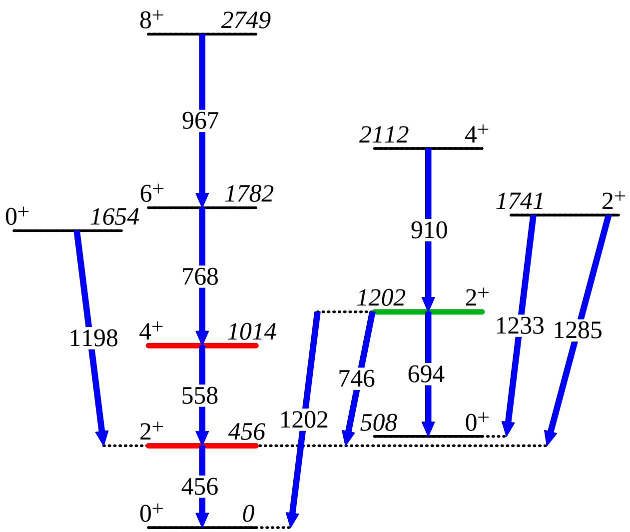

- new lifetimes in agreement with Coulex
- enhanced sensitivity for diagonal and intra-band transitional matrix elements

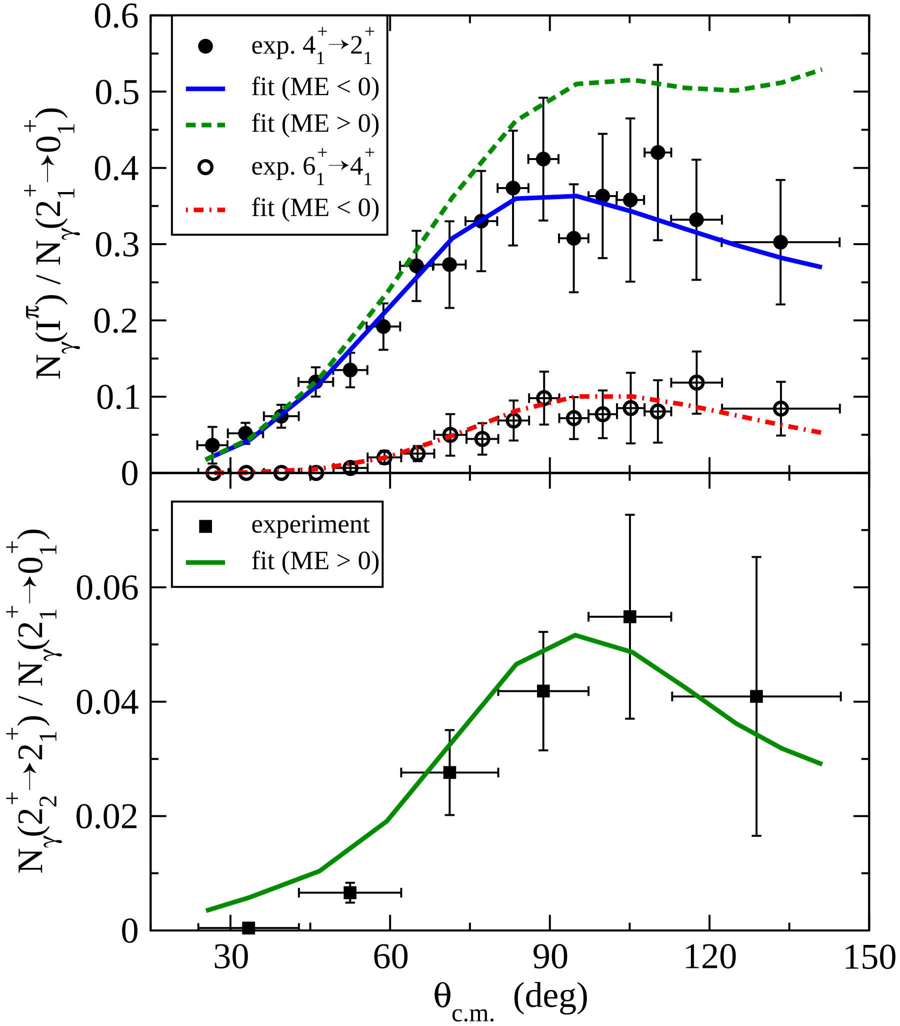
# Results: shape coexistence in light Kr isotopes

