# Coulomb excitation of neutron-rich $^{44}$Ar at SPIRAL: Determination of nuclear static moments using post-accelerated exotic beams

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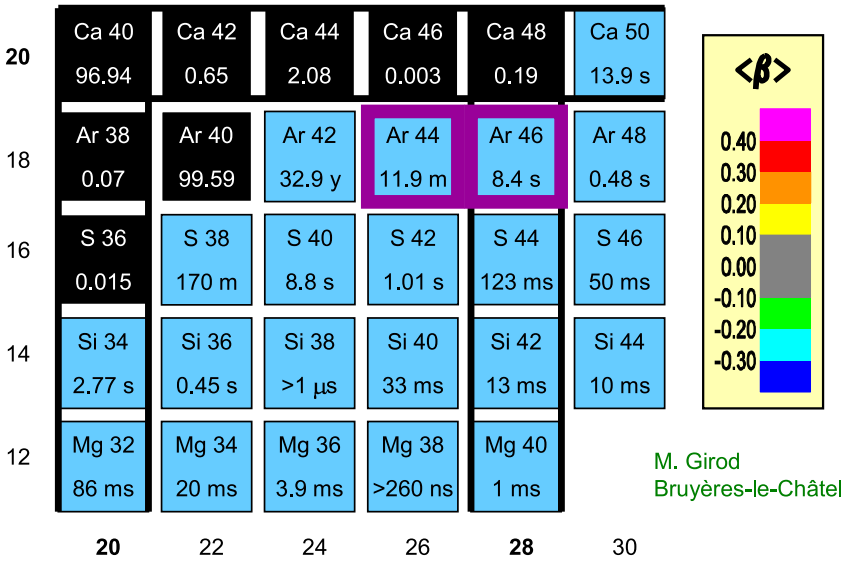
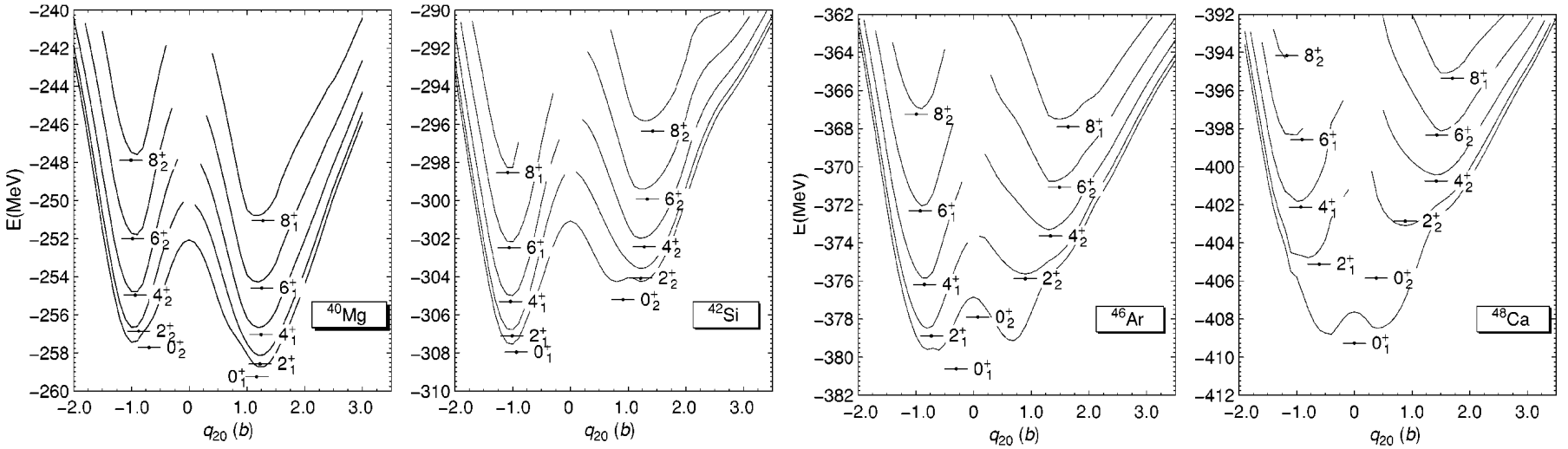
7) Warsaw University of Technology, Poland; 8) NBI Copenhagen, Denmark;

# Neutron-rich nuclei around $^{48}$Ca

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



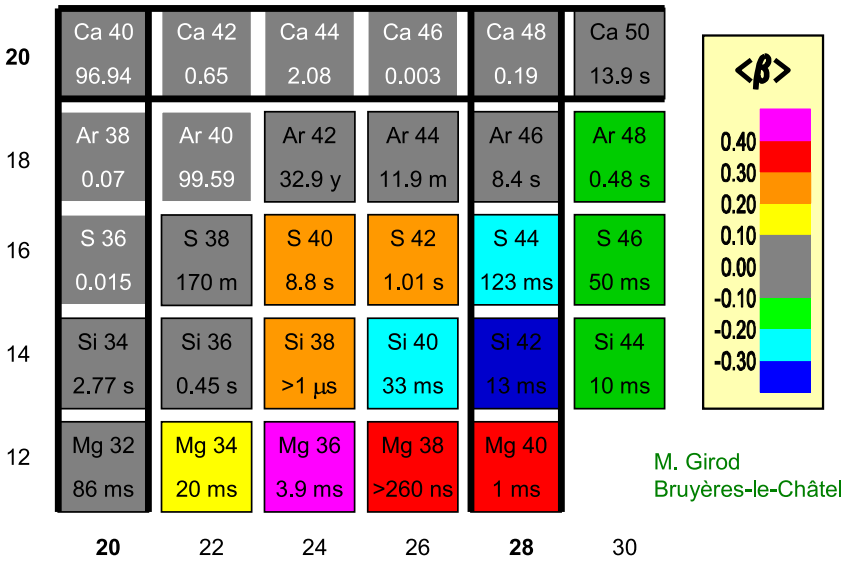




angular momentum projected generator coordinate method

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

# Neutron-rich nuclei around $^{48}$Ca

- evolution of the N=28 shell closure below $^{48}$Ca
- challenging region for nuclear spectroscopy

