Nuclear structure studies with the PRISMA/CLARA setup

- Italy
  - INFN LNL-Legnaro
  - INFN and University Padova
  - INFN and University Milano
  - INFN and University Genova
  - INFN and University Torino
  - INFN and University Napoli
  - INFN and University Firenze
  - University of Camerino
- Spain
  - University of Salamanca
- Romania
  - NIPNE Bucharest
- France
  - IReS Strasbourg
  - GANIL Caen
- U.K.
  - University of Manchester
  - Daresbury Laboratory
  - University of Surrey
  - University of Paisley
- Germany
  - HMI Berlin
  - GSI Darmstadt

Gamma spectroscopy in grazing reactions

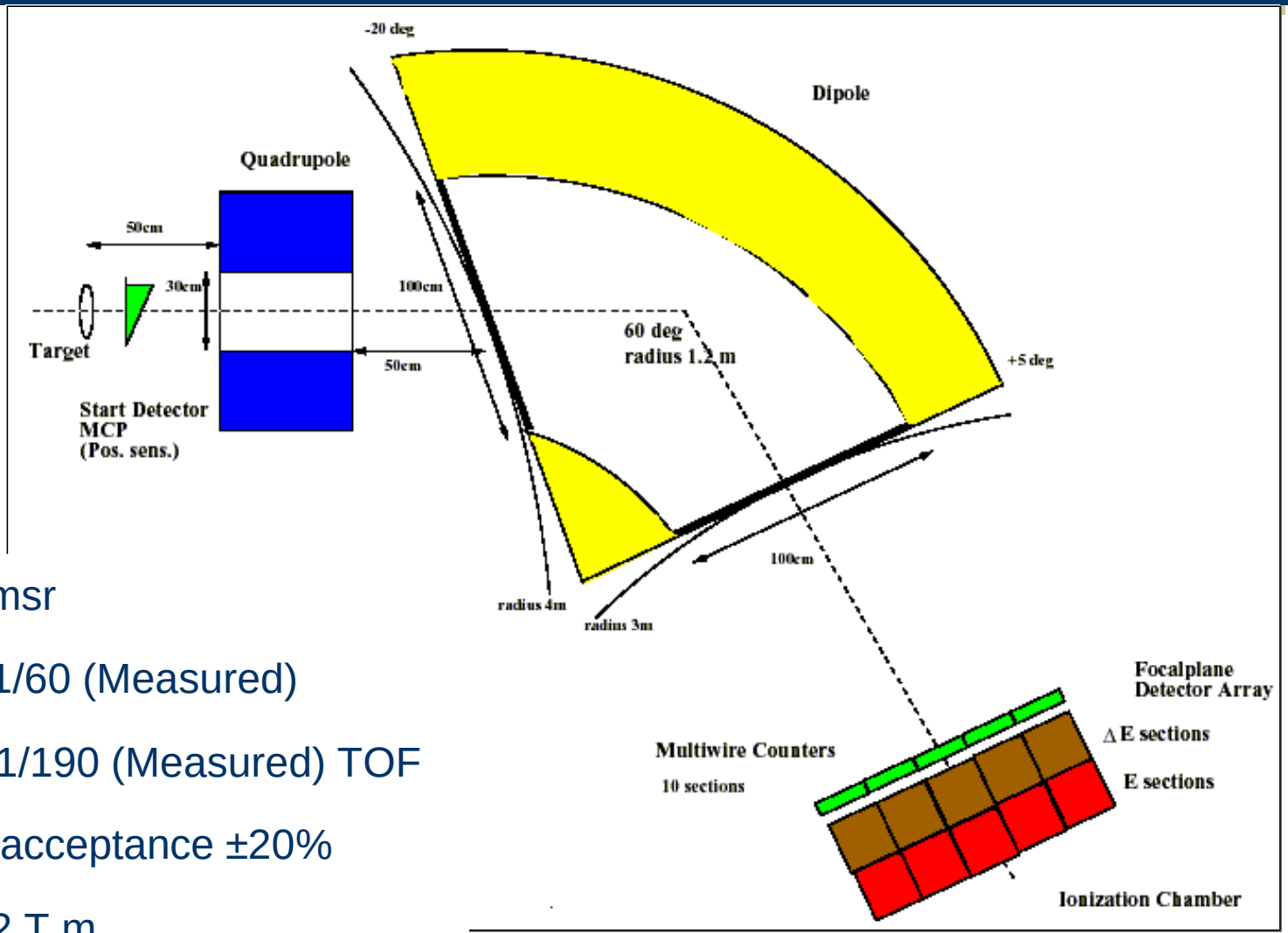
Thick-target experiments R. Broda and collaborators