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

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

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



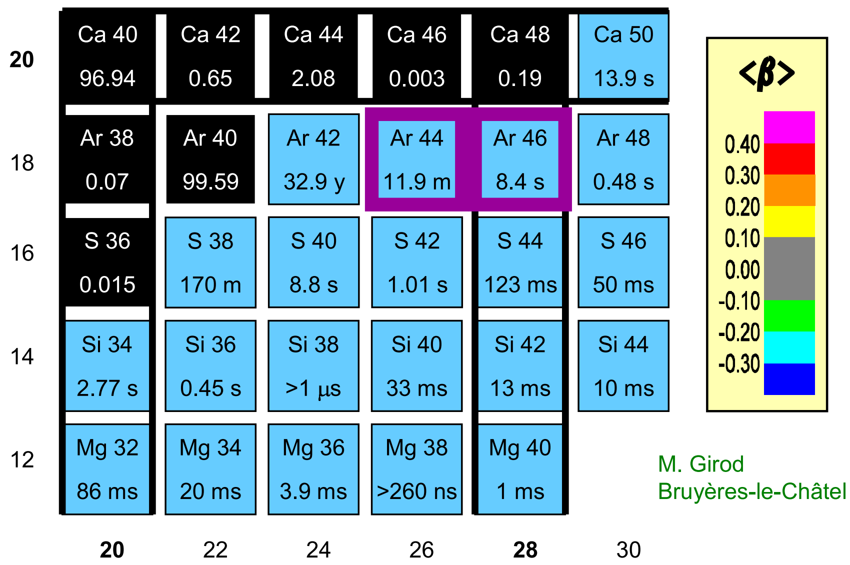



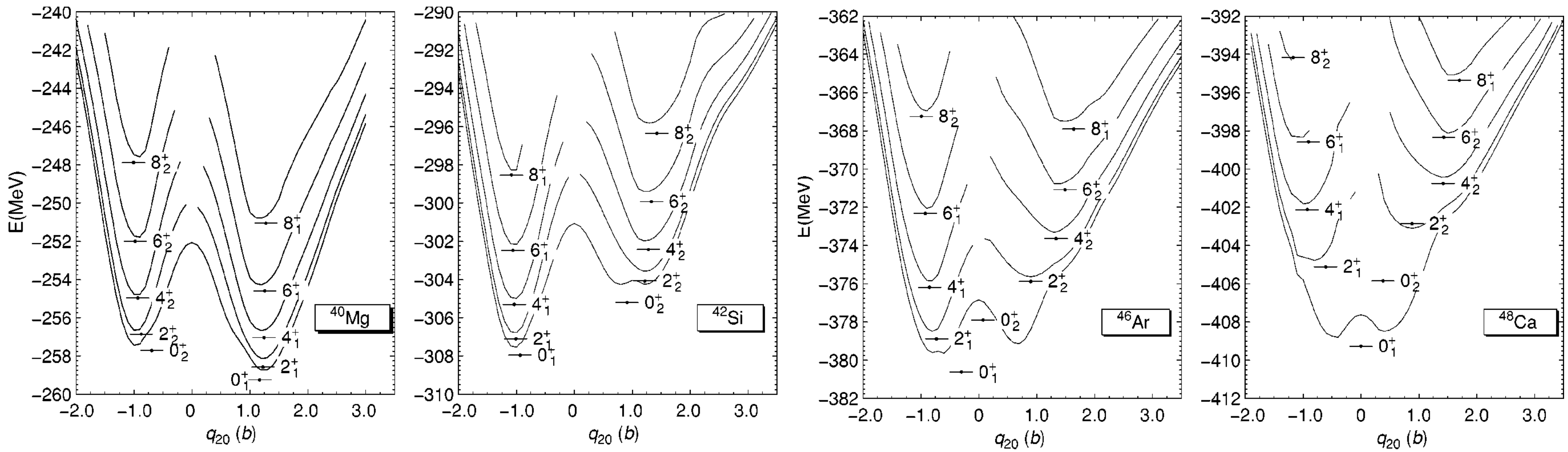

First measurement of diagonal E2 matrix elements using Coulex of radioactive beam