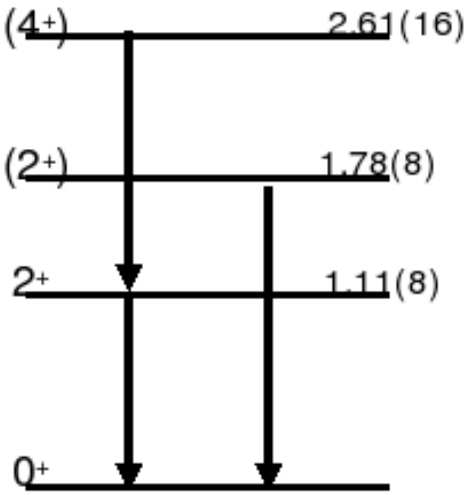



Known spectroscopic data:

- B(E2;$2_1^+ \rightarrow 0^+$) from intermediate energy Coulex: $^{44,46}$Ar, $^{38-44}$S
- energy of the first excited state in $^{42}$Si
- lifetime measurement for $^{44,46}$Ar produced in deep-inelastic reaction: data under analysis
- g factors (and B(E2)) measurement in $^{42,44,46}$Ar (A. Stuchbery *et al.*, MSU, October 2008): data under analysis

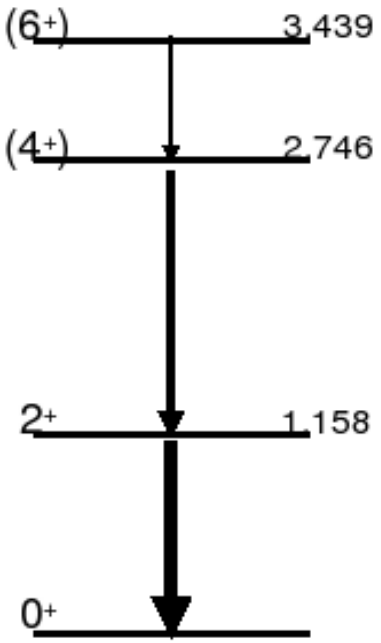
# Spectroscopic data on $^{44}$Ar

double fragmentation



