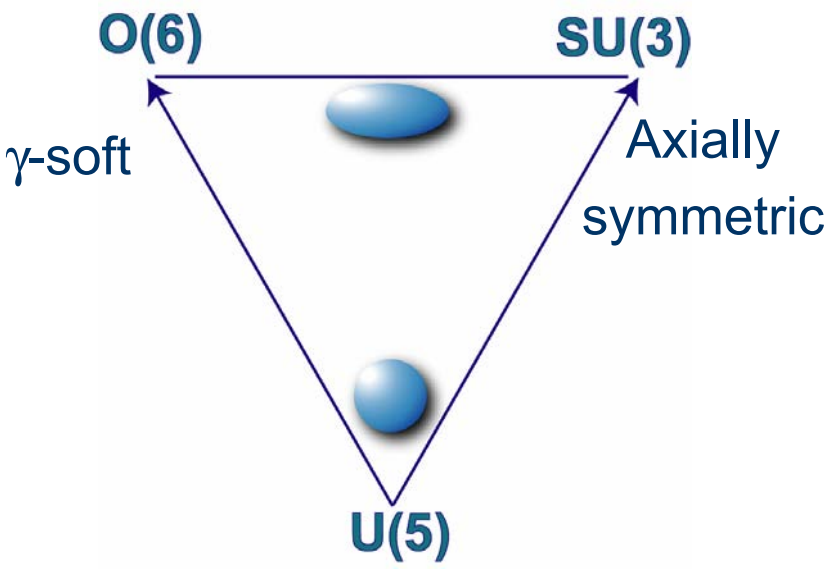
Shape phase transitions far from stability

Shape phases in collective nuclei

Stable quadrupole deformation



Vibration around spherical shape

The three limits of the Interacting Boson Model

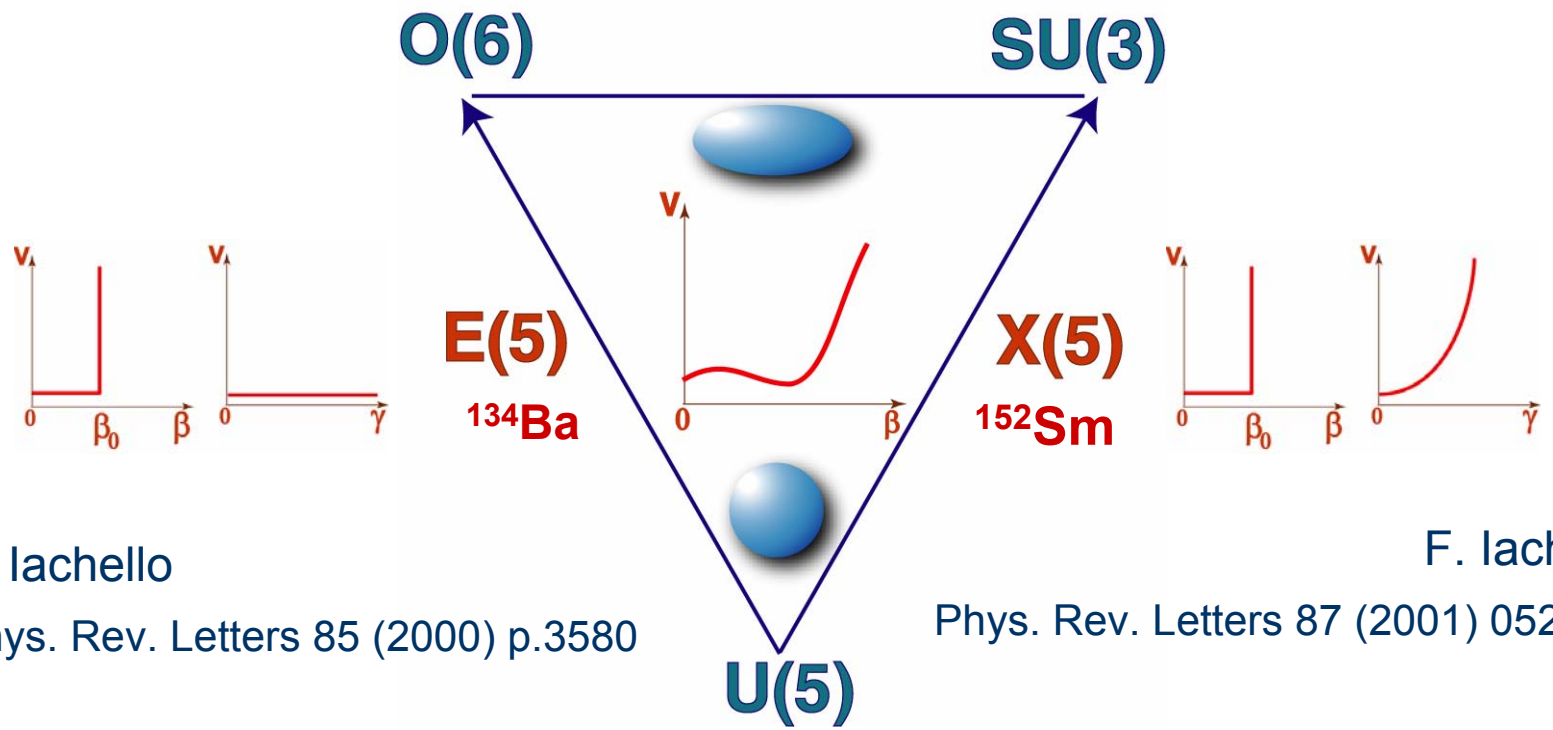
"*This three limits, associated with dynamical symmetries of the Hamiltonian, appear as shape phases at the classical level ($N \to \infty$)*"