E. Clément *et al.* Phys. Rev. C75, 054313 (2007)

# Coexisting shapes around neutron-rich N=28 nuclei

- evolution of the N=28 shell closure below $^{48}$Ca
- possible shape coexistence




angular momentum projected generator coordinate method

R. Rodríguez-Guzmán et al., Phys. Rev. C 65, 024304 (2002)

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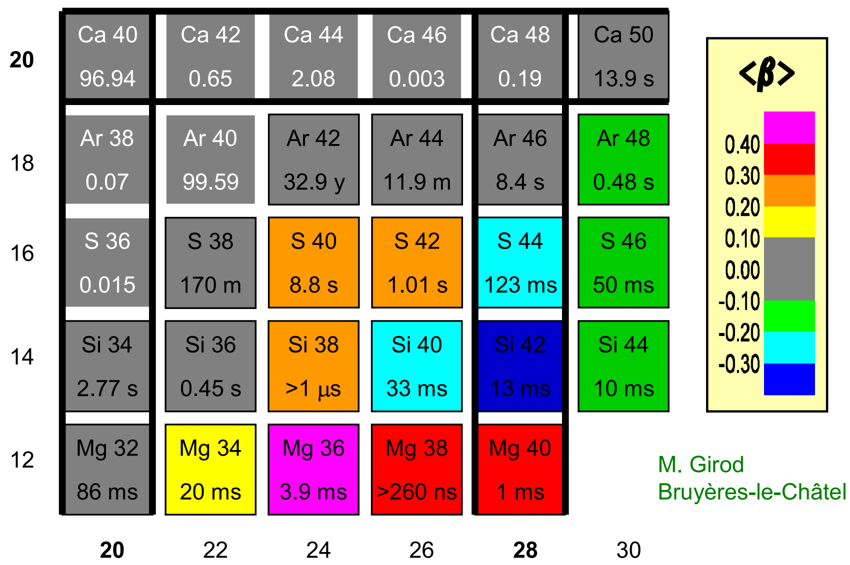