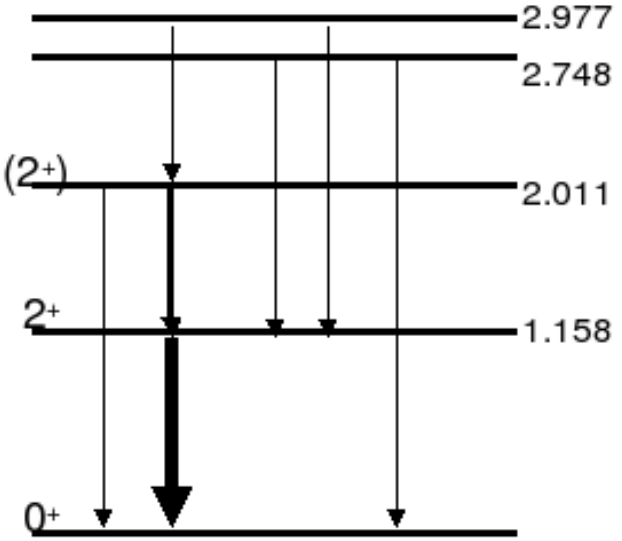

S. Wan et al.,
EPJA 6, 167 (1999)

deep inelastic




B. Fornal et al.,
EPJA 7, 147 (2000)

beta decay

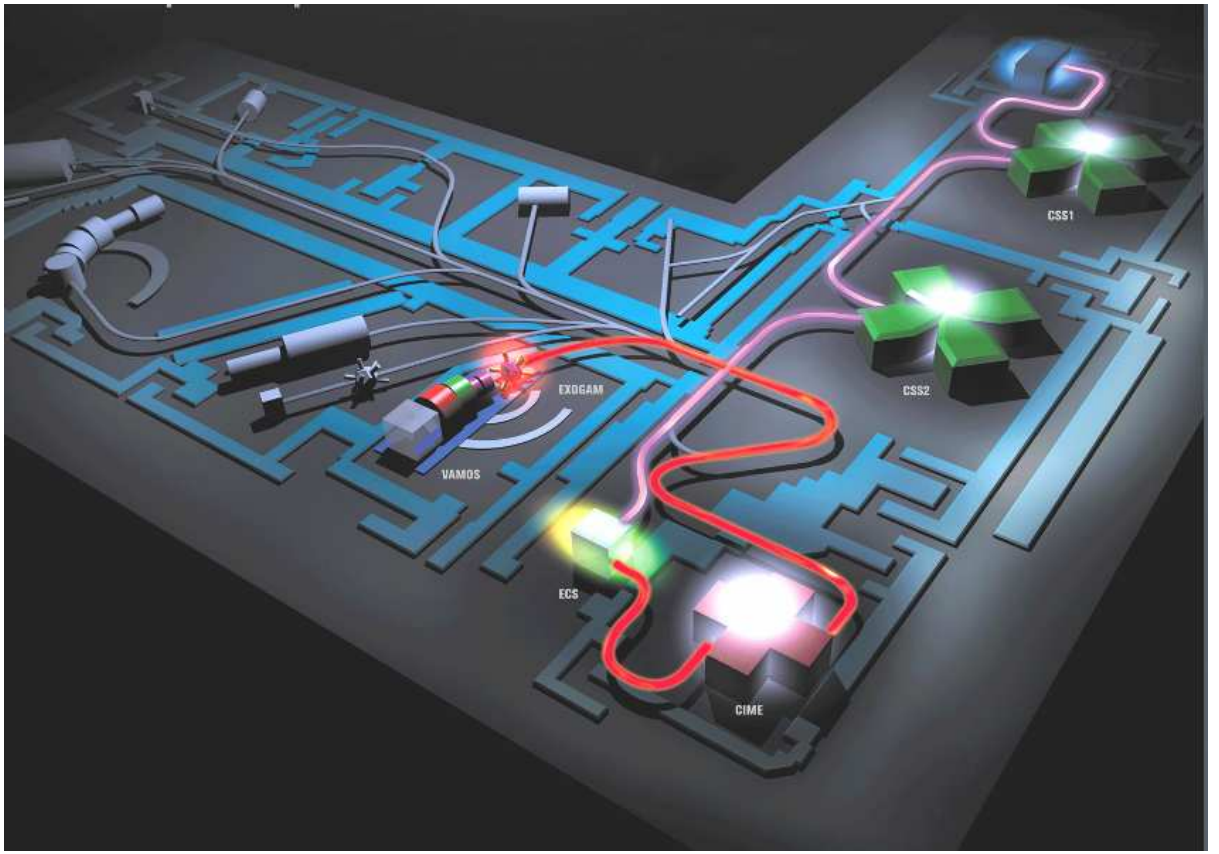



J. Mrazek et al.,
Nucl. Phys. A 734, E65 (2004)

- $B(E2;2^+ \rightarrow 0^+) = 345\ (41)\ e^2fm^4$

intermediate energy Coulex, H. Scheit et al., Phys. Rev. Lett. 77, 3967 (1996)

# Beams and targets

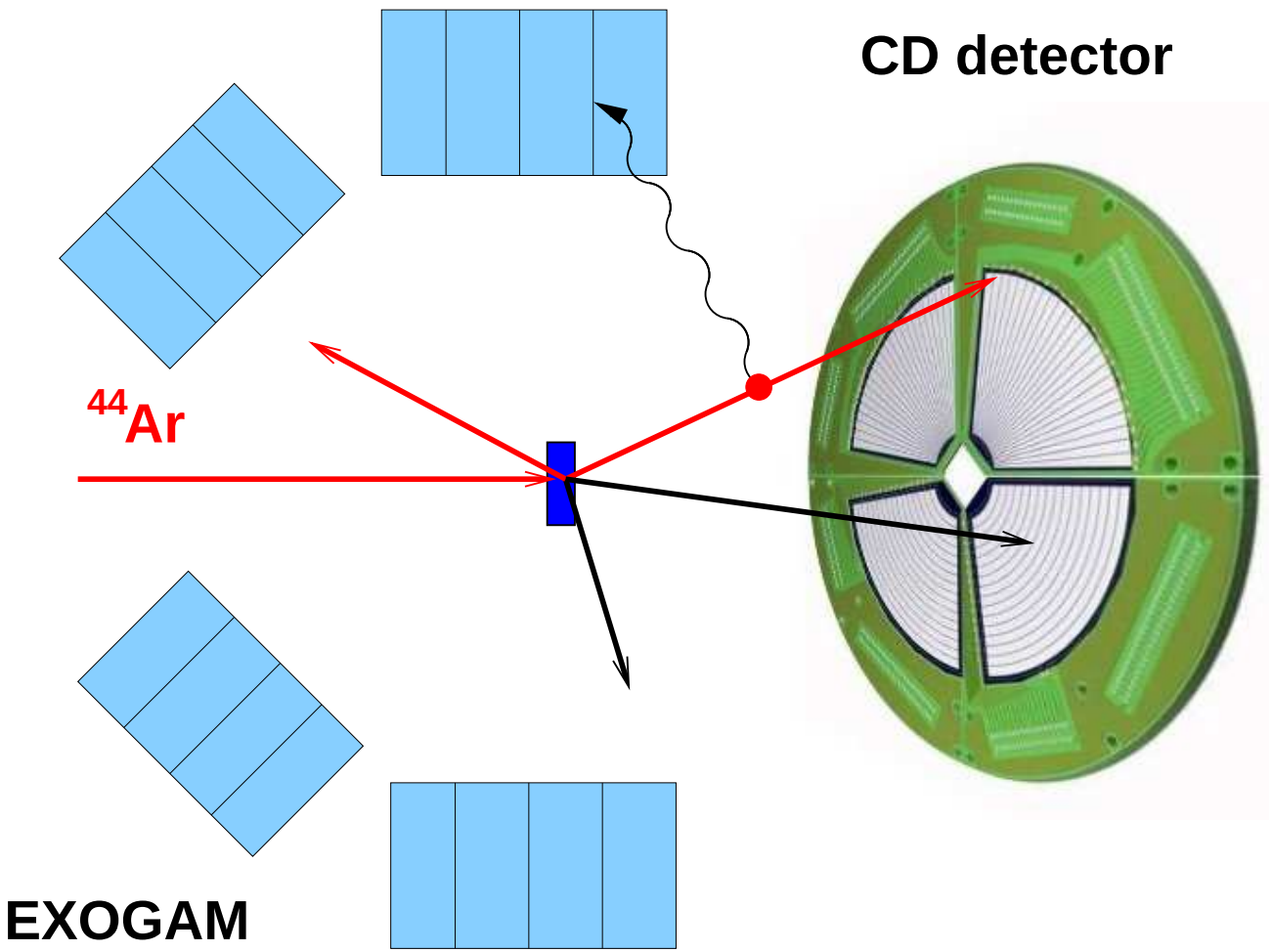



- Primary beam: $^{48}$Ca
60 MeV/A,
3.5 $\mu$A (nearly 600W)