A.E.L. Dieperink and O. Scholten

Phys. Rev. Letters 44 (1980) p.1747

Phase transitions and critical points

Parameter-free analytical approximations can be obtained for the critical points



F. Iachello

Phys. Rev. Letters 85 (2000) p.3580

F. Iachello

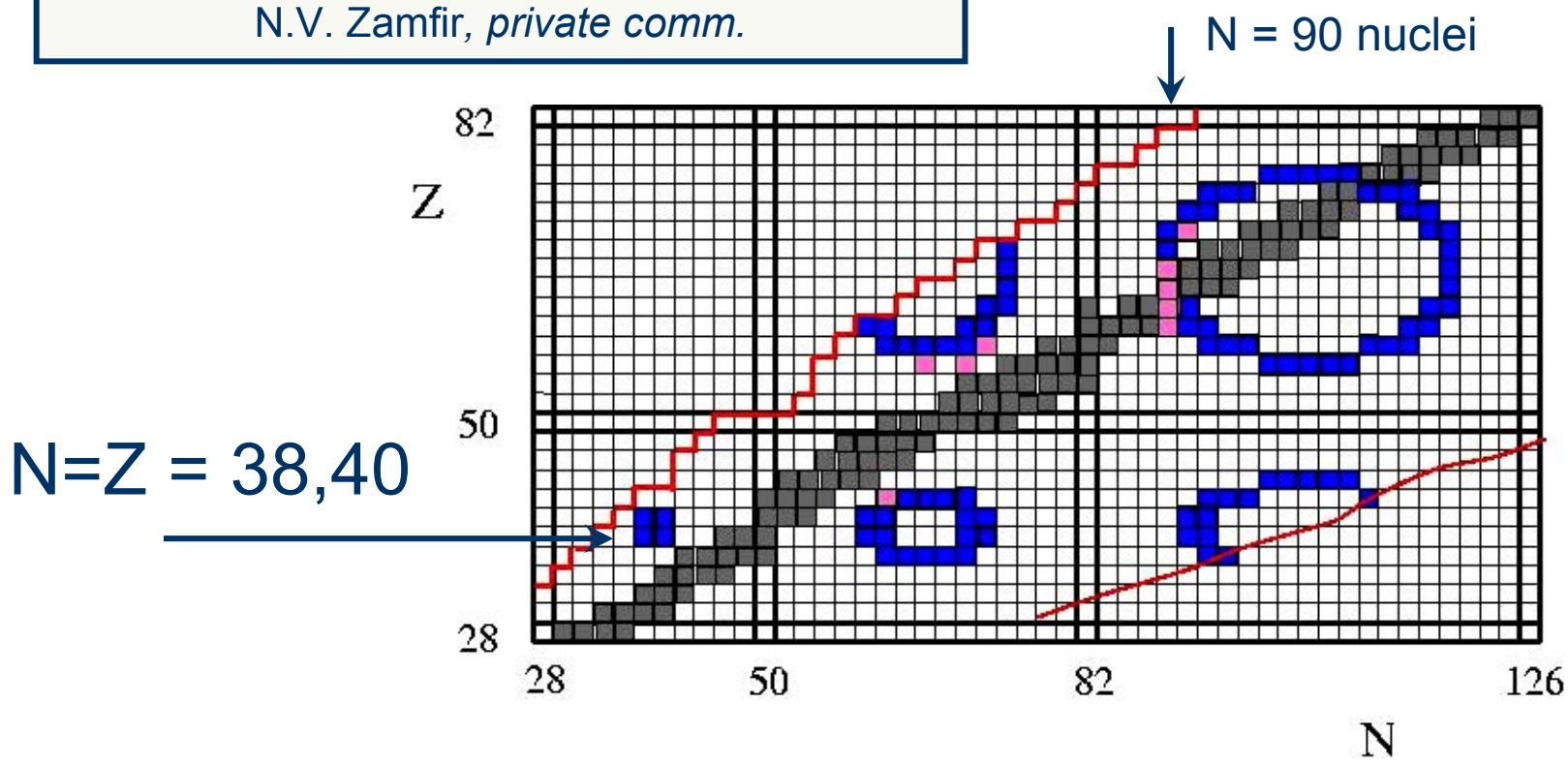
Phys. Rev. Letters 87 (2001) 052502

Critical points: not only close to stability

Empirical X(5) search criterion

$$4.5 < N_p N_n/(N_p+N_n) < 5.5$$

N.V. Zamfir, *private comm.*



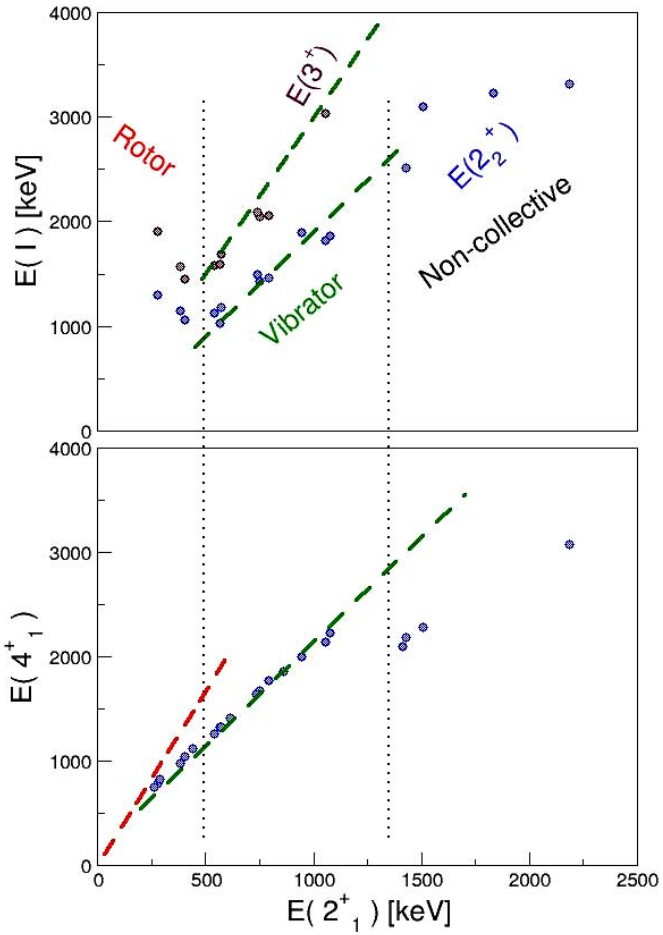
Quasi-γ Bands in N≈Z ≈40 region

4 GASP experiments

Quasi-γ bands identified or completed in ^{78}Sr, ^{80}Sr, ^{82}Zr, ^{84}Zr, ^{86}Zr, ^{86}Mo, ^{88}Mo

The plot of $E(2^+_\gamma, 3^+_\gamma)$ versus $E(2^+_1)$ clearly indicates the ***Rotor-Vibrator phase transition***

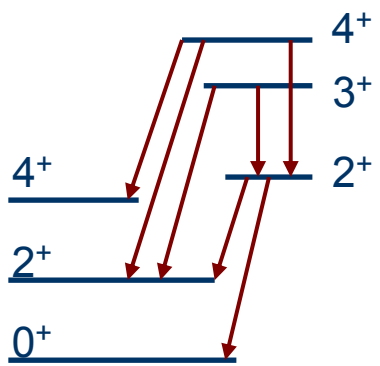
Even-even Sr-Zr-Mo with N≤50



IBA description

$$H_{IBA} = a\left[(1-\zeta)n_d - \frac{\zeta}{4N}(Q\cdot Q) + \zeta'\cdot(L\cdot L)\right]$$

