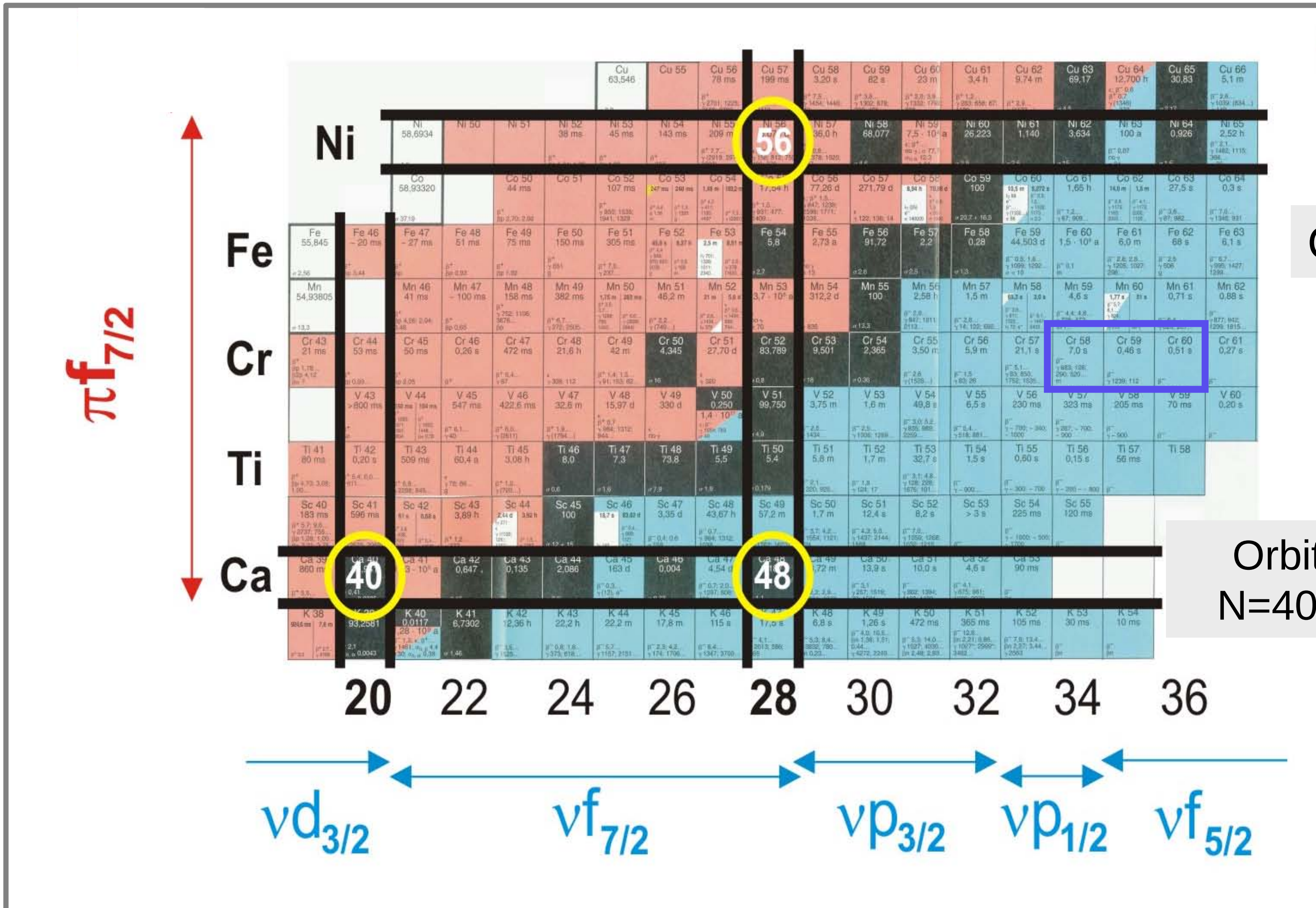
# Lifetime measurements of the neutron-rich Cr isotopes

J.J. Valiente-Dobón (LNL-INFN)

# Overview

- Physics motivation
  - Understanding the new island of inversion around N=40 $^{60}Cr$
  - Disentagling the E(5) character of $^{58}Cr$
- Setup and very preliminary results
- Counting rate considerations: Future experiments

# Nuclei in the fp shell

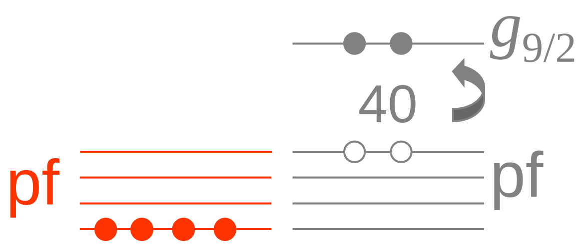


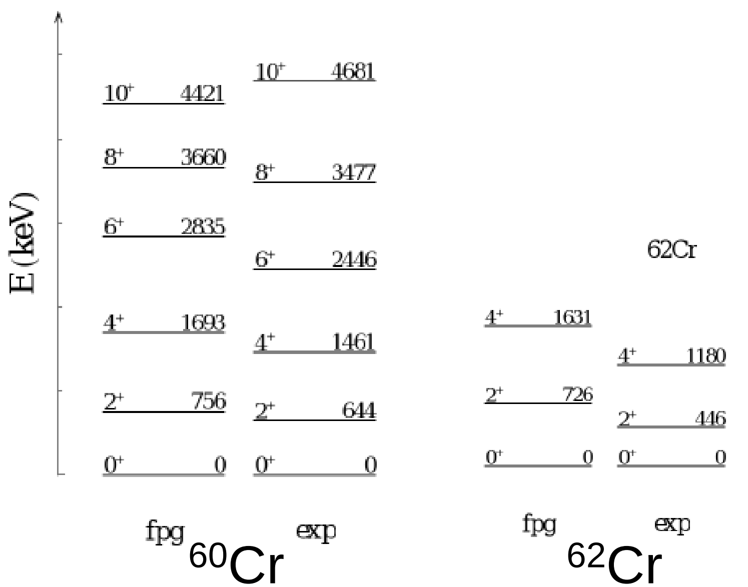

Cr isotopes

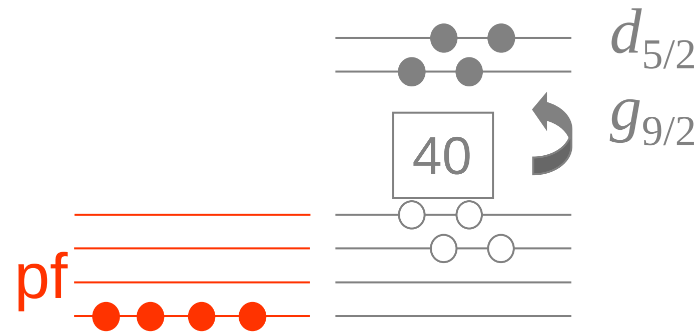
Orbitals above N=40: $\mathbf{g_{9/2} - d_{5/2}}$

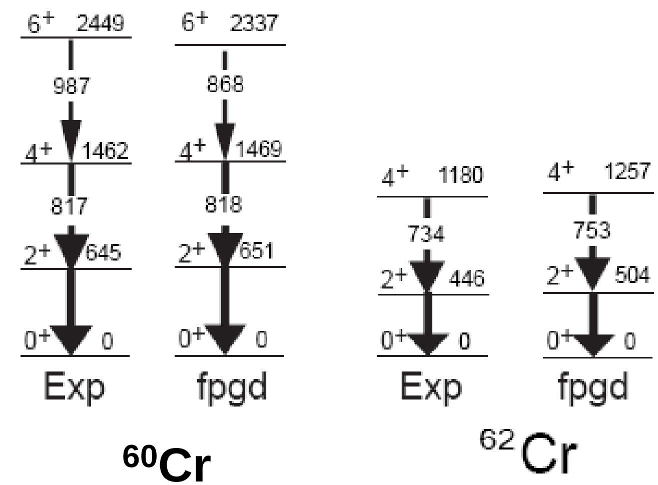
# The role of the $g_{9/2}$ and $d_{5/2}$ orbitals