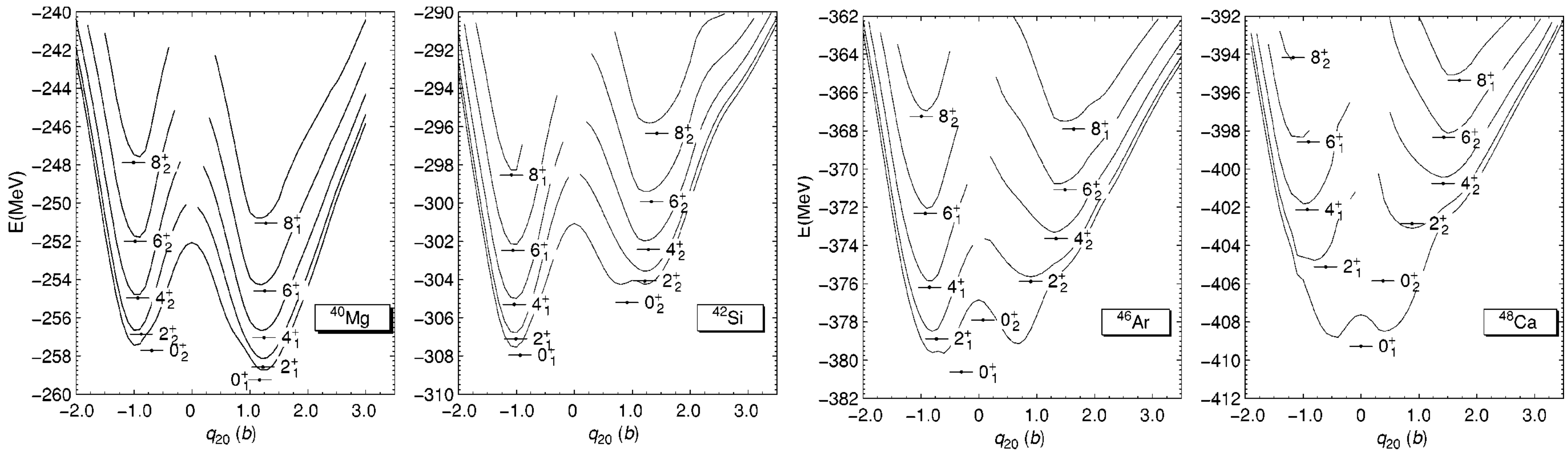


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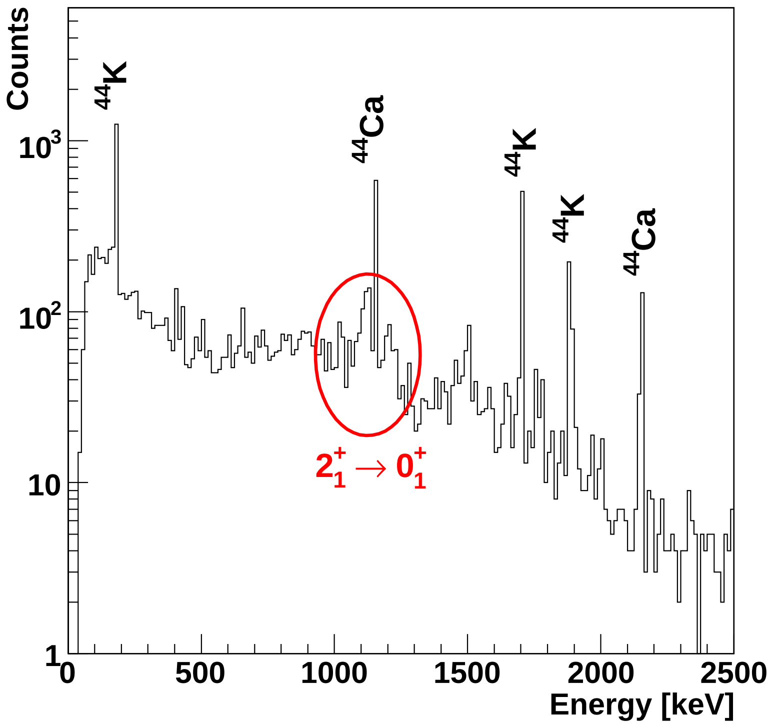
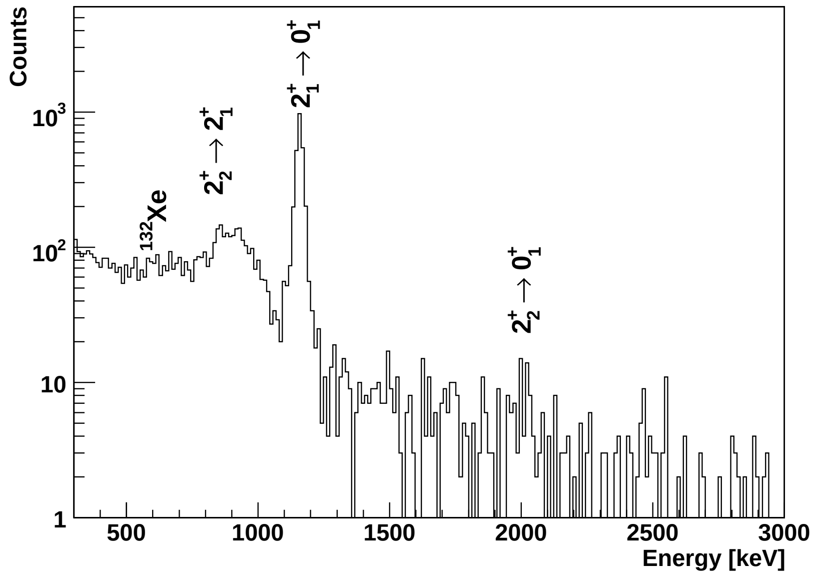
# Coulomb excitation of $^{44}$Ar

| Beam energy | Beam intensity | Target | Target thickness | Duration |
|---|---|---|---|---|
| 3.68 MeV/A | $2.4 \cdot 10^5$ pps | $^{208}$Pb | 1 mg/cm$^2$ | 13 UT |
| 2.68 MeV/A | $2.0 \cdot 10^5$ pps | $^{109}$Ag | 0.9 mg/cm$^2$ | 8 UT |