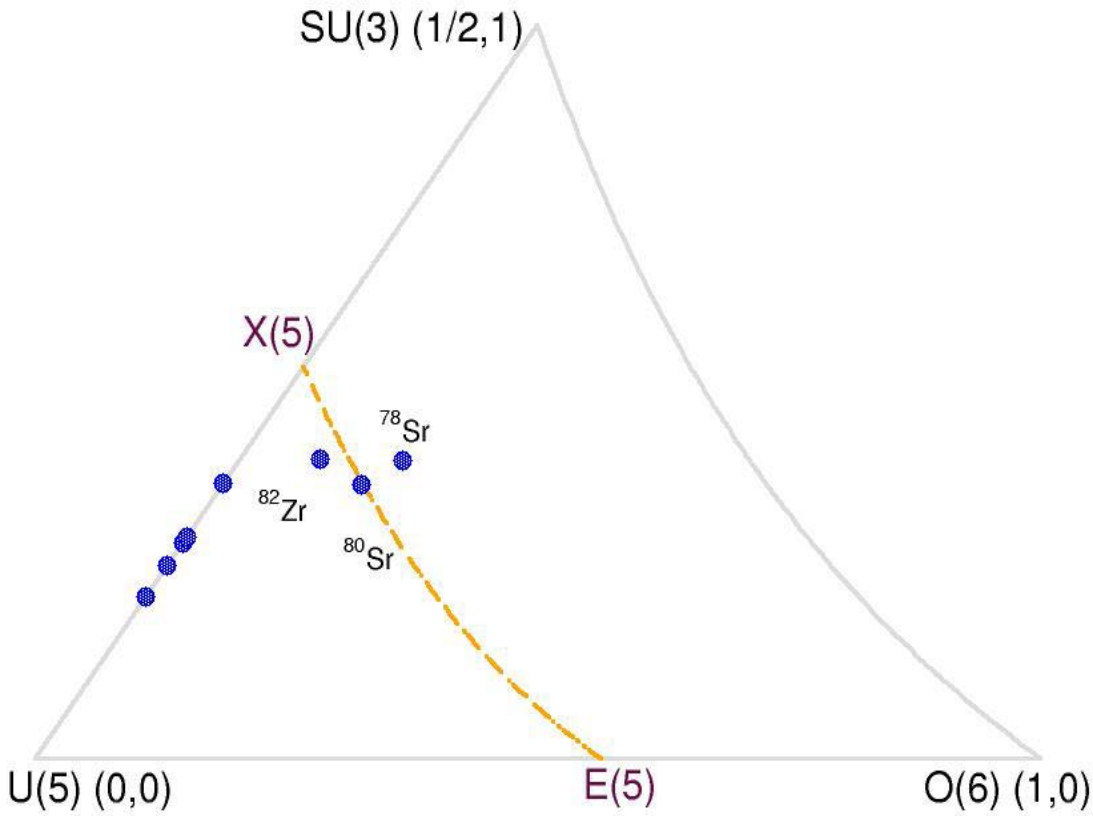
$$Q = s^{+}\tilde{d} + d^{+}\tilde{s} + \chi[d^{+}\tilde{d}]^{(2)}$$



- Fine grid on parameter space
- χ^2 merit function including both energy and branching ratios

New parameters: $x = \zeta \cdot \frac{1}{1+\frac{|\chi|}{\sqrt{7}/2}}$ $y = \frac{\zeta\cdot|\chi|}{\sqrt{7}/2}$

Phase Transition near N=Z line



Nuclear structure studies using PRISMA/CLARA setup

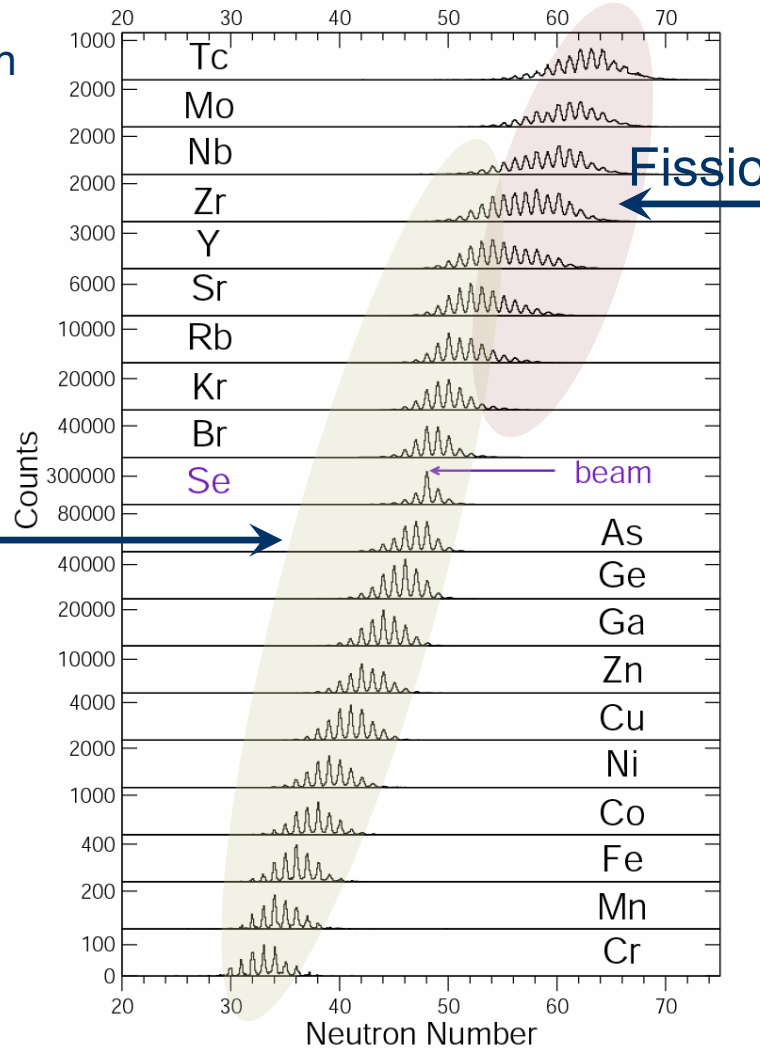
- Multi-nucleon transfer reactions with neutron-rich, stable projectiles on heavy targets
- Projectile-like reaction products are detected with PRISMA placed around the grazing angle