**Generating collectivity**



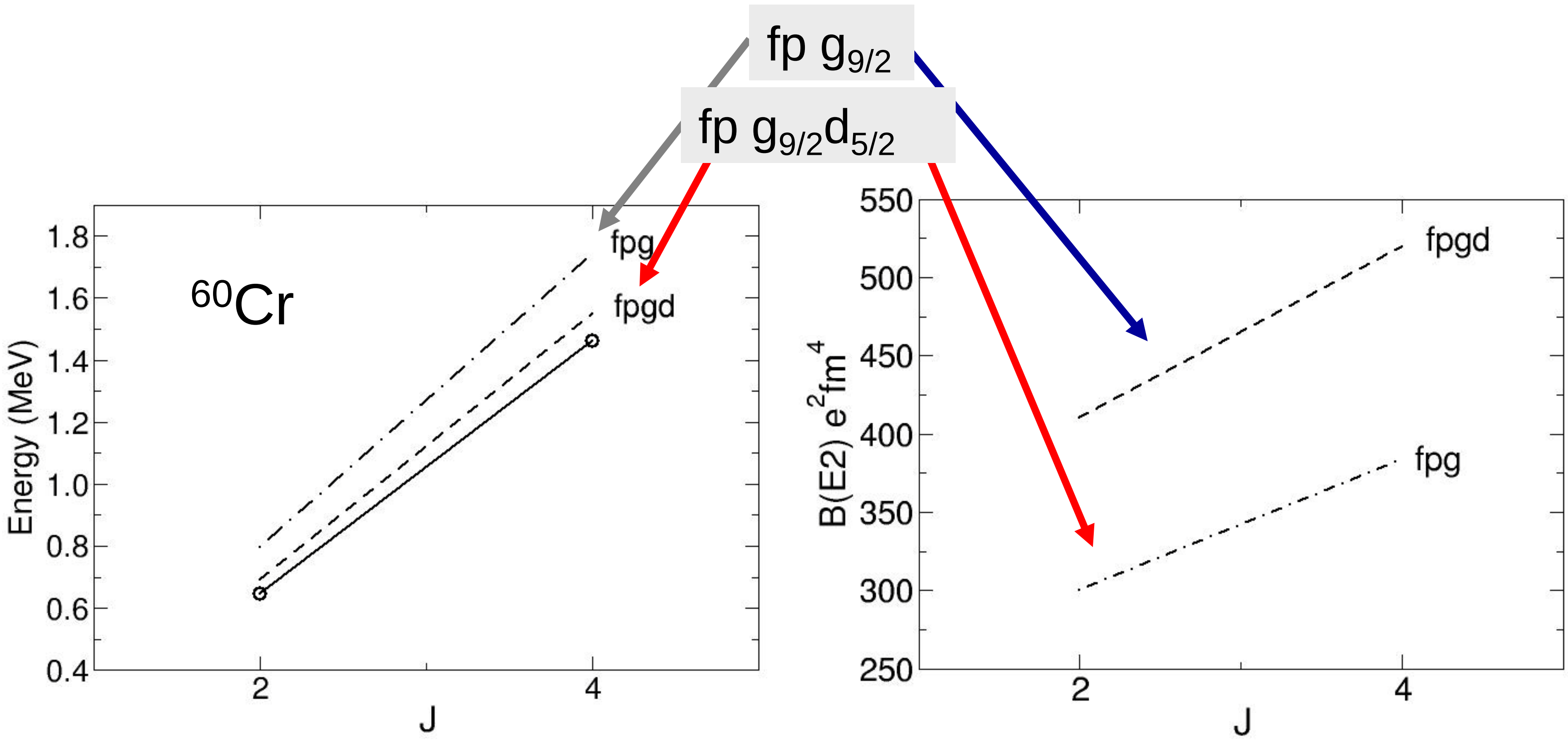

The experimental level schemes are more collective than the calculated ones.

The evolution of the deformation in the Cr isotopes is better reproduced including $d_{5/2}$ orbital

S. Lenzi et al., LNL Ann. Rep. 2008

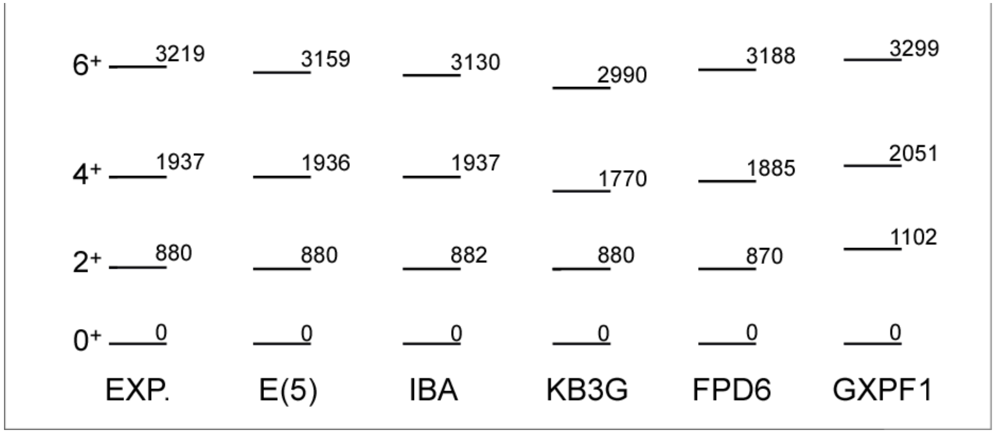
Lenzi, Nowacki, Poves, Sieja (to be published)

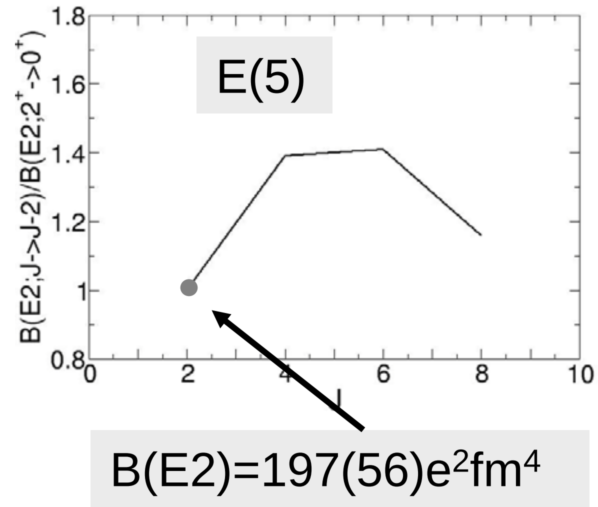
# Shell-Model caculations $^{60}Cr$




Lifetime measurements will elucidate the involvement of the $d_{5/2}$ orbital quasi-SU(3) symmetry

# $^{58}$Cr is a E(5) Shape-Phase-Transition Critical Point?




$^{58}$Cr gives the opportunity to compare analytic, algebraic and microscopic models in the same physical system.

*A. Bürger et al. PLB 622 (2005) 29.*

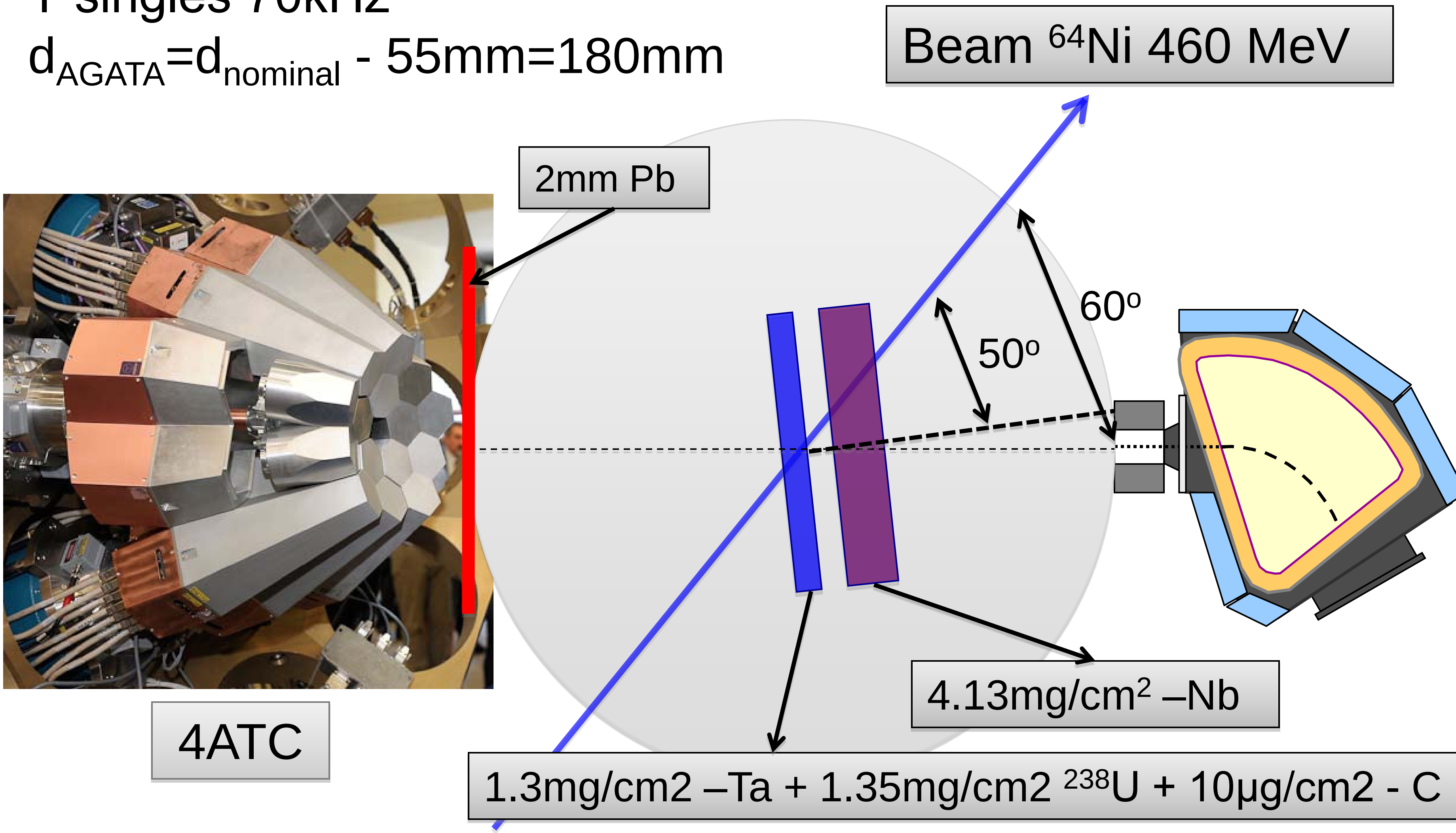
Experimental B(E2) values are needed to firmly demonstrate the existence of E(5) symmetry in $^{58}$Cr (two complementary experiments):

- First experiment LNL to measure B(E2) yrast states
- Second experimental proposal at AGATA-PRESPEC at GSI to measure B(E2) non-yrast