- Secondary beam: $^{44}$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 |

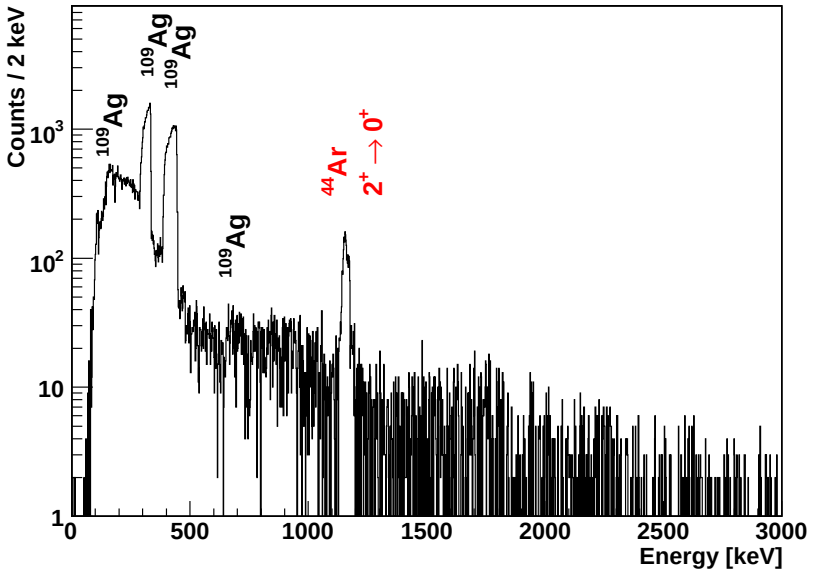
# Experimental setup



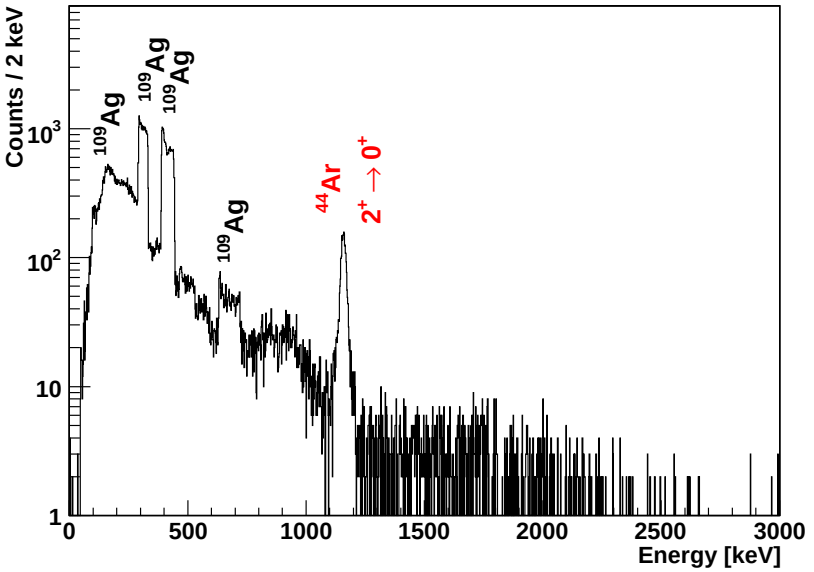

- 10 segmented clovers in EXOGAM
- highly segmented particle detector: 96 strips, 16 rings