^{82}Se(500 MeV) + ^{238}U

Multi-nucleon transfer

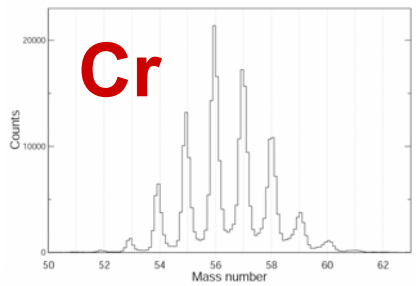
Deep–inelastic collisions

The evolution of the nuclear structure can be observed over large regions



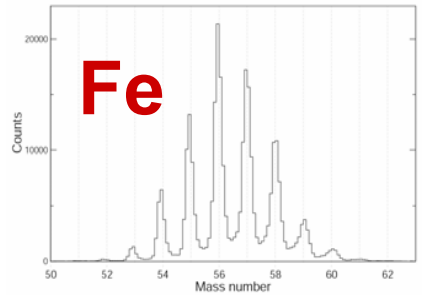
Onset of deformation towards N=40

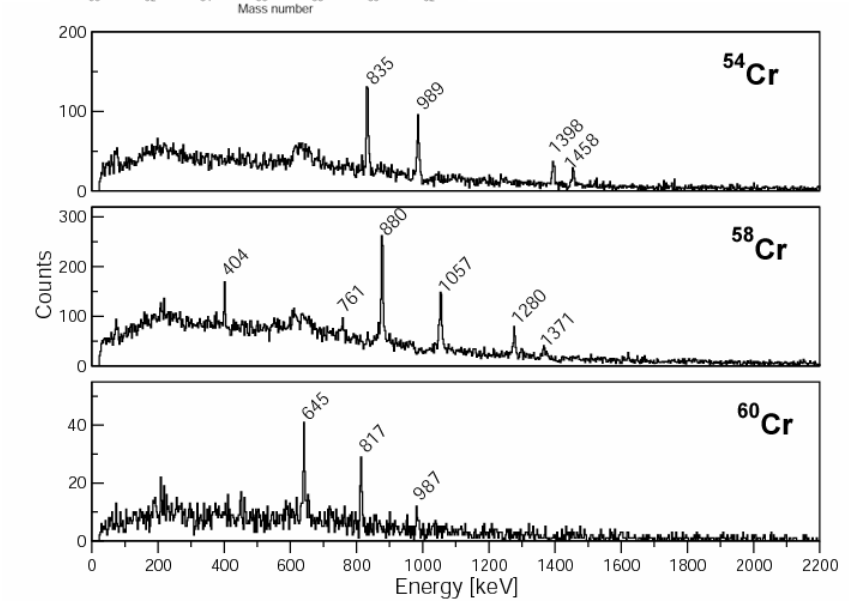
- First identification of 4^+ and possibly 6^+ states in ^{64}Fe
- First observation of γ rays from the yrast levels of ^{58}Cr