- Use γ-γ cross-coincidence technique
- More than one partner/nucleus
- Only γ rays emitted after the nucleus stop can be resolved

Thin-target experiments PRISMA/CLARA approach

- Prompt γ-ray spectroscopy (CLARA) tagged with the identification of reaction products (PRISMA)
- Good quality Doppler correction required

The Magnetic Spectrometer PRISMA



$\Omega = 80$ msr

$\Delta Z/Z \approx 1/60$ (Measured)

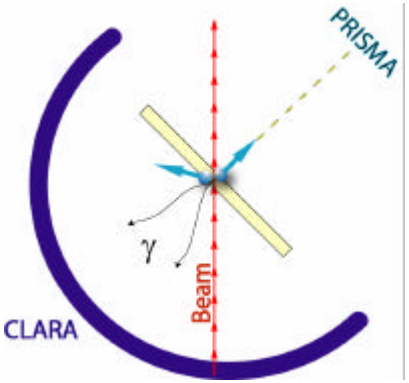
$\Delta A/A \approx 1/190$ (Measured) TOF

Energy acceptance ±20%

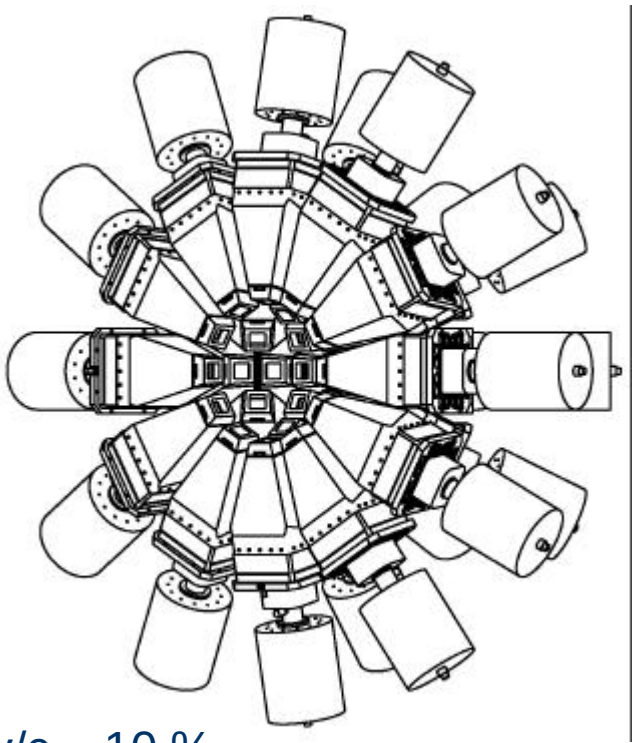
$B\rho = 1.2$ T.m

The CLARA Array

25 Euroball Clover detectors from the EU GammaPool



Placed at backward angles respect to the optical axis of PRISMA



2π coverage ? Efficiency ~ 3 %

Anti-Compton BGO shields ? Peak/Total ~ 45 %

High granularity ? FWHM ~ 0.8% at v/c ~ 10 %

PRISMA: trajectory reconstruction

- The simulations of the ion transport in PRISMA (A. Latina) shown that the fringing fields of the magnetic elements have small impact on the trajectories (big magnets)
- Adopted : simplified reconstruction algorithm, optimized for speed
  - Ideal magnetic elements
  - All trajectories treated in the horizontal plane after the quadrupole