# AGATA + PRISMA + Plunger

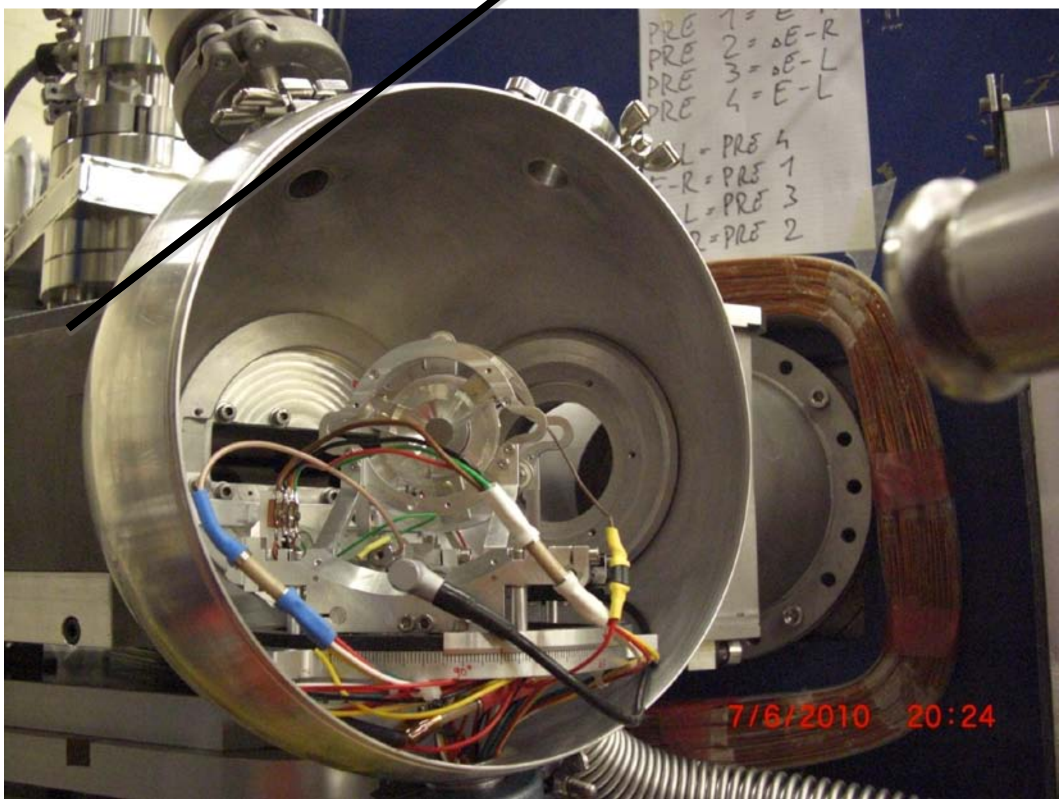
Y singles 70kHz

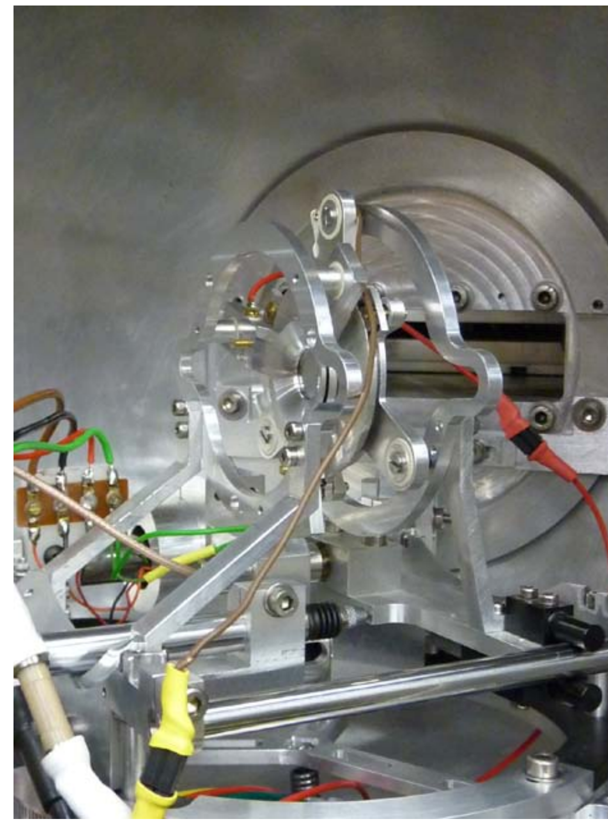
$d_{AGATA} = d_{nominal}$ - 55mm=180mm



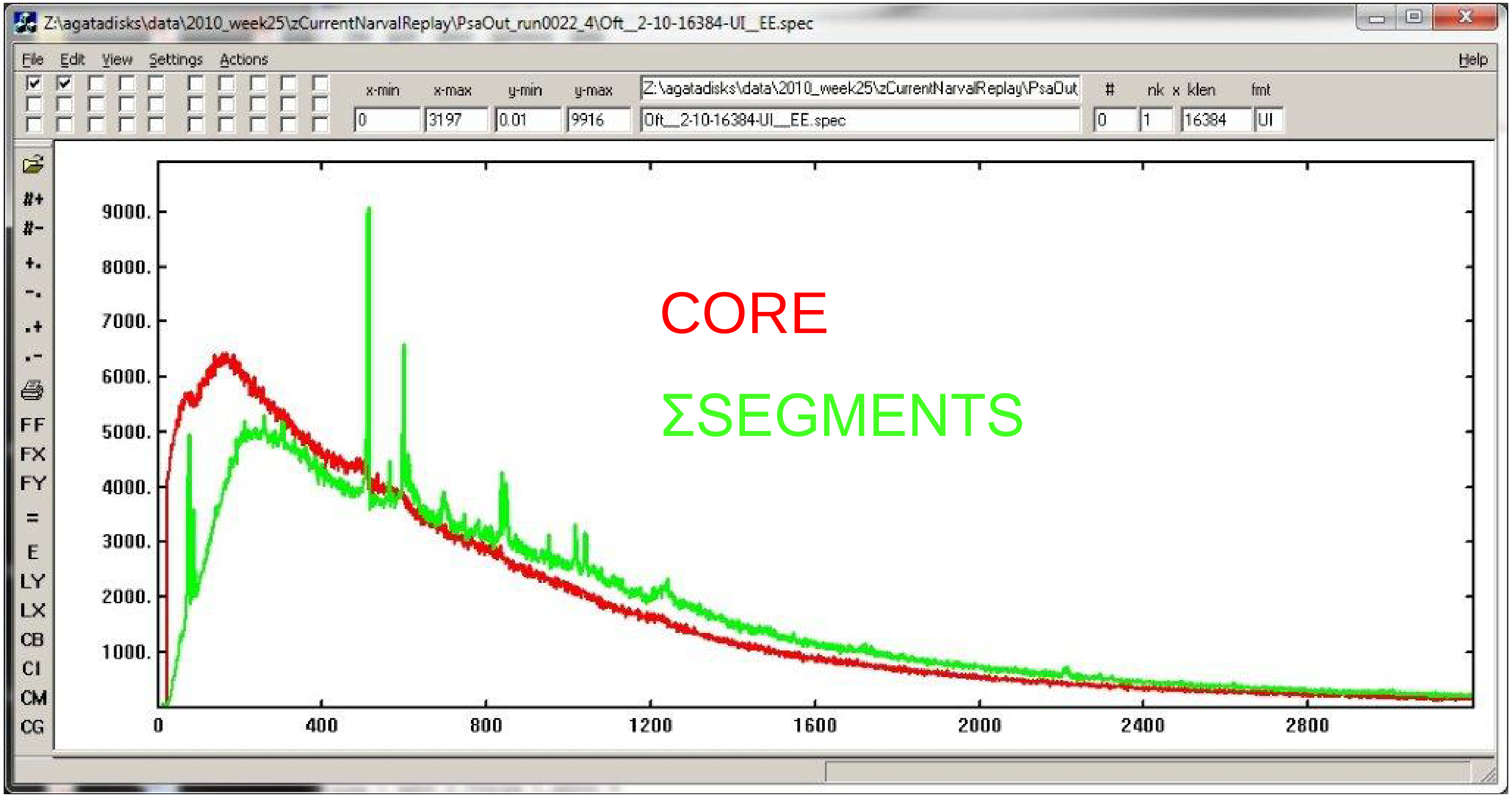
# Plunger setup

Beam dump to be improved



# Counting rate in AGATA




Shaping time 1.5μs – the intrinsic resolution does not change much

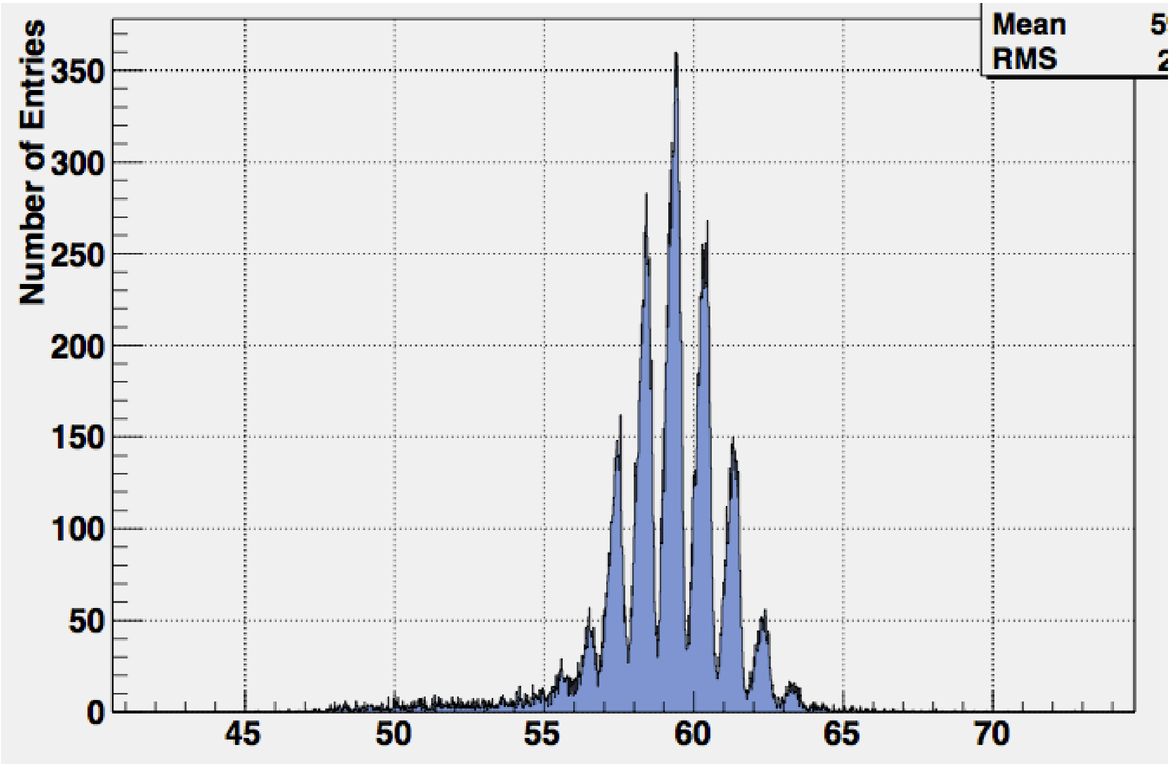
# Counting rate issue

- Starting point 4mg/cm$^2$ Mg ➔ end up with 4mg/cm$^2$ Nb

| Degrader | Thickness | Nº atoms | Energy loss |
|---|---|---|---|
| Mg | 4 mg/cm$^2$ | $10 \times 10^{19}$ | ~95MeV |
| Nb | 4 mg/cm$^2$ | $2.5 \times 10^{19}$ | ~65MeV |
| Ta | 4 mg/cm$^2$ | $1.3 \times 10^{19}$ | ~48MeV |

$^{93}$Nb: low B(E2)~0.3e$^2$fm$^4$ compared to $^{24}$Mg: B(E2)~400e$^2$fm$^4$
Should take into account *also* the cross section in degrader for coming experiments

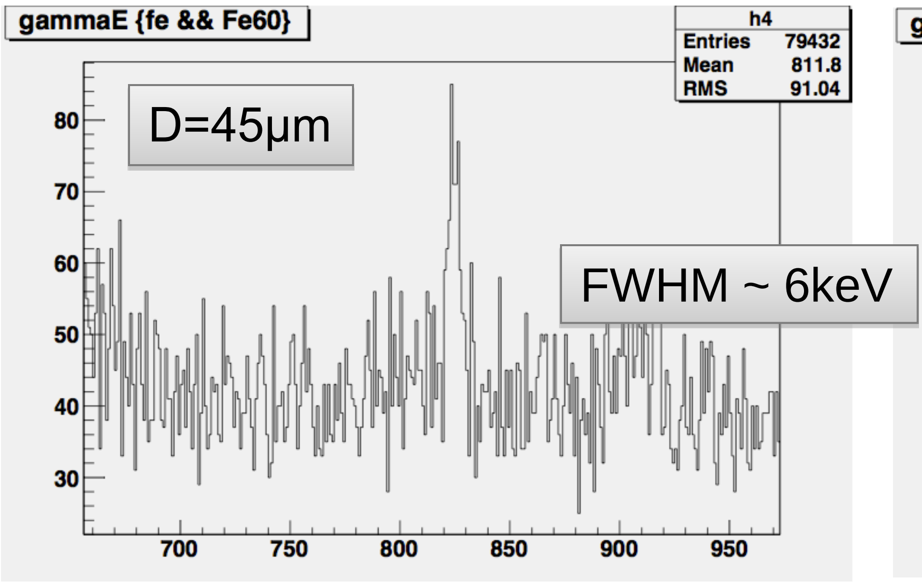
# Results: PRISMA analysis

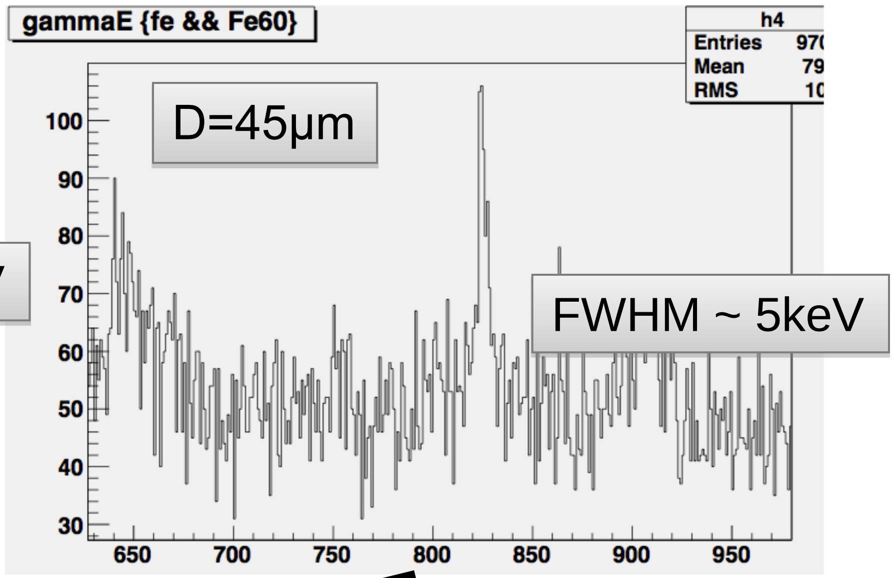



Fully implemented in the PRISMA library the aberrations corrections ➔ Preliminary, can be still done better

# Results: AGATA Demostrator

Three distances 20-45-150µm




Latest PSA signal bases calculated by B. Bruynee
Rough correction on neutron damage effects using the parameters modelled by B. Bruyneel

# Coming experiments

- RDDS lifetime measurement in the region of the neutron-rich doubly magic $^{132}$Sn: Lifetime of the $6^+$ state in $^{136}$Te – A. Gadea
  - Beam $^{136}$Xe at 1.2GeV onto $^{238}$U – 8 days
- Structure beyond the N=50 shell closure in neutron-rich nuclei in the vicinity of $^{78}$Ni: The case of N=51 nuclei – D. Verney, G. Duchene, G de Angelis
  - Beam $^{82}$Se at 570MeV onto $^{238}$U – 10 days
- *Lifetimes of intruder states in N ~ 20 sd-pf-shell neutron-rich nuclei* – R. Chapman, F. Hass