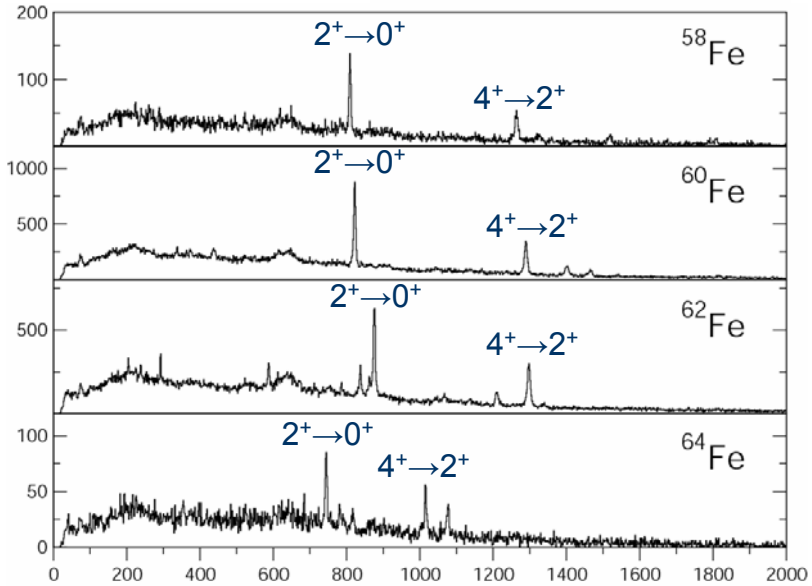


^{64}Ni(404 MeV) + ^{238}U

PRISMA/CLARA

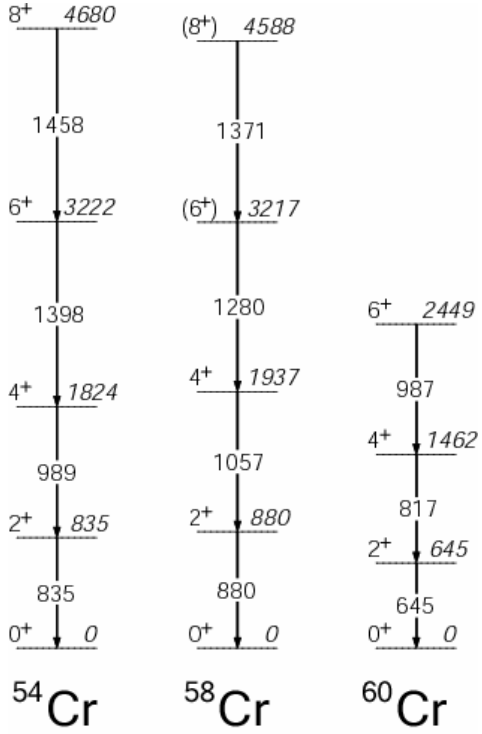


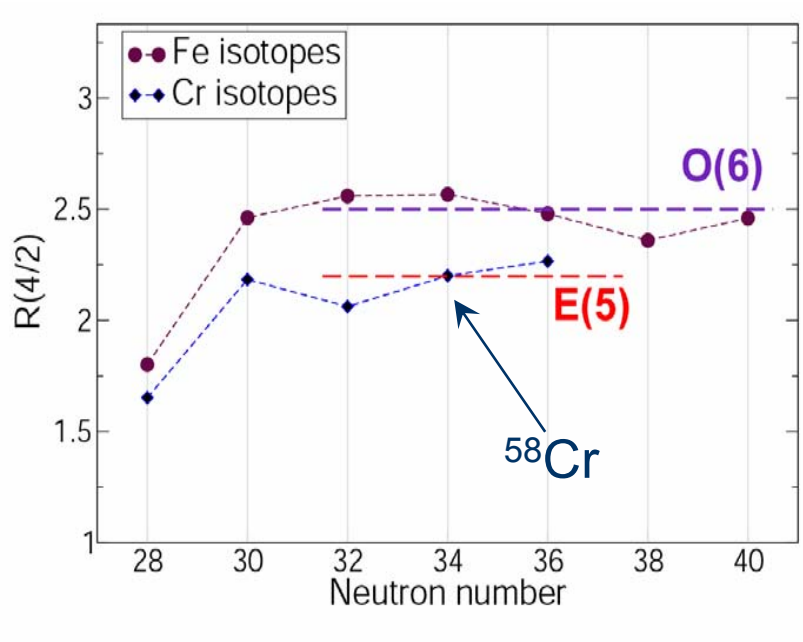




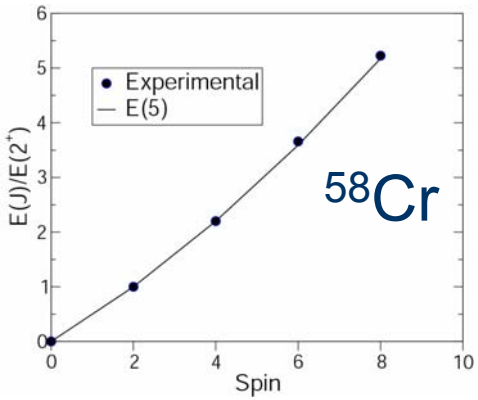
γ-softness in heavy Cr and Fe isotopes

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





^{58}Cr : A shape phase transition critical point ?

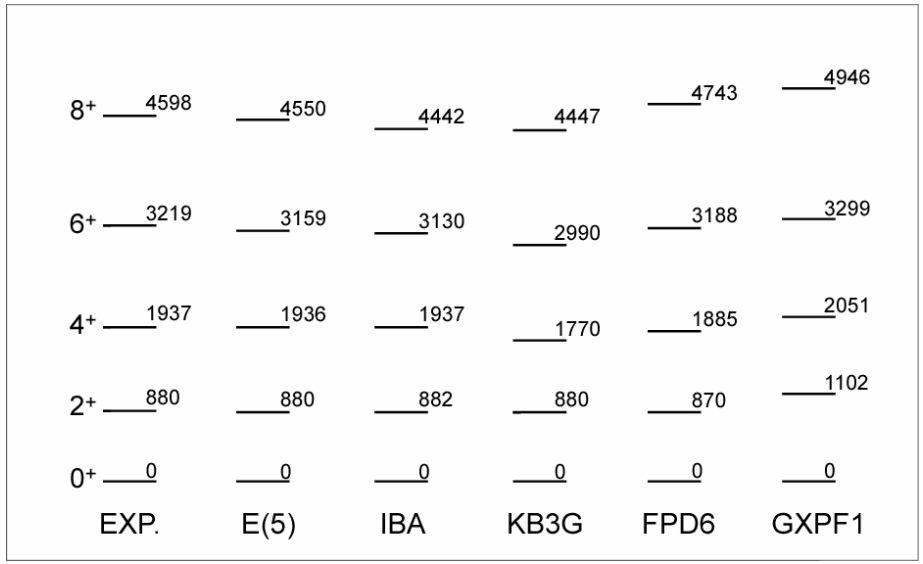


$H_{IBA} = \varepsilon n_d + A \cdot P^+ P$ Critical point $\varepsilon/A = 2(N-1)$

$N = 5$, empirical $e_B = 0.2 \cdot Z$ [efm^2]

$B(E2; 2^+ \rightarrow 0^+)_{IBA} = 170\ e^2fm^4$

$B(E2; 2+ \rightarrow 0+)_{exp} = 197(56)\ e^2fm^4$



- The excitation energies for all states in the yrast band of ^{58}Cr are very close to the predictions of the E(5) symmetry
- Several large-scale Shell-Model results are also in good agreement with the E(5) solution

N. Marginean et al. Phys. Lett. B 633(2006)696

^{58}Cr : A shape phase transition critical point ?

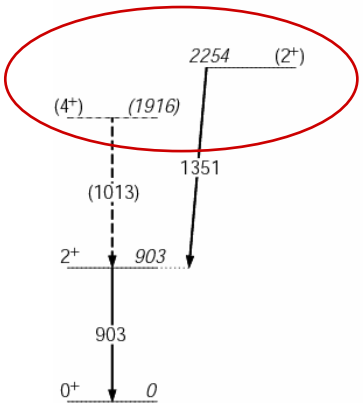
	Exp	IBM	KB3G	FPD6	GXPF1
$E_{4_1^+}/E_{2_1^+}$	2.20	2.20	2.01	2.17	1.86
$E_{6_1^+}/E_{2_1^+}$	3.66	3.55	3.40	3.66	2.99
$E_{8_1^+}/E_{2_1^+}$	5.22	5.04	5.05	5.45	4.49
$\frac{B(E2):4_1^+\rightarrow 2_1^+}{B(E2):2_1^+\rightarrow 0_1^+}$		1.39	1.15	1.38	1.13
$\frac{B(E2):6_1^+\rightarrow 4_1^+}{B(E2):2_1^+\rightarrow 0_1^+}$		1.41	1.13	1.24	0.93
$\frac{B(E2):8_1^+\rightarrow 6_1^+}{B(E2):2_1^+\rightarrow 0_1^+}$		1.16	1.18	1.16	1.01

More experimental B(E2) values are needed to firmly demonstrate the existence of E(5) symmetry in ^{58}Cr

Collectivity above N=20 shell closure

^{36}S (230MeV) + ^{208}Pb

^{40}Ar(205MeV) + ^{170}Er

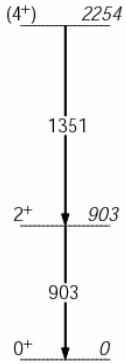


β decay

NSCL-MSU

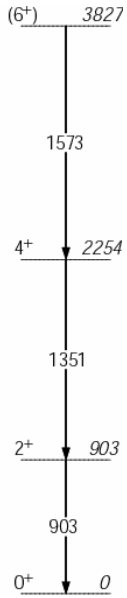
(1)