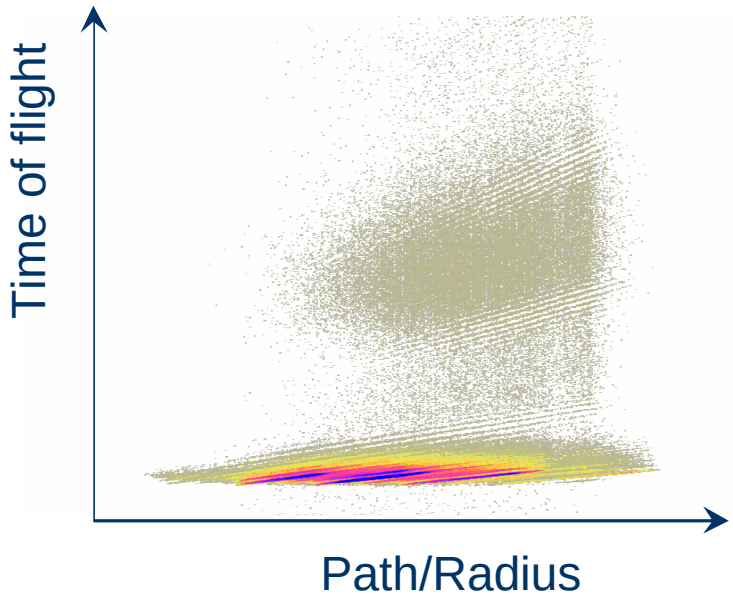
Entrance position (x,y) $\xrightarrow{\text{Radius in the dipole } \mathbf{R}}$ Focal-plane position (x)

Unique solution

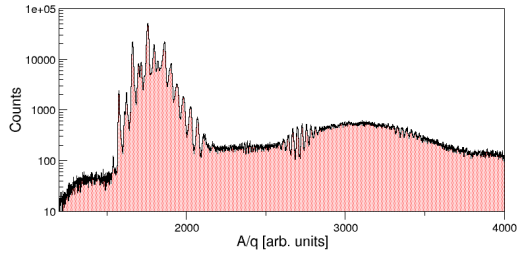
Fast convergence

  - Only the magnetic fields ratio B_Q/B_D is needed

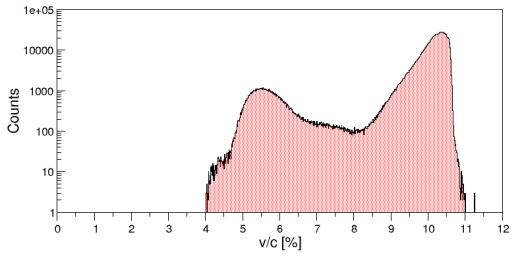
PRISMA: velocity, A/q, Doppler correction



A/q distribution



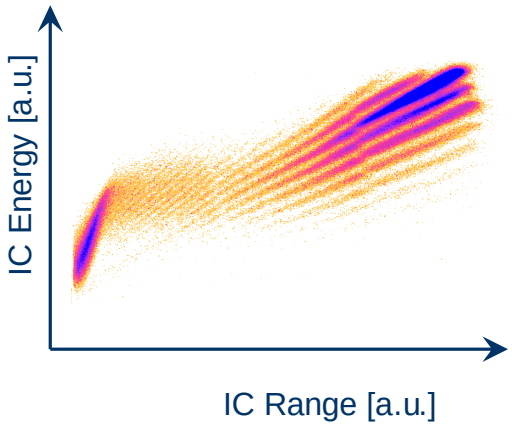
Velocity distribution



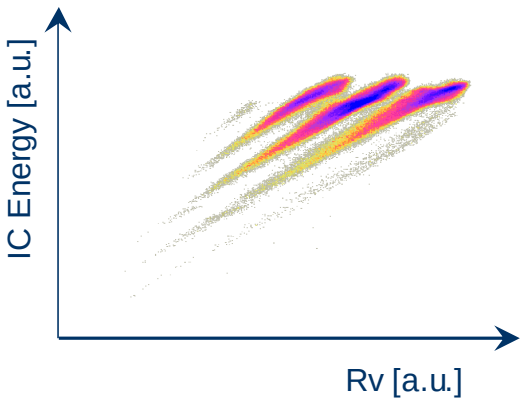
The absolute Time-of-Flight offset is checked/determined by looking to the Doppler correction in CLARA spectra