  - Beam $^{36}$S at 216 MeV onto $^{208}$Pb – 8 days

17$^{th}$-18$^{th}$ January 2011 Meeting at LNL for the preparation of the coming and future experiments.

# Summary

- Study of the Cr new region of deformation – Lifetimes measurements
- Initial problems with counting rate solved(?) by using a Nb degrader
- Analysis on the PRISMA part almost completed: Aberrations corrected.
- AGATA analysis
  - Check the consistency of the analysis with previous performed experiments at LNL with CLARA -Statistics
  - Lifetime analysis

# Building up collectivity

RAPID COMMUNICATIONS

PHYSICAL REVIEW C VOLUME 52, NUMBER 4 OCTOBER 1995

**Spherical shell model description of rotational motion**

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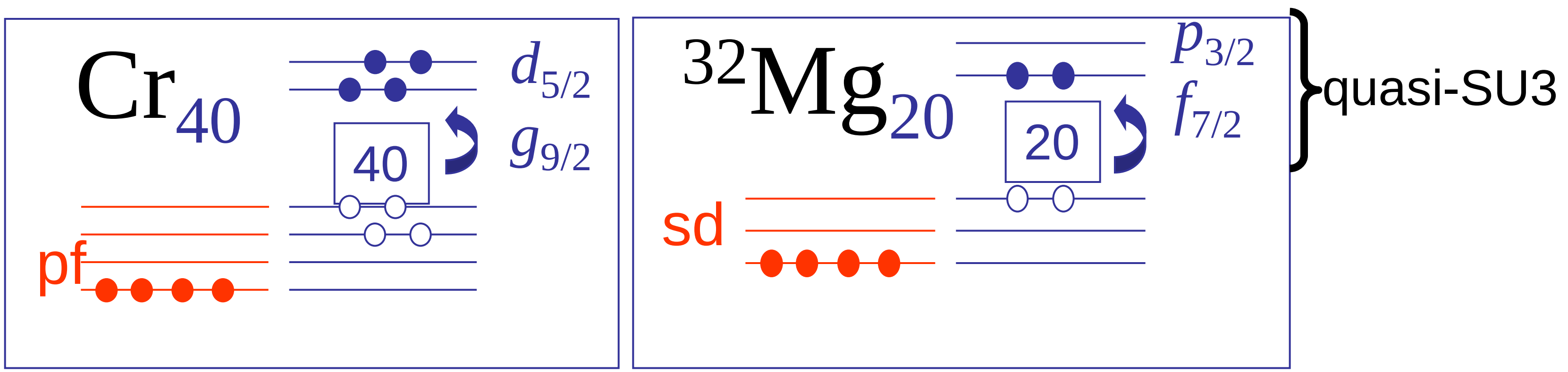
[1] *Physique Théorique, Bâtiment 40/1 CRN, Institut National de Physique Nucléaire et des Particles-CNRS/Université Louis Pasteur, Boîte Postale 28, F-67037 Strasbourg Cedex 2, France*

[2] *Departamento de Física Teórica, Universidad Autónoma de Madrid, E-28049 Madrid, Spain*

(Received 13 July 1994)

Exact diagonalizations with a realistic interaction show that configurations with four neutrons in a major shell and four protons in another—or the same—major shell, behave systematically as backbending rotors. The dominance of the $q\cdot q$ component of the interaction is related to an approximate "quasi-SU3" symmetry. It is suggested that the onset of rotational motion in the rare earth nuclei is due to the promotion of the eight particle blocks to the major shells above the ones currently filling. Assuming a "pseudo-SU3" coupling for the particles in the lower orbits, it is possible to account remarkably well for the observed $B(E2)$ rates at the beginning of the region.