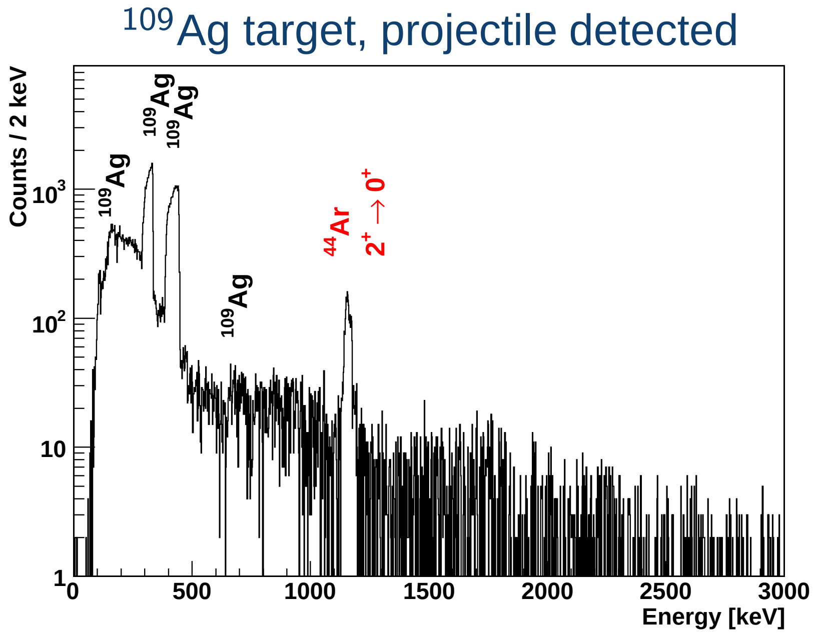

- 10 EXOGAM clovers (efficiency 13% at 1.3 MeV)
- higher segmentation of the particle detector (96 sectors, 16 rings)