PRISMA: Z, Charge states, A

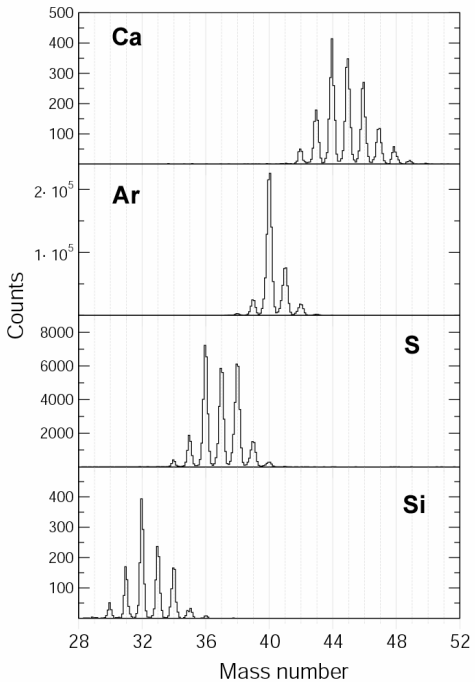
Z selection



Charge state identification



Complete A and Z identification



PRISMA: efficiency and resolving power

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

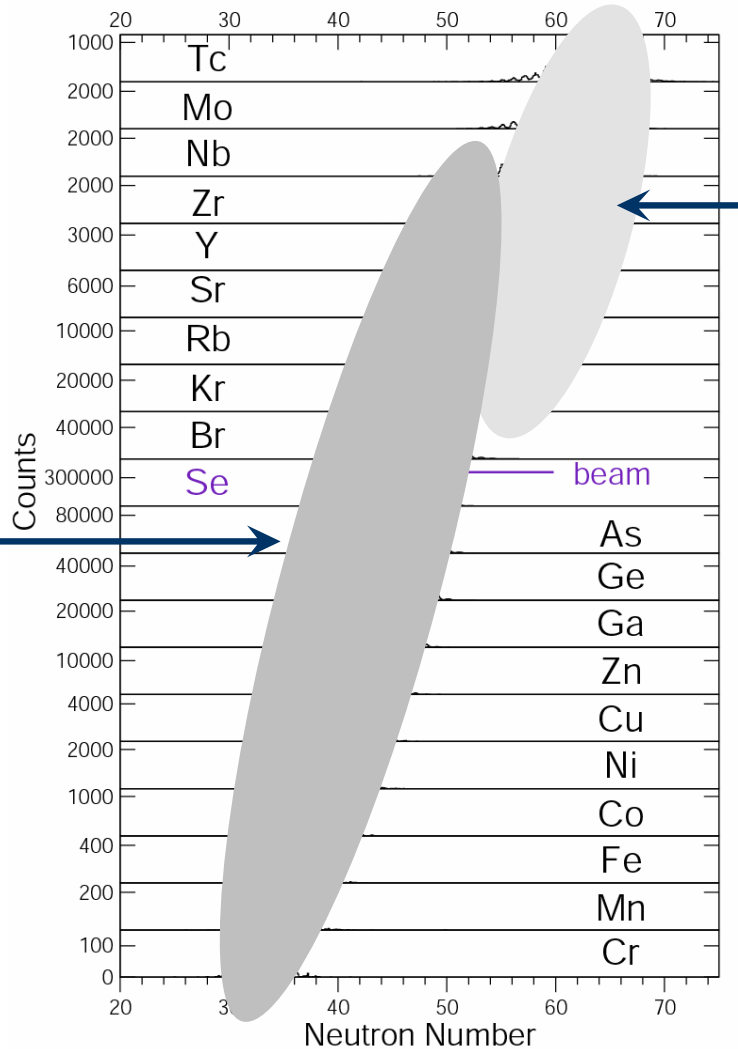
Projectile-like detected around 64º

Multi-nucleon transfer

Deep–inelastic collisions

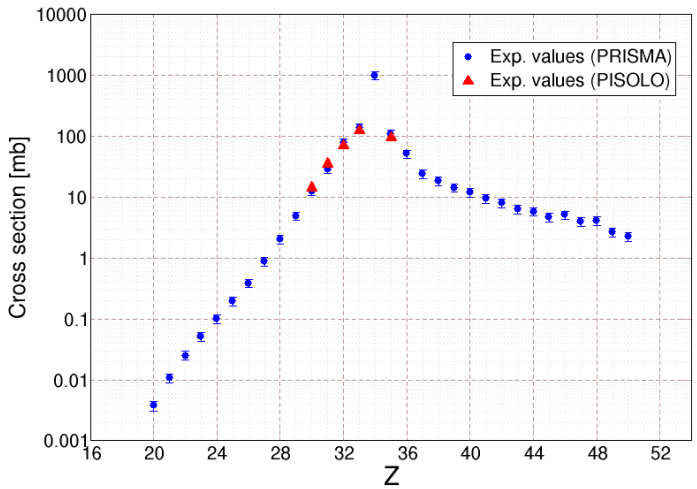
v/c range : 4-10%

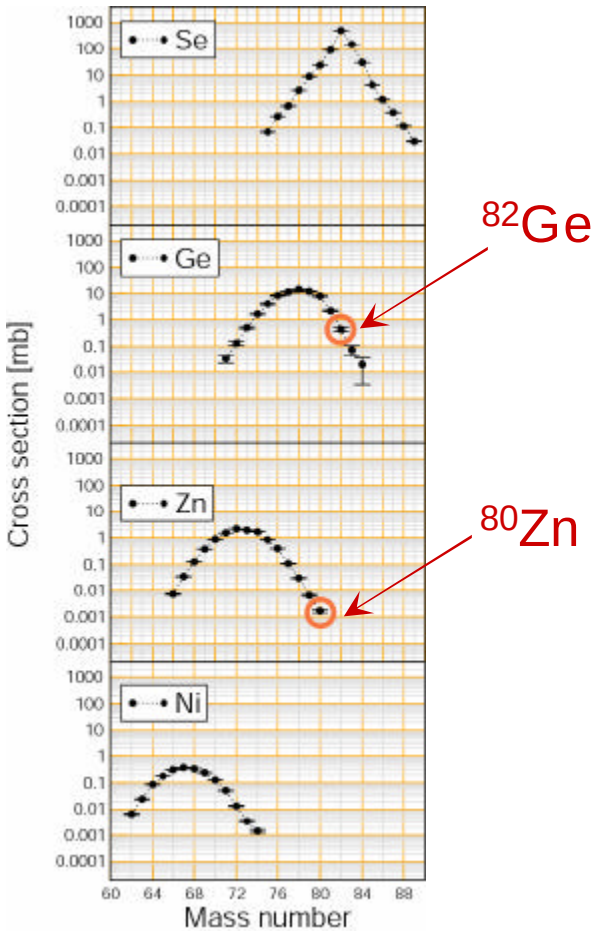
Mass range : 50-110



Experimental production cross-sections

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





Reliable production cross sections for exotic nuclei like the N=50 ^{82}Ge or ^{80}Zn are very useful when one project γ-spectroscopy experiments

CLARA/PRISMA Campaign for the Experimental Study of Neutron-rich Nuclei

- 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

$^{36}S+^{208}Pb$ Medium spin - spectroscopy of Ne, Mg, and Si neutron-rich isotopes

X.Liang, Paisley F.Azaiez, Orsay, Zs.Dombradi, Debrecen

$^{82}Se+^{238}U$ Nuclear spectroscopy of neutron rich nuclei in the N=50 region

G.Duchene, Strasbourg, G.de Angelis, Legnaro