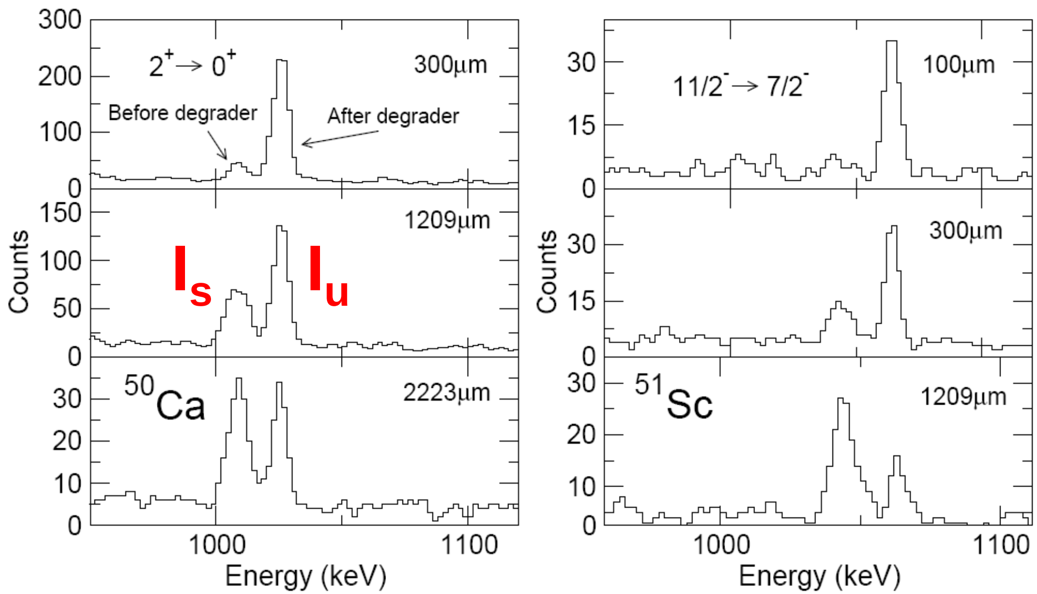


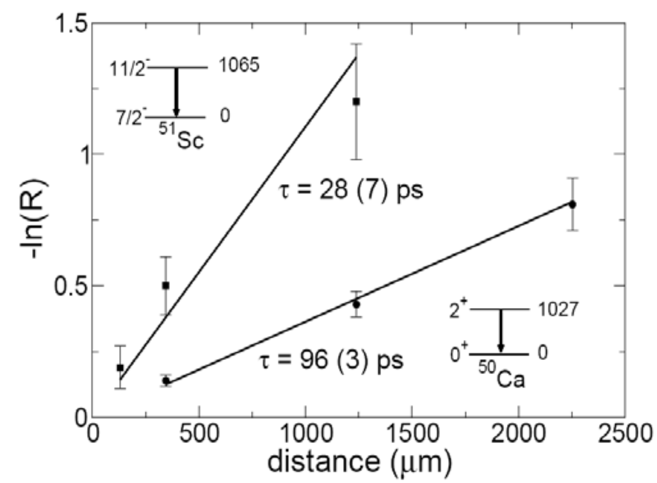

Quadrupole deformation can be generated by using a quadrupole force with the central field in the subspace spanned by a sequence of Δj = 2 orbits that come lowest by the spin-orbit splitting representing this relevant subspace a quasi-SU3. **In the Cr region it happens something similar to what happens in the Island of inversion $^{32}$Mg**.

# RDDS method for MNT

$^{48}$Ca onto $^{208}$Pb at 310 MeV

RDDS spectra of the $2^+$ and $11/2^-$ in $^{50}$Ca and $^{51}$Sc (mass gate in PRISMA)




Lifetimes of $^{50}$Ca and $^{51}$Sc

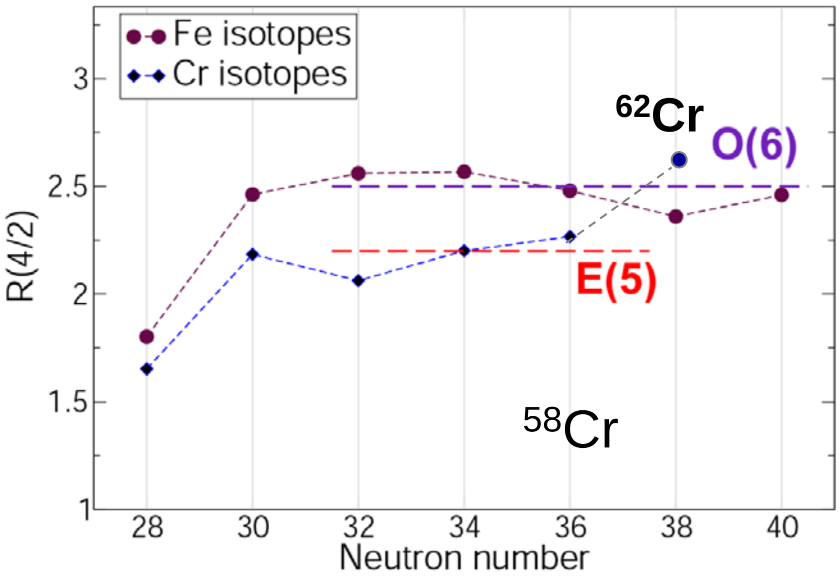

A. Gadea et al., Acta Phys. Pol. B 38 1311 (2007)
D. Mengoni et al., Eur. Phys. J. A42 387 (2009).
J.J.V.D et al., Phys. Rev. Lett. 102 242502 (2009).

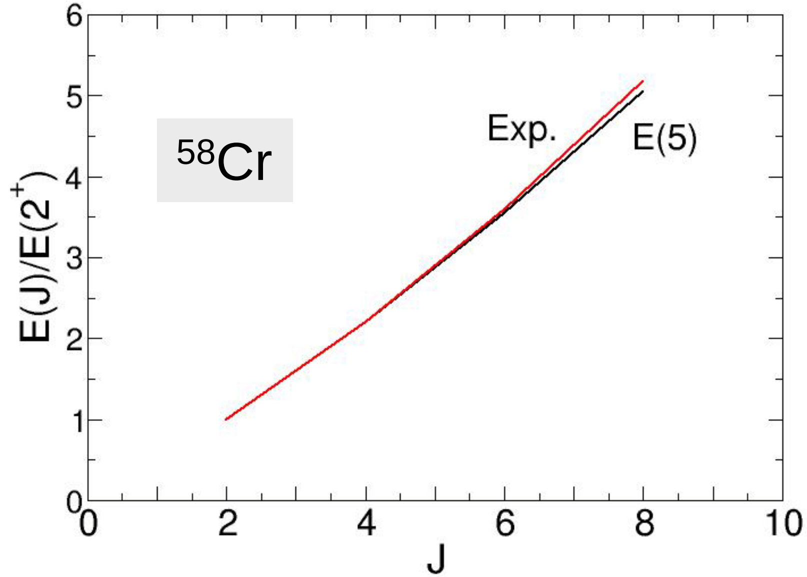
# Beam time request

- Beam: $^{64}Ni$ at 410 MeV 5pnA – Plunger: 1mg/cm$^2$ Ta backing 1mg/cm$^2$ $^{238}U$ + degrader ~3 mg/cm$^2$ Mg
- Five distances:
  - Lifetimes range from ~0.5 ps up to ~8 ps
  - Distances range ($\beta \approx 10\%$) ~20 μm up to ~200 μm
- Around 150-200 counts in the weakest populated transitions for each distance
  - $^{58}Cr$ $6^+$ and $^{60}Cr$ $2^{+,}$ $4^+$
- This reaction with the present setup allows to measure the two nuclei contemporarily → Complementary to RIB studies with dedicated beam time for each nucleus of interest.
- Strong link and feedback with parallel theoretical investigations

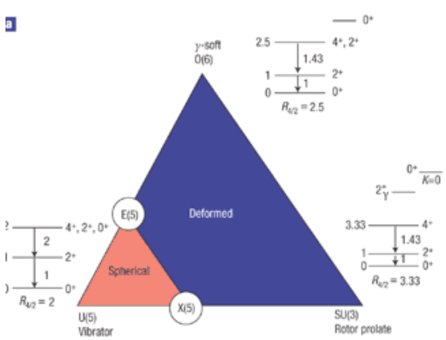
**We request a total of 6 days of beam time.**

# E(5) symmetry in the $^{58}$Cr isotope

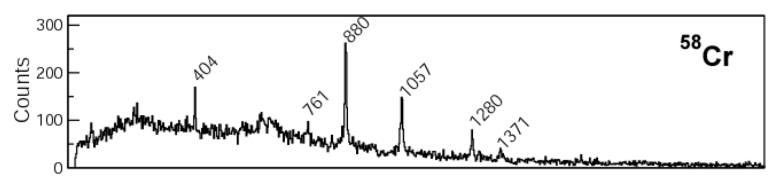



The R(4/2) of $^{58}$Cr has exactly the value predicted for E(5) critical point




Excitation energies in $^{58}$Cr are in very good agreement to the predictions of the E(5) symmetry