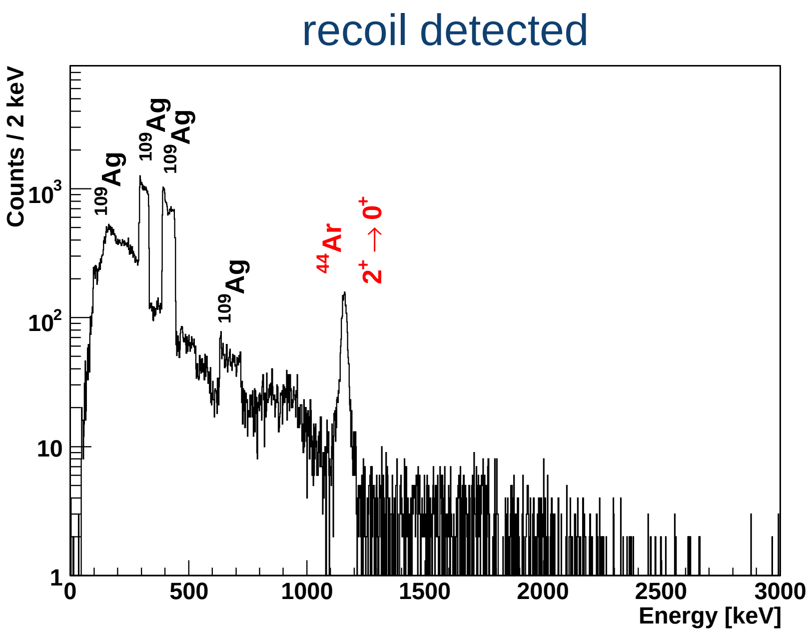
- higher background from $\beta$ decay




$^{208}$Pb target

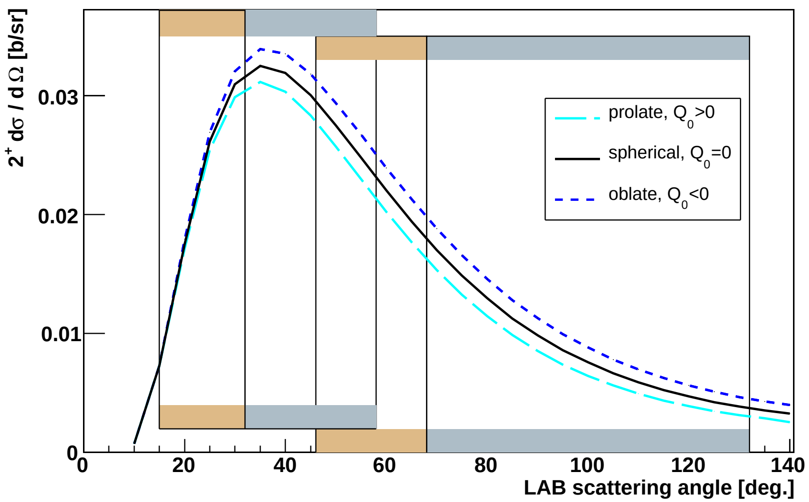
# Coulomb excitation of $^{44}$Ar



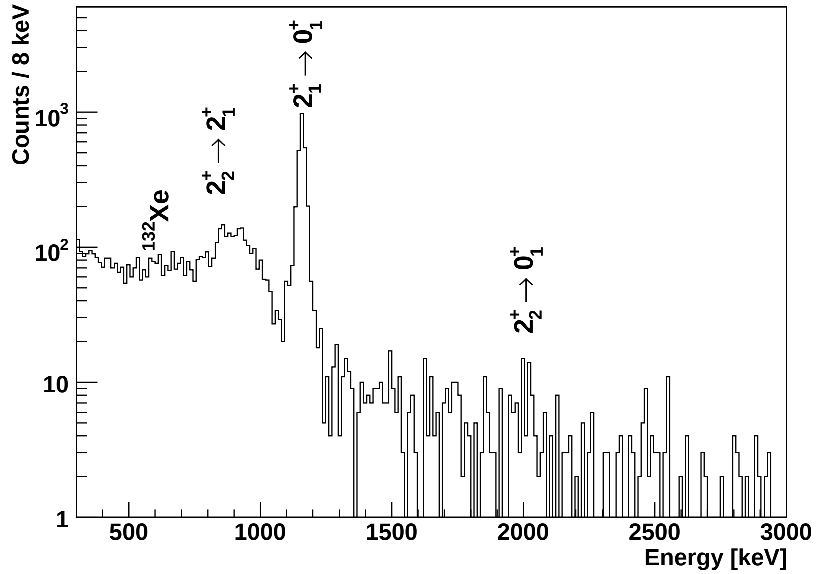




- statistics sufficient to subdivide the data into several angular ranges:
  - ∼4300 counts in the $2^+_1 \rightarrow 0^+$ line (1158 keV)
  - ∼50 counts in the $2^+_2 \rightarrow 2^+_1$ line (852 keV)
  - for normalization: more than 50 000 counts in 310 keV and 415 keV lines in $^{109}$Ag

# Extraction of E2 matrix elements



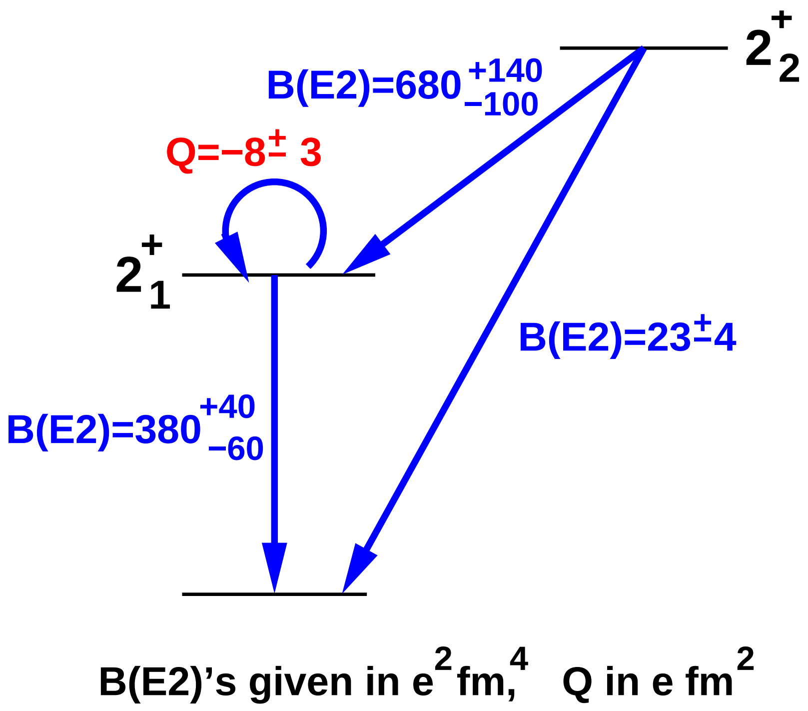

$^{208}$Pb target, recoil detected




- lowest angular range – influence of quadrupole moment negligible → determination of B(E2;$2_1^+ \rightarrow 0^+$)
- information from other bins + data collected on Pb target → determination of quadrupole moment of the $2_1^+$ state and other B(E2)'s
- relative normalization of the bins based on target excitation
- angular ranges chosen to obtain maximum sensitivity to the quadrupole moment

## Results

- $B(E2;2_1^+ \rightarrow 0^+)$ in agreement with the result from intermediate energy Coulex (345 (41) $e^2fm^4$)
- quadrupole moment of the $2_1^+$ state measured with precision of 35%
- $B(E2;2_2^+ \rightarrow 2_1^+)$ and $B(E2;2_2^+ \rightarrow 0^+)$ measured with precision of 20%




- test case for JACOB code - implementation of genetic algorithm to Coulex data analysis (see presentation of P. Napiorkowski)
- future plans:
  - low-energy Coulomb excitation of $^{42,46}$Ar – proposed at GANIL (M. Zielińska, A. Görgen *et al.*)

## People involved in the project:

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