^{40}S

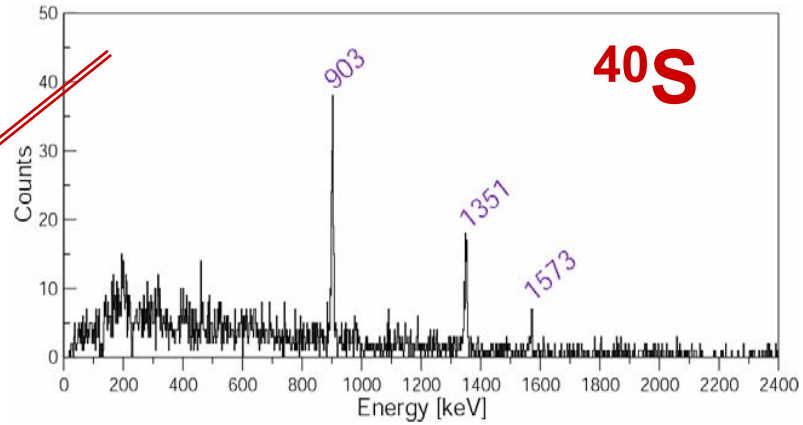


GANIL

(2)



PRISMA/CLARA



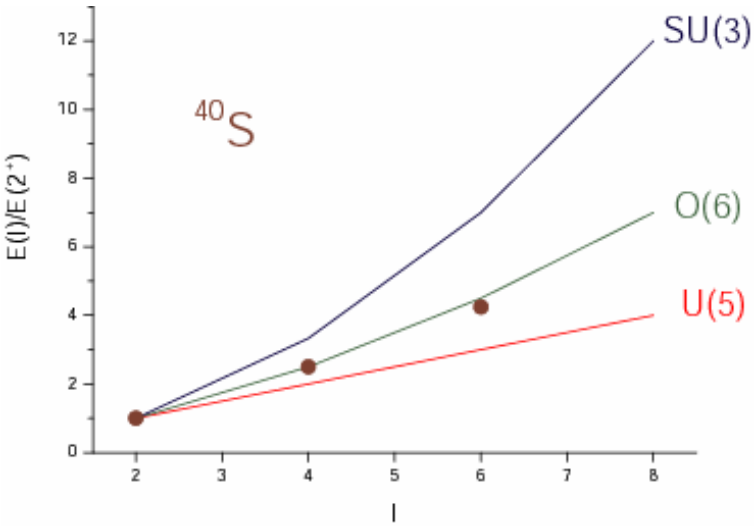
(1) J.A. Wigner et al.
Phys. Rev C 64(2001)064318

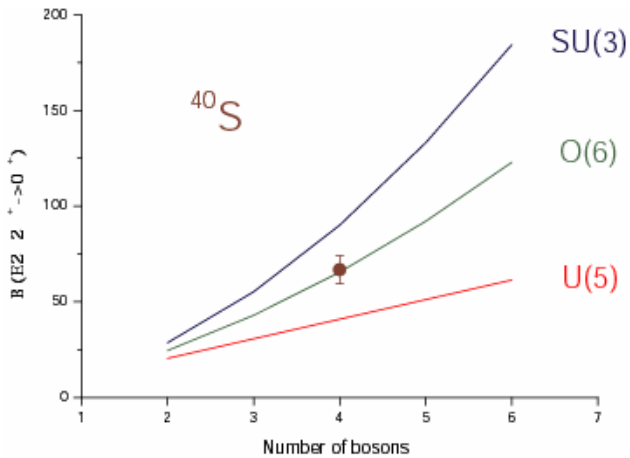
(2) D. Sohler et al.
Phys. Rev C 66(2002)054302

γ-softness in heavy S isotopes

Analytic IBA formulas

Realistic effective charge $q_{eff} = 0.2 \times Z$





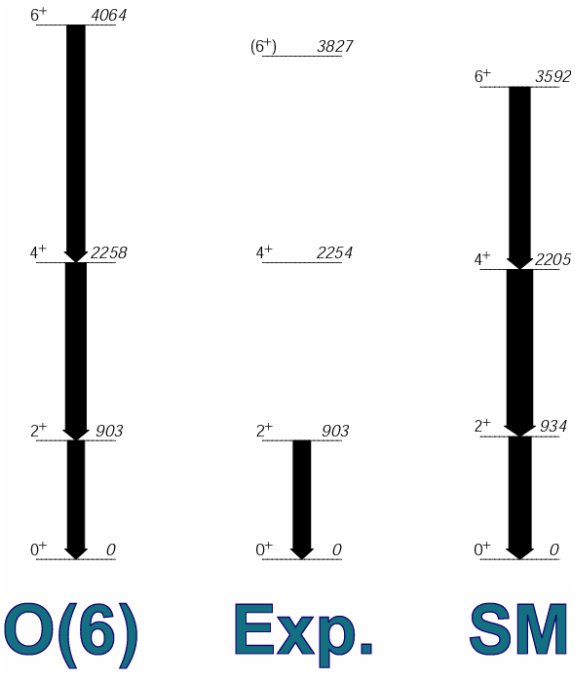
The level scheme and B(E2) value suggest a significant degree of γ-softness in ^{40}S

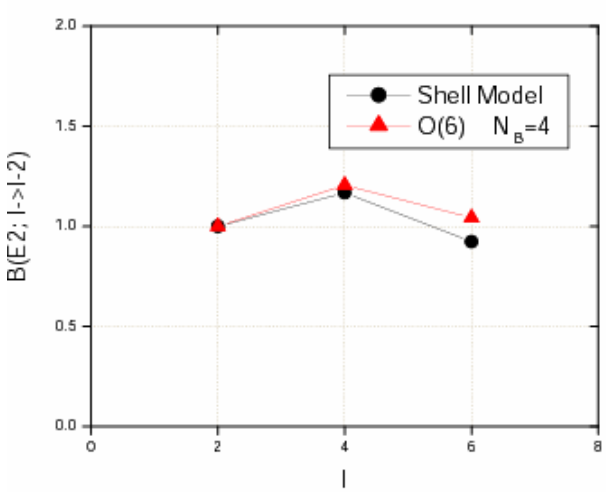
^{40}S – Shell model and O(6) predictions

- Shell model : *sd-fp* interaction (USD+KB'+KLE)