S. Zhu et al., PRC 74, 064315 (2006).
N. Marginean et al., PLB (2006) 696

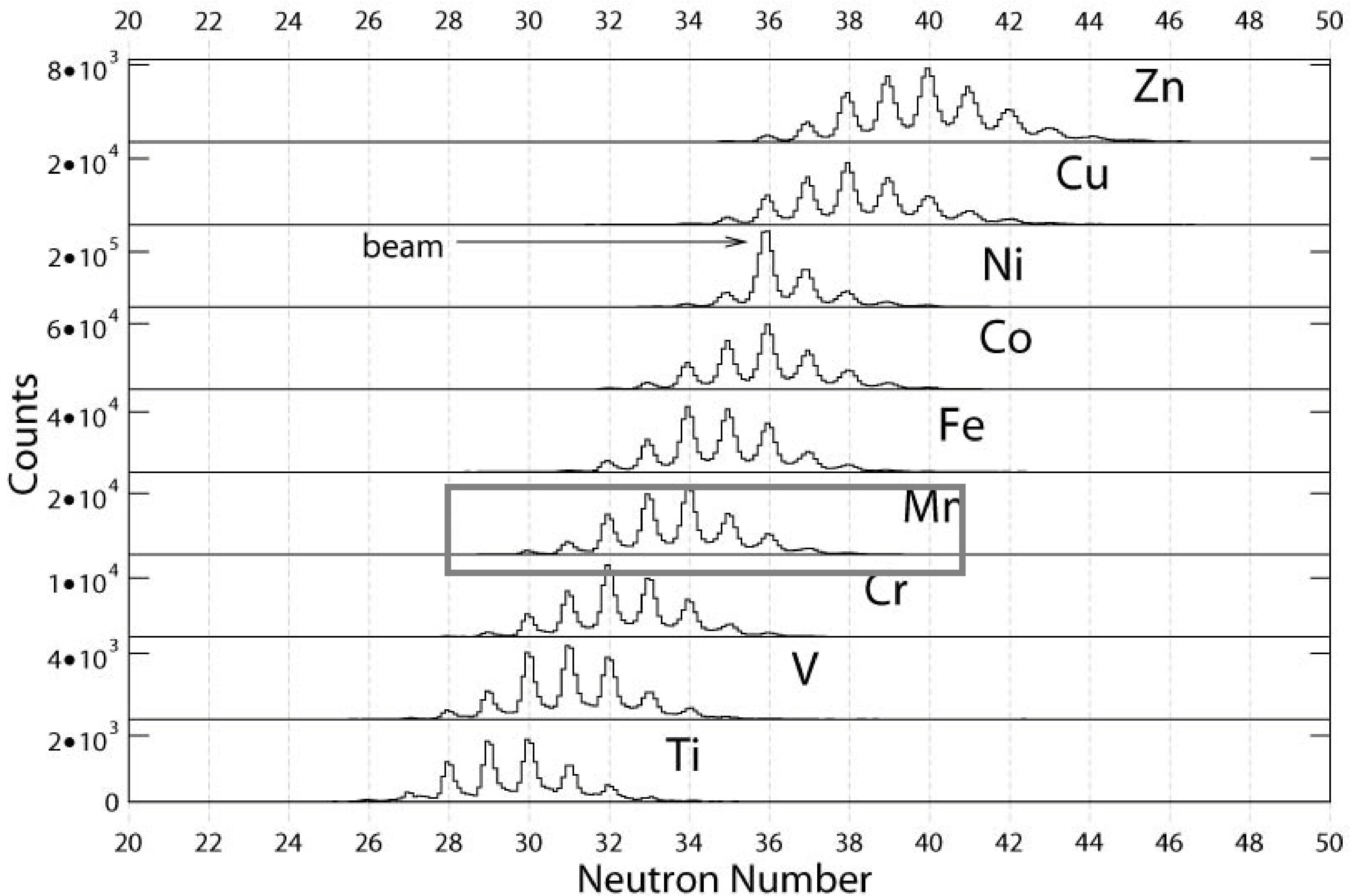
# Summary of the scientific motivation

- Measurement of $B(E2; 2^+ \rightarrow 0^+)$ and $B(E2; 4^+ \rightarrow 2^+)$ in $^{60}Cr$
  - To understand the development of deformation in neutron-rich Cr isotopes when going towards N=40
  - Relevance of the $d_{5/2}$ orbital in building up the deformation in the region → New Island of Inversion at N=40

- Measurement of $B(E2; 2^+ \rightarrow 0^+)$, $B(E2; 4^+ \rightarrow 2^+)$, $B(E2; 6^+ \rightarrow 4^+)$ in $^{58}Cr$
  - Is the yrast structure of $^{58}Cr$ compatible with the E(5) critical point? → Future experiment at GSI with AGATA+PRESPEC to look at non-yrast states
  - Unique physical system to explore the bridge between very different model approaches.

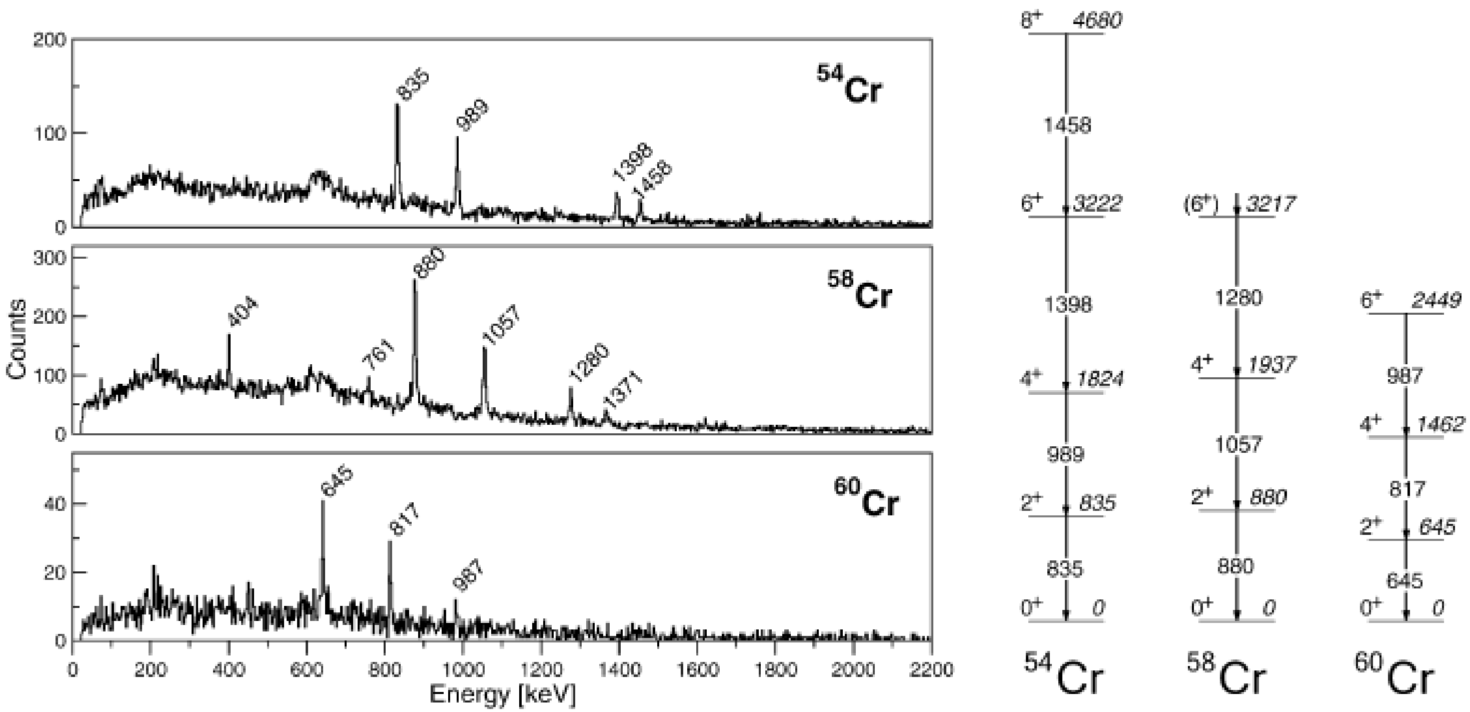
# Experimental details

$^{64}Ni$ on $^{238}U$ at 400 MeV CLARA+ PRISMA



# Experimental details

## $^{58}Cr$ and $^{60}Cr$




On the bases of a previous experiment, we habe performed the beam time estimation. The same reaction was used (400µg/cm$^{2}$ $^{238}U$ – 3% CLARA efficiency)→ Optimized beam time request.