# Results from the $^{109}$Ag target

$^{109}$Ag target, projectile detected



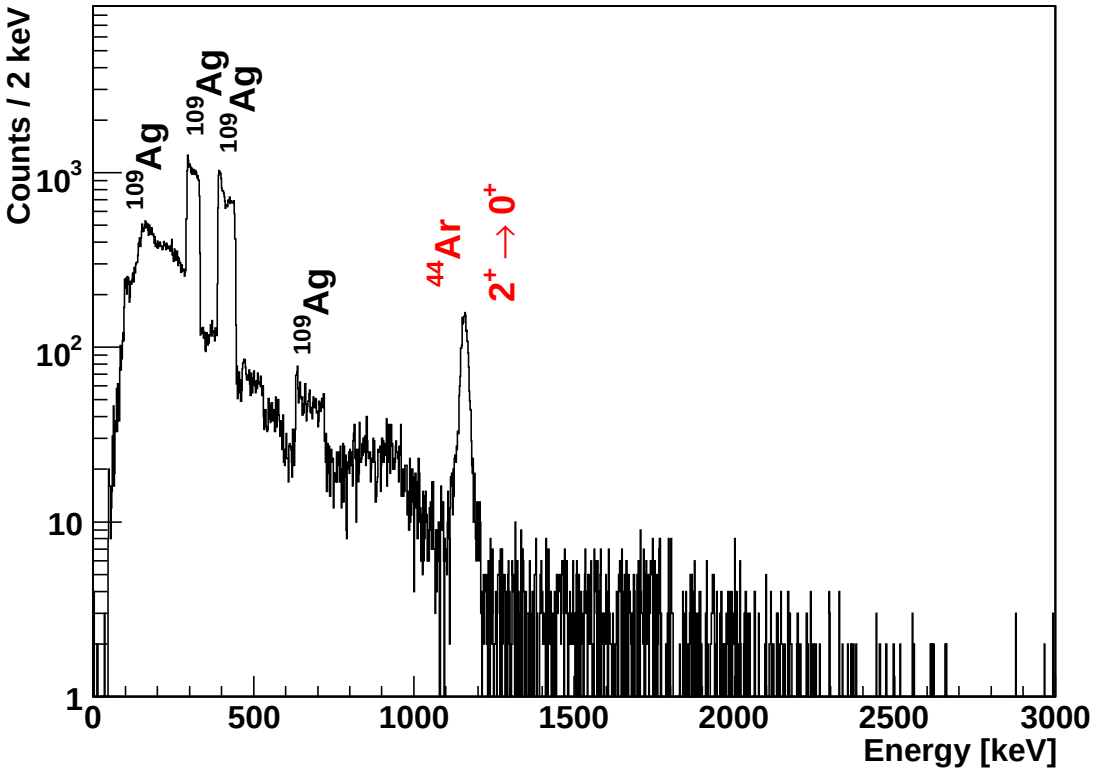

recoil detected

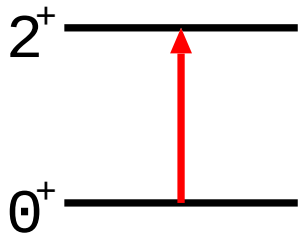



- statistics sufficient to subdivide the data into several angular ranges:
  - $\sim$4300 counts in the $2_1^+ \rightarrow 0^+$ line (1158 keV)
  - $\sim$50 counts in the $2_2^+ \rightarrow 2_1^+$ line (852 keV)
  - for normalization: more than 50 000 counts in 310 keV and 415 keV lines in $^{109}$Ag

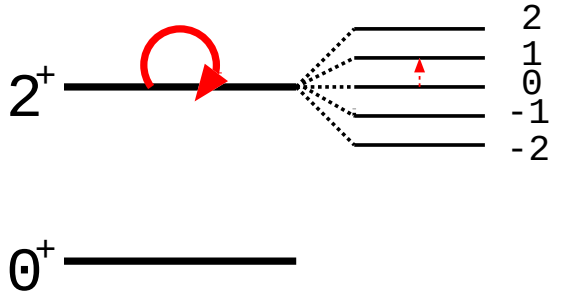
# B(E2)'s in radioactive nuclei measured with Coulex

- usually only $2^+ \rightarrow 0^+$ transition visible
- normalisation to target excitation needed



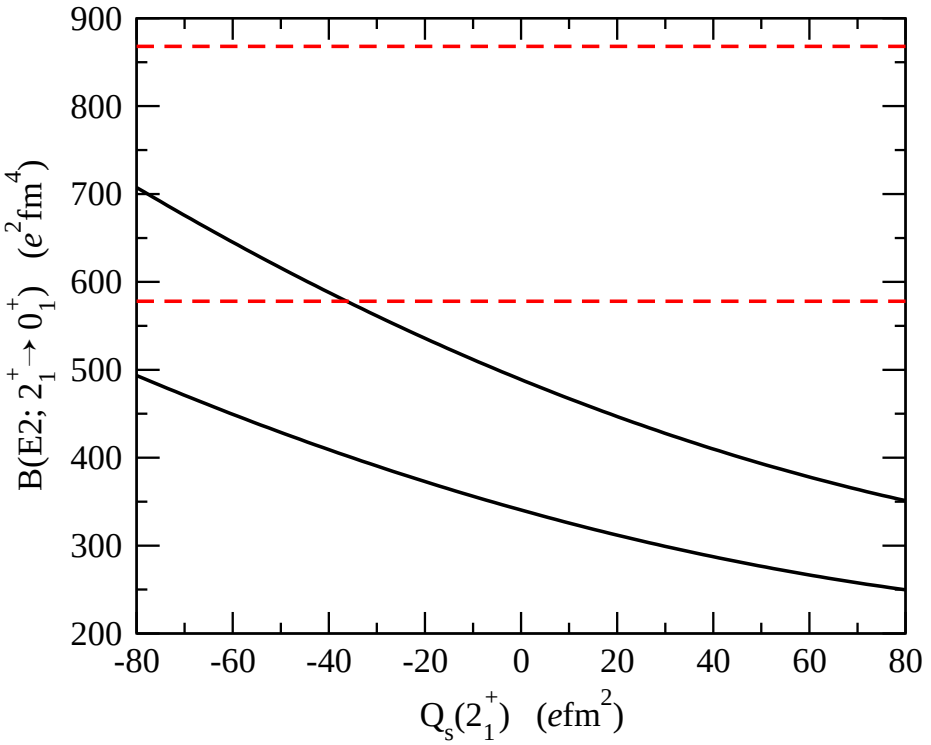

$\langle 2^+ || E2 || 0^+ \rangle^2$
$\sim$ B(E2; $2^+ \rightarrow 0^+$)




$\langle 2^+ || E2 || 2^+ \rangle \sim Q_0$

- Coulex cross-section depends both on the B(E2;$2_1^+ \rightarrow 0^+$) and the quadrupole moment!