Phys. Rev. C 55 (1997) 1266

Phys. Rev. C 63 (2001) 044316

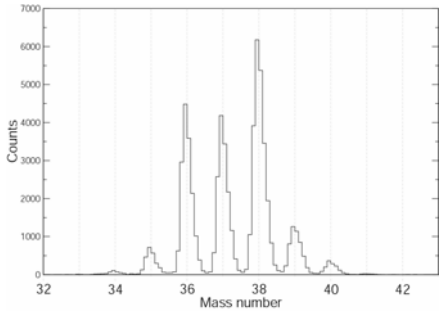




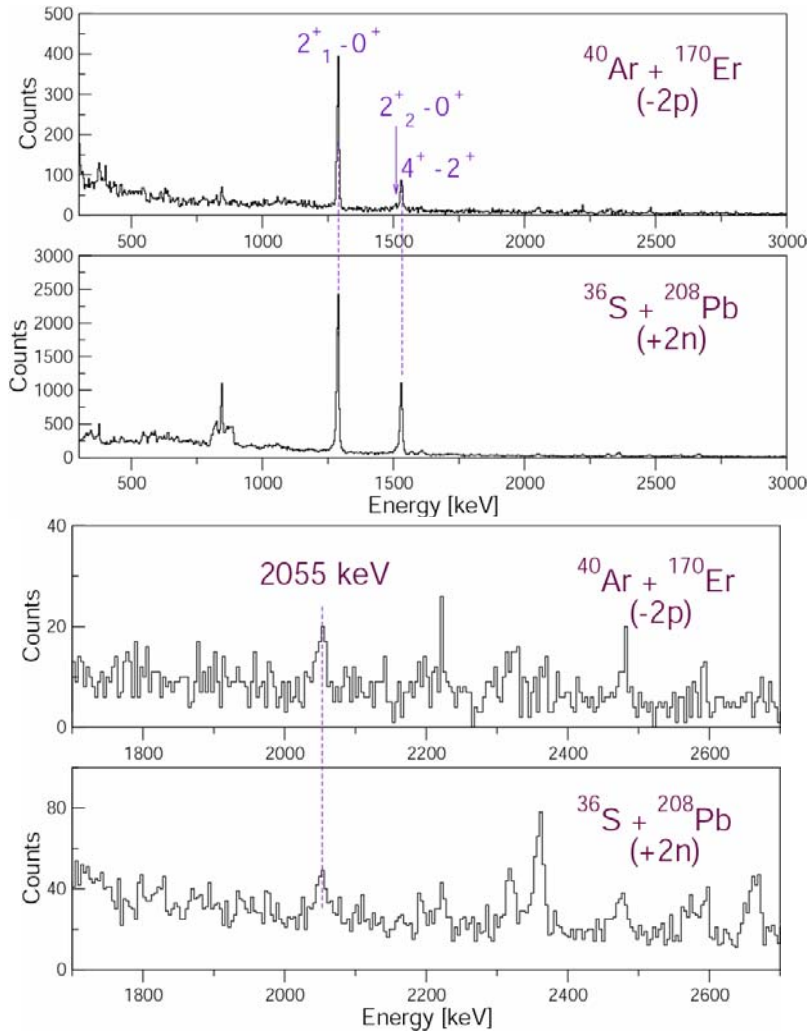
Spectroscopy of ^{38}S

^{36}S (230MeV) + ^{208}Pb

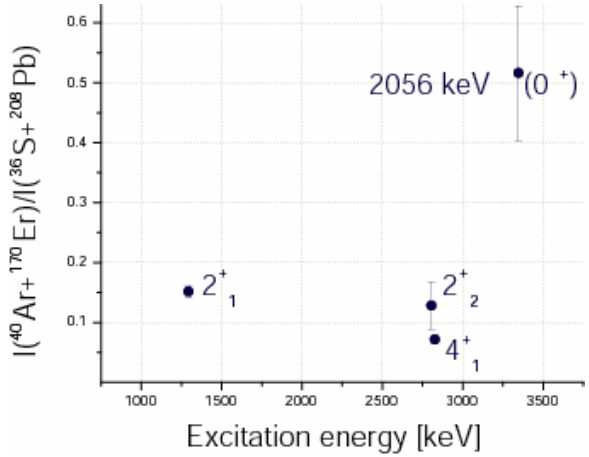
^{40}Ar(205MeV) + ^{170}Er



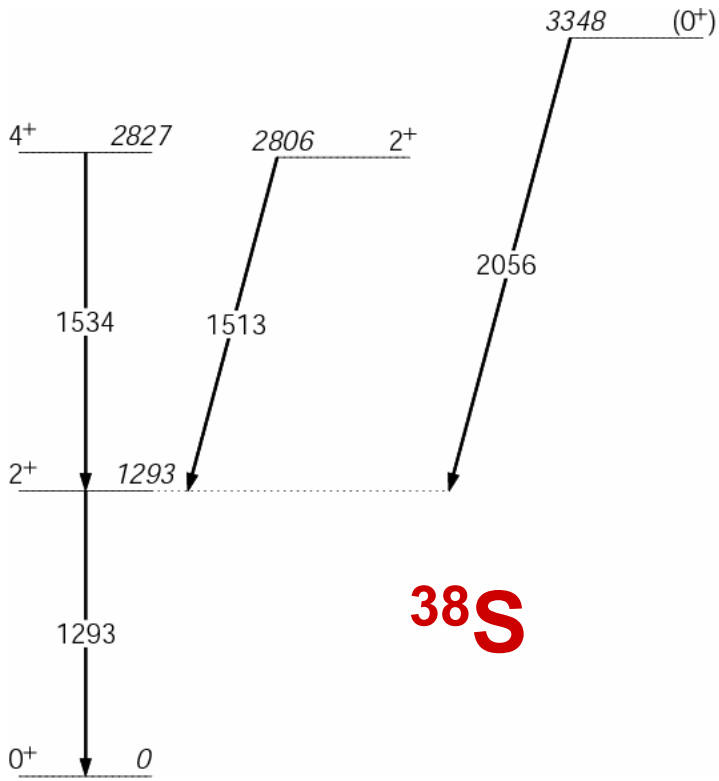
- The 2055 keV gamma ray corresponds to the fourth excited state of ^{38}S
- This state was previously observed only in (t,p) experiments