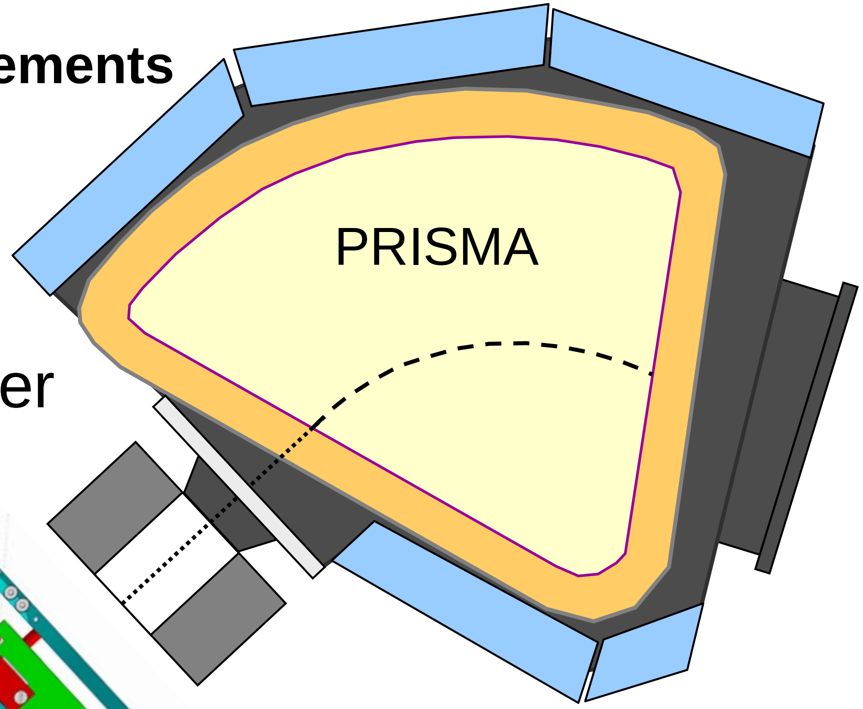
N. Marginean et al., PLB (2006) 696

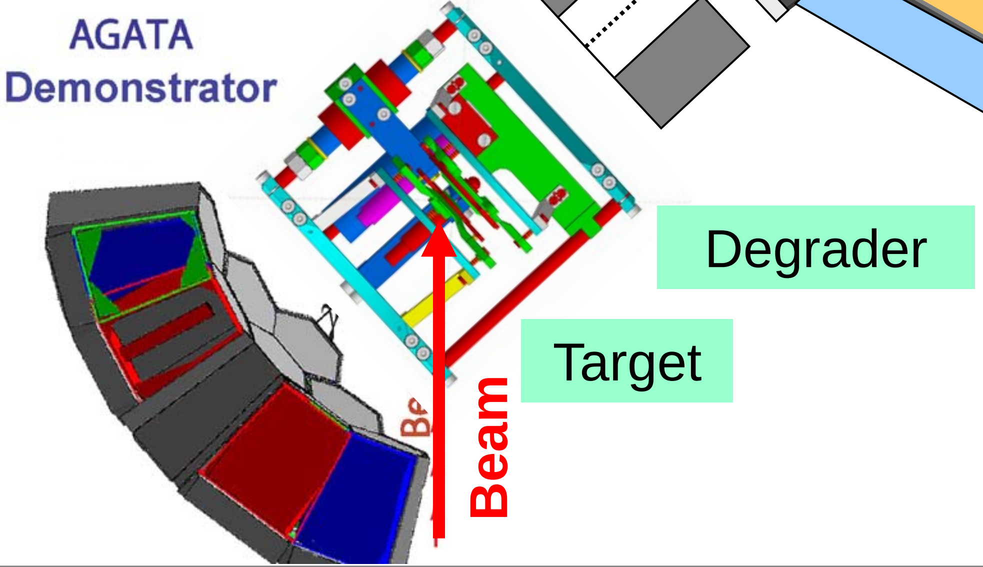
# AGATA Demonstrator & PRISMA

RDDS method for deep inelastic reactions

**Lifetime measurements**

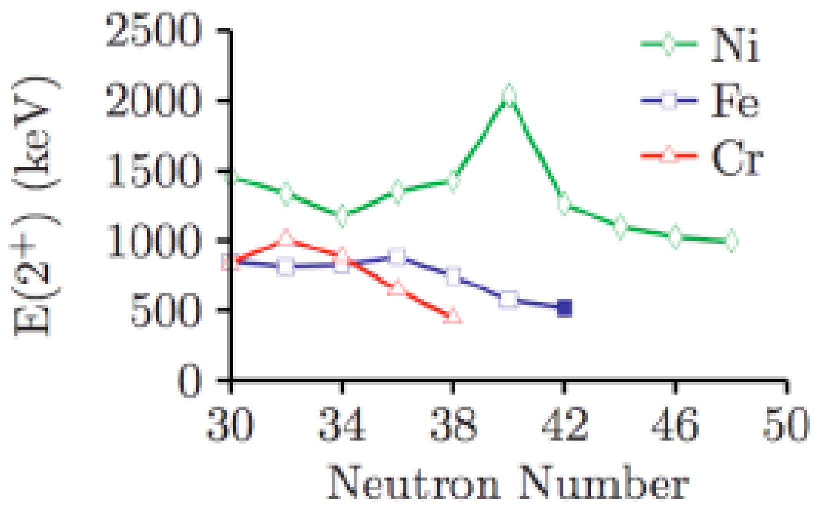
- AGATA $0^{o} – 45^{o}$
- $\varepsilon_{AD} \approx 6\%$
- Cologne Plunger
- PRISMA $64^{o}$



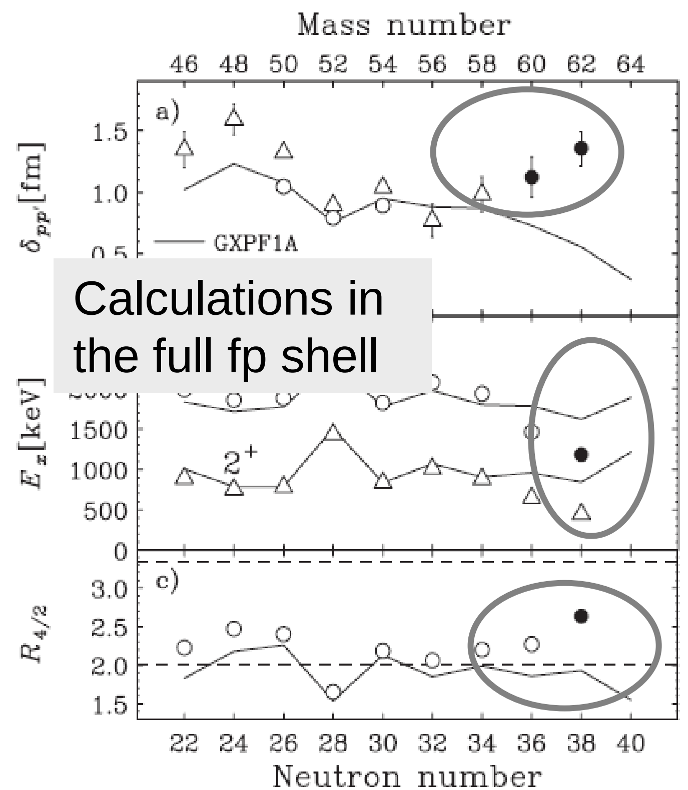



# Deformation evolution towards N=40

N=40 subshell gap in $^{68}$Ni, disappears when protons are removed from the $f_{7/2}$ → Monopole part of the tensor interaction



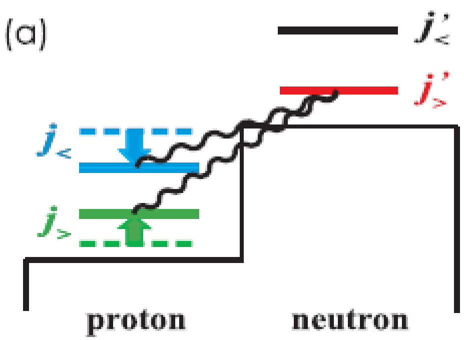

S. Lunardi et al., Phys. Rev. C **76**, 034303 (2007). S. Lenzi et al., LNL Annual Report (2008). P. Adrich et al. Phys. Rev. C **77**, 054306 (2008). O. Sorlin et al., Eur. Phys. J A **16** 55 (2003).

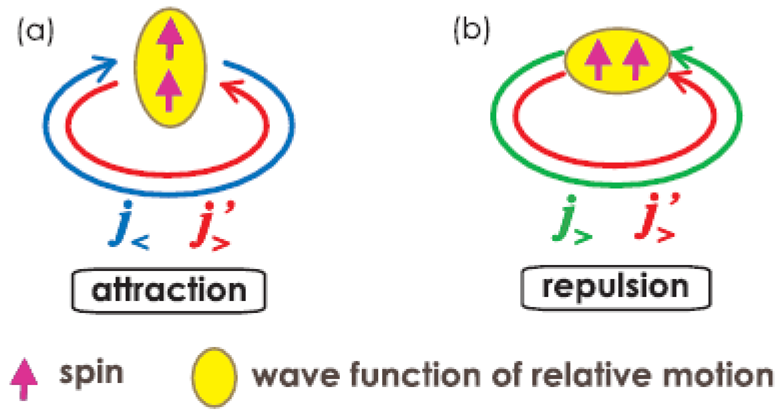



N. Aoi, et al., PRL 102, 012502 (2009)
(p,p') reaction with radioactive beams

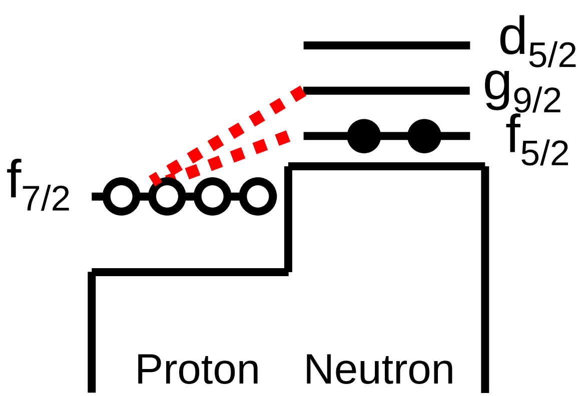
# N=40 subshell gap

Monopole effect of the tensor interaction in shell evolution




T. Otsuka et al., PRL95 232502 (2005)




- Cr isotopes 4 holes in the $\pi f_{7/2}$
- Atraction between the $f_{7/2}$ and $f_{5/2}$
- Repulsion between the $f_{7/2}$ and $g_{9/2}$
- Disappearance N=40 subshell gap
- Role of the $d_{5/2}$?