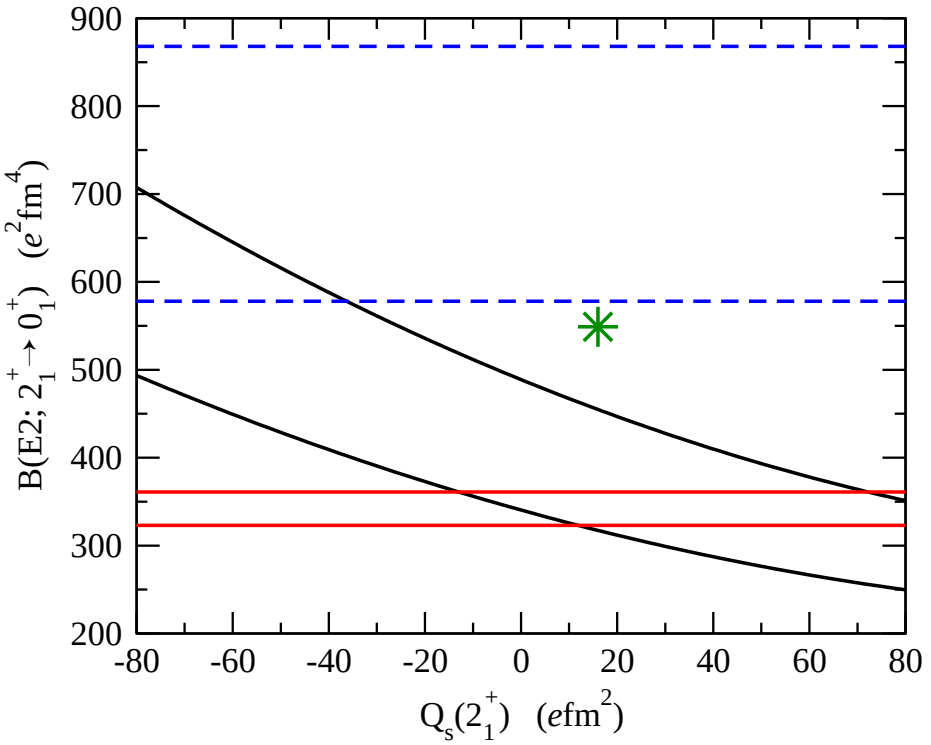
# Measurement of the quadrupole moment in $^{70}$Se




A.M. Hurst *et al.*,
Phys. Rev. Lett. 98, 072501 (2007)

- Measurement of the Coulex yield
- Lifetime known from an earlier RDM experiment
- Negative quadrupole moment deduced