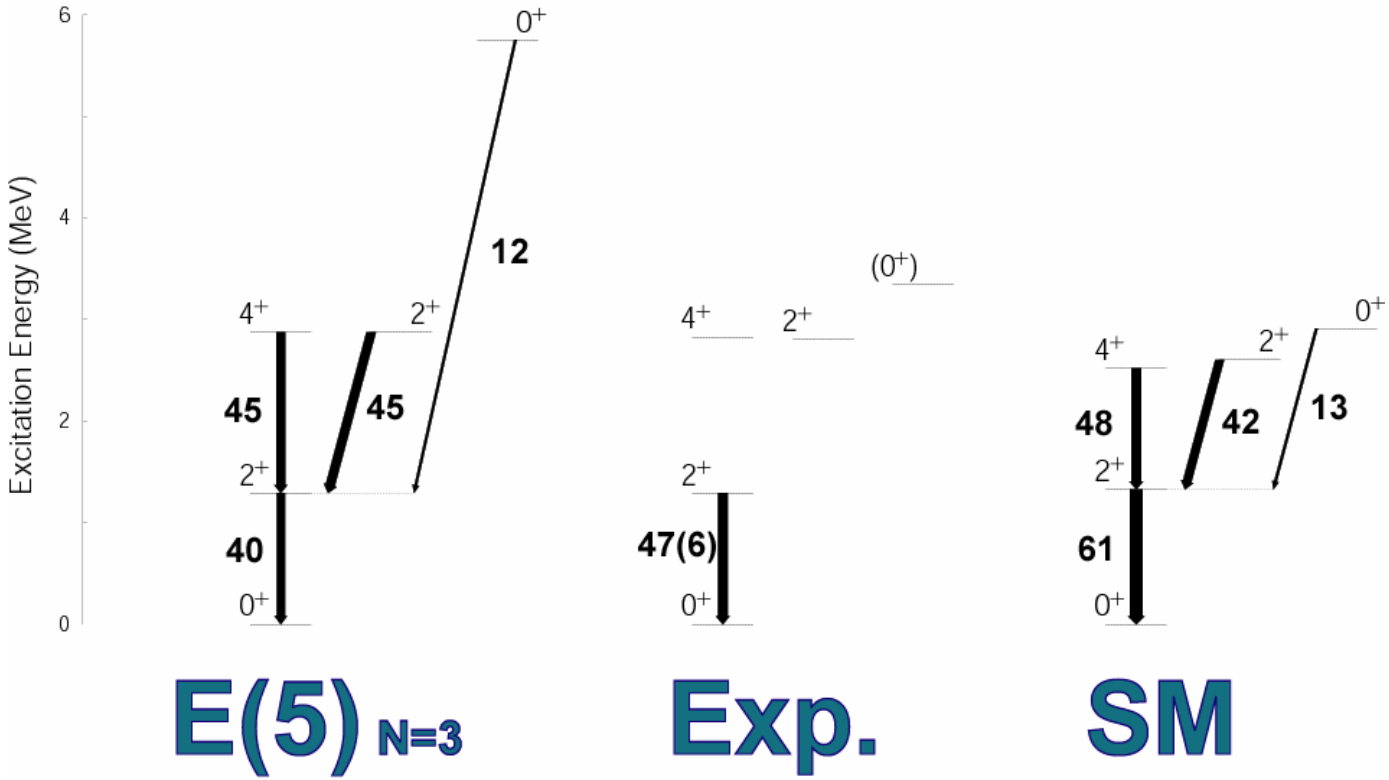
Low-energy states of ^{38}S



	Exp	E(5)
$E(4^+_1)$	2.19	2.20
$E(2^+_2)$	2.17	2.20
$E(0^+_2)$	2.59	3.03



Theoretical predictions for ^{38}S



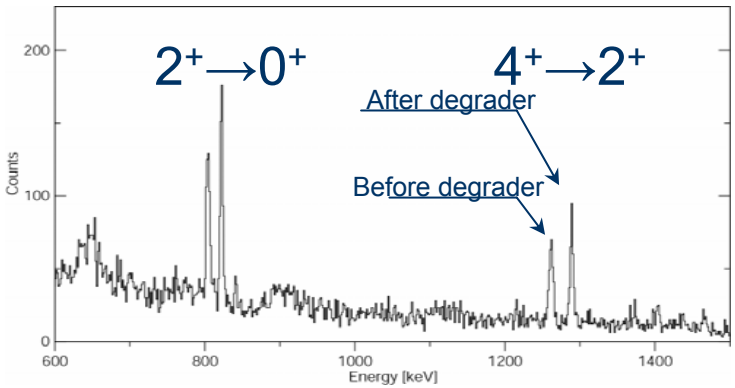
Development projects:

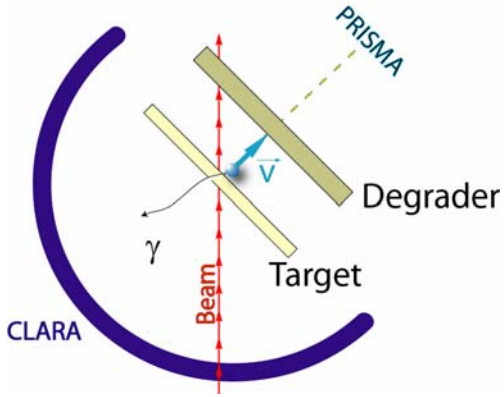
Differential plunger with PRISMA/CLARA

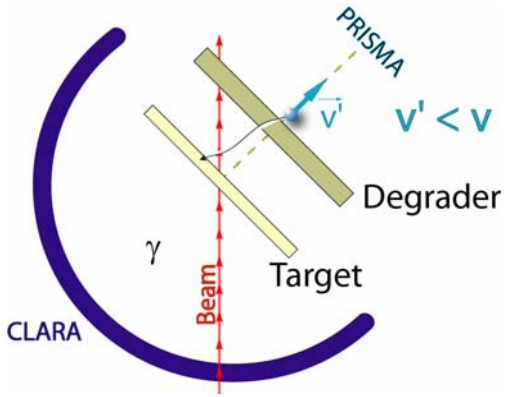
Collaboration with IKP-Köln

- Consists in having an energy degrader at fixed distance after the target
- The gamma rays emitted before or after the recoil passes the degrader will have different Doppler shifts
- The lifetimes will be obtained from the intensity ratio before/after degrader

^{60}Fe – simulation based on existing experimental data







Summary

- Shape phase transitions are encountered also far from stability, both on proton-rich and neutron-rich regions
- The ^{58}Cr nucleus is a good E(5) candidate and could provide the opportunity to compare the E(5) model with large-scale shell-model calculations
- New experimental information obtained with PRISMA/CLARA suggests that the deformation in heavy S isotopes could be characterized by γ softness
- Further developments will provide the possibility to measure lifetimes with PRISMA/CLARA