# Building up collectivity

Starting from the SU(3) model of Eliott where the classical case of $^{20}$Ne is described in the full sd but could also be described within a quasi-SU3 by considering only the relevant $\Delta j = 2$ orbits $d_{5/2}$ and the $s_{1/2}$.

RAPID COMMUNICATIONS

PHYSICAL REVIEW C VOLUME 52, NUMBER 4 OCTOBER 1995

**Spherical shell model description of rotational motion**

A. P. Zuker,[1] J. Retamosa,[2] A. Poves,[2] and E. Caurier[1]

[1]*Physique Théorique, Bâtiment 40/1 CRN, Institut National de Physique Nucléaire et des Particles-CNRS/Université Louis Pasteur, Boîte Postale 28, F-67037 Strasbourg Cedex 2, France*

[2]*Departamento de Física Teórica, Universidad Autónoma de Madrid, E-28049 Madrid, Spain*

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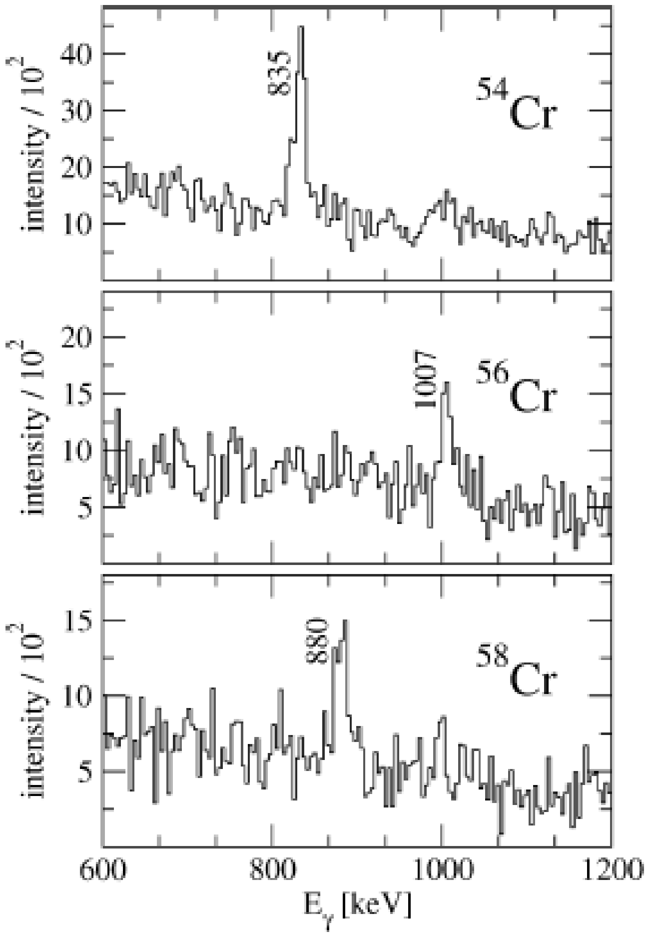
Exact diagonalizations with a realistic interaction show that configurations with four neutrons in a major shell and four protons in another—or the same—major shell, behave systematically as backbending rotors. The dominance of the $q \cdot q$ component of the interaction is related to an approximate "quasi-SU3" symmetry. It is suggested that the onset of rotational motion in the rare earth nuclei is due to the promotion of the eight particle blocks to the major shells above the ones currently filling. Assuming a "pseudo-SU3" coupling for the particles in the lower orbits, it is possible to account remarkably well for the observed $B(E2)$ rates at the beginning of the region.

Quadrupole deformation can be generated by using a quadrupole force with the central field in the subspace spanned by a sequence of $\Delta j = 2$ orbits that come lowest by the spin-orbit splitting representing this relevant subspace a quasi-SU3. In the Cr region it happens something similar to what happens in the Island of inversion $^{32}$Mg.

# B(E2) known in $^{58}$Cr




GSI - FRS + RISING
Coulomb excitation at relativistic energies

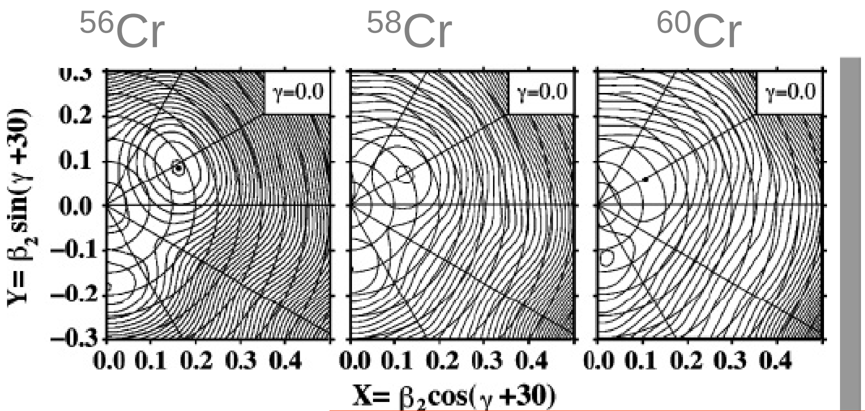
Table 2
Number of projectiles identified as Cr before and after the target ($N_{pro}$), number of counts in the $2_1^+$ peaks ($N_\gamma$), $\gamma$-ray intensities ($I_\gamma$), $B(E2; 2_1^+ \rightarrow 0+)$ values and gamma-ray energies ($E_\gamma$), for $^{54,56,58}$Cr

| Isotope | $^{54}$Cr | $^{56}$Cr | $^{58}$Cr |
|---|---|---|---|
| $N_{pro}$ [$10^6$] | 37 | 18 | 12 |
| $N_\gamma$ | 501(64) | 126(44) | 148(43) |
| $I_\gamma$ [$10^2$] | 211(27) | 61(20) | 73(19) |
| $B$(E2) [W.u.] | 14.6(0.6)[a] | 8.7(3.0) | 14.8(4.2) |
| $E(2_1^+)$ [keV] | 835[a] | 1007[a] | 880[b] |

7.8ps

*A. Bürger et al. / Physics Letters B 622 (2005) 29.*

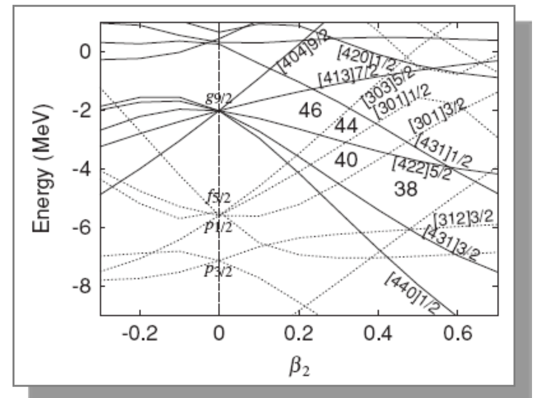
# Collectivity at N≤40, Z<28




S. Zhu et al., PRC 74, 064315 (2006)

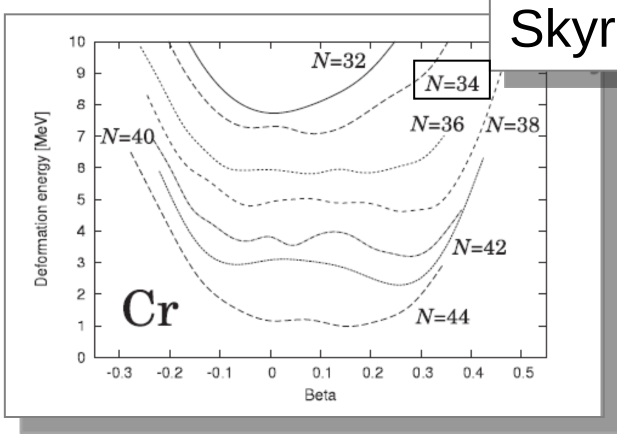
Ground-state potential energy surfaces (TRS) Cr isotope seem to exhibit $\gamma$ softness for large N values

single particle energies in a deformed WS potential



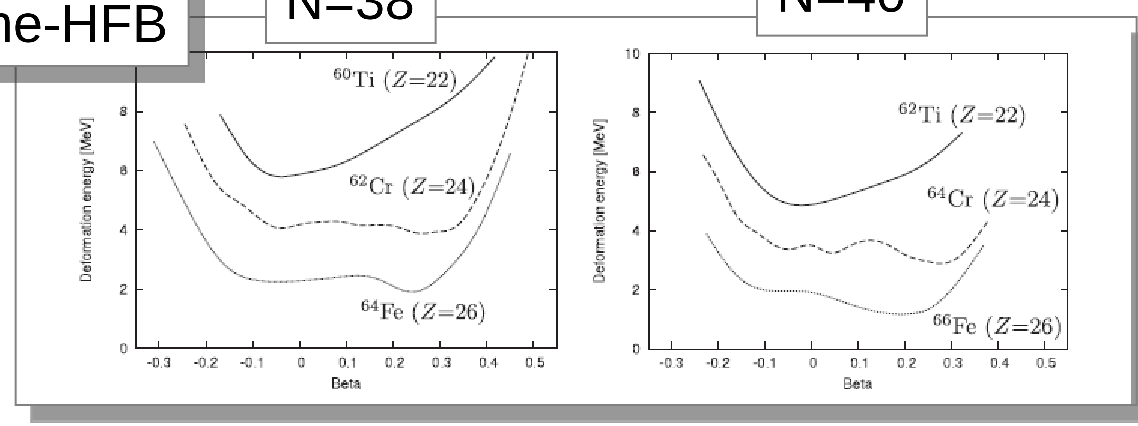

K. Yoshida and M. Yamagami, PRC 77, 044312 (2008)

Skyrme-HFB




N=38

N=40




H. Oba and M. Matsuo, Prog. Theo. Phys. 120, 143 2008

# Deep inelastic reactions