# Measurement of the quadrupole moment in $^{70}$Se

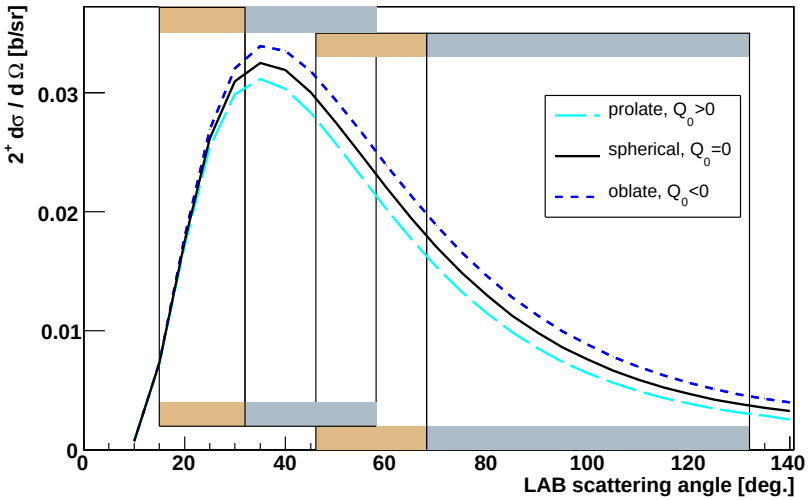


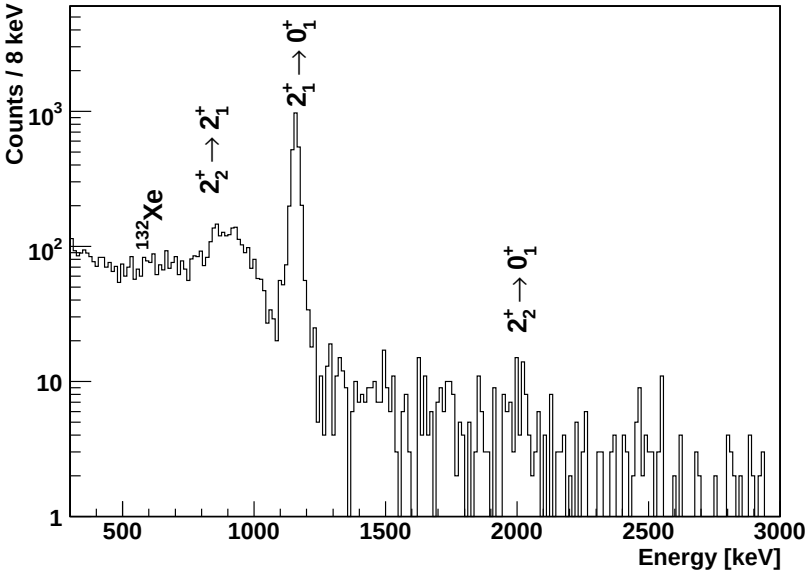

J. Ljungvall *et al.*,
Phys. Rev. Lett. 100, 102502 (2008)

- New, more precise lifetime measurement
- Positive quadrupole moment favoured

# Extraction of E2 matrix elements

$^{208}$Pb target, recoil detected

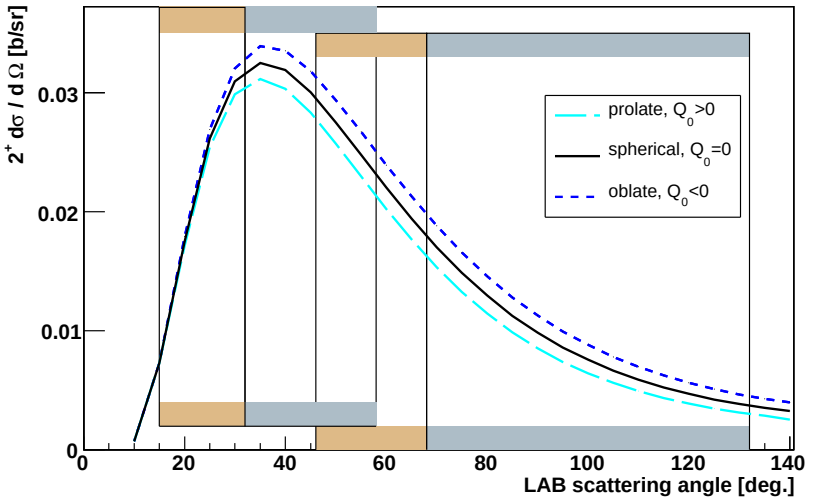


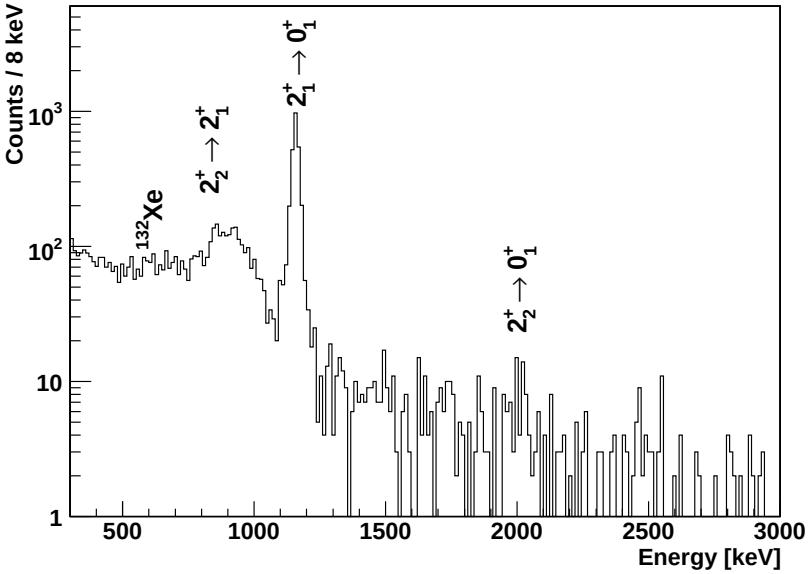




- lowest angular range – influence of quadrupole moment negligible $\rightarrow$ determination of B(E2;$2_1^+ \rightarrow 0^+$)
- information from other bins + data collected on Pb target $\rightarrow$ determination of quadrupole moment of the $2_1^+$ state and other B(E2)'s using standard GOSIA code
- relative normalization of the bins based on target excitation

# Extraction of E2 matrix elements

$^{208}$Pb target, recoil detected

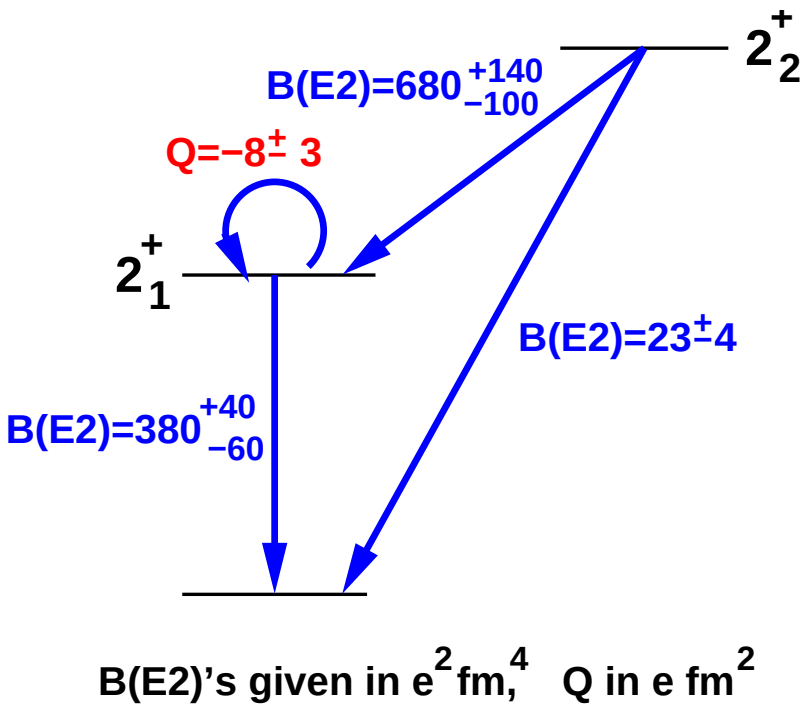



- several methods of data subdivision tested (3, 4, 6, 7, 8 bins)
- compromise between level of statistics in an individual experiment and number of $\gamma$-ray yields corresponding to different ranges of the scattering angle
- obtained values of the quadrupole moment consistent
- accuracy varies from 35 % to 70 %

## Results

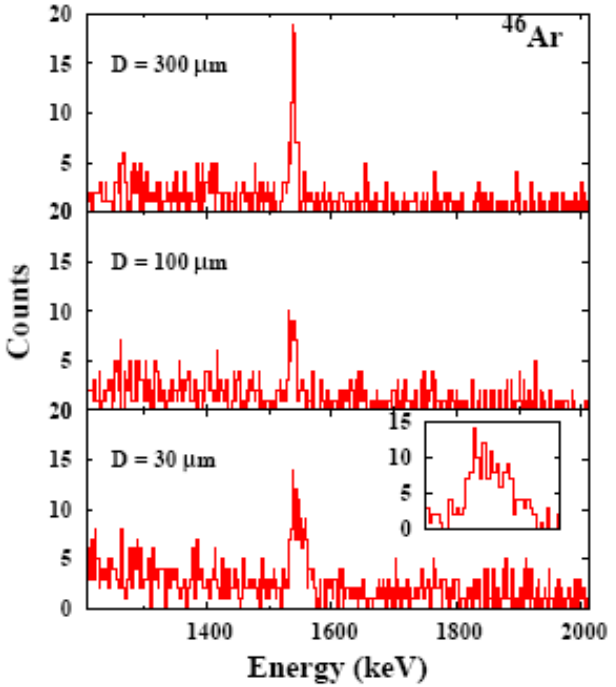
- B(E2; $2_1^+ \rightarrow 0^+$) in agreement with the result from intermediate energy Coulex (345 (41) $e^2fm^4$)
- quadrupole moment of the $2_1^+$ state – direct measurement of the nuclear shape – 35% accuracy
- B(E2)'s beyond $2_1^+$ measured for the first time in this mass region

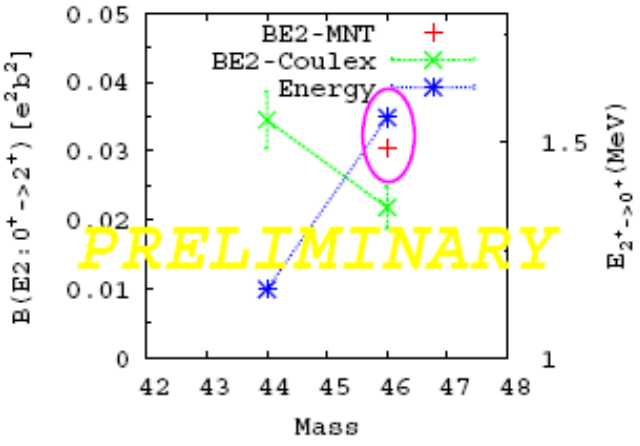



- $\beta$ deformation: 0.23
- diagonal matrix element – 50% of the rotational value $\rightarrow$ triaxiality ?
- $\langle 2_1^+ \| E2 \| 2_2^+ \rangle$ surprisingly large

# Lifetime measurement in $^{44,46}$Ar

fully shifted peak for D=30$\mu$m (short lifetime) $\Rightarrow$ simulation!




H. Scheit *et al.*, Phys. Rev. Lett **77** (1996) 3967.

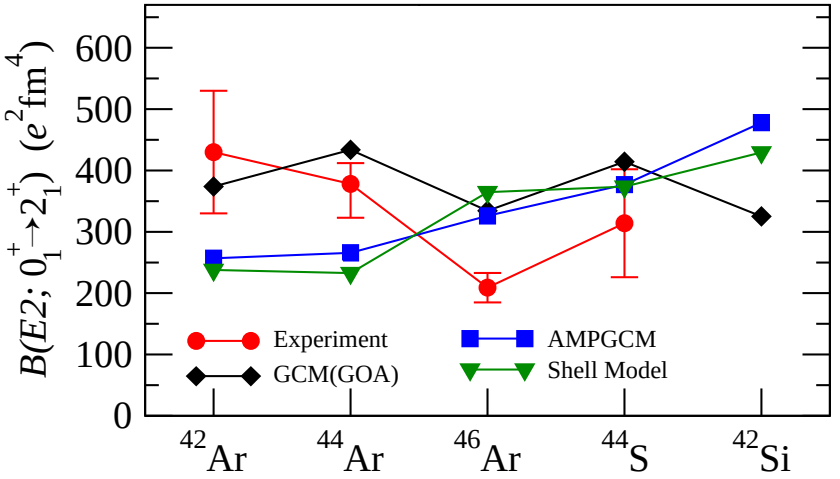
preliminary results, data under analysis

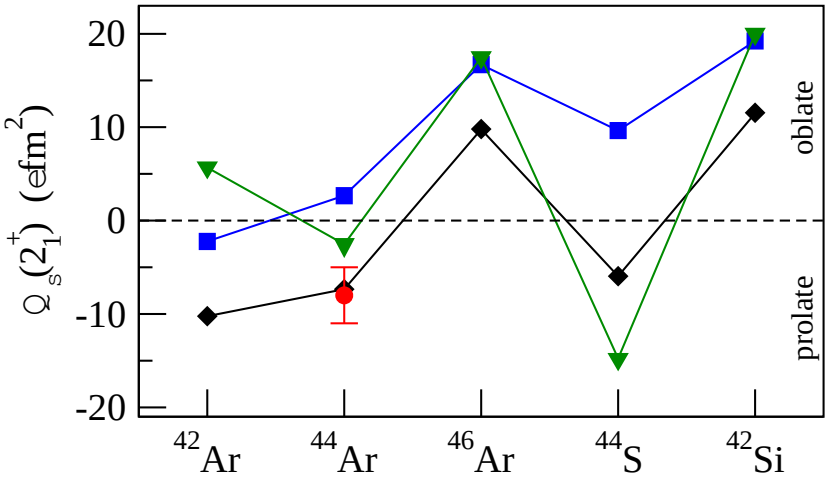
- for $^{44}$Ar lifetime in agreement with results from intermediate energy Coulex and present experiment
- for $^{46}$Ar lifetime shorter by at least 30%; so far only upper limit deduced

  D. Mengoni et al, Acta Phys. Pol. B40 (2009) 485

# Conclusions

M. Zielińska *et al.*, Phys. Rev. C 80 (2009) 014317




- more experimental data on quadrupole moments and transition strenghts needed

- deformation softness of $^{42,44}$Ar
- energy spectra from both GCM calculations too ditated
- systematic trend of B(E2)'s best described by triaxial GCM

- test case for JACOB code - implementation of genetic algorithm to Coulex data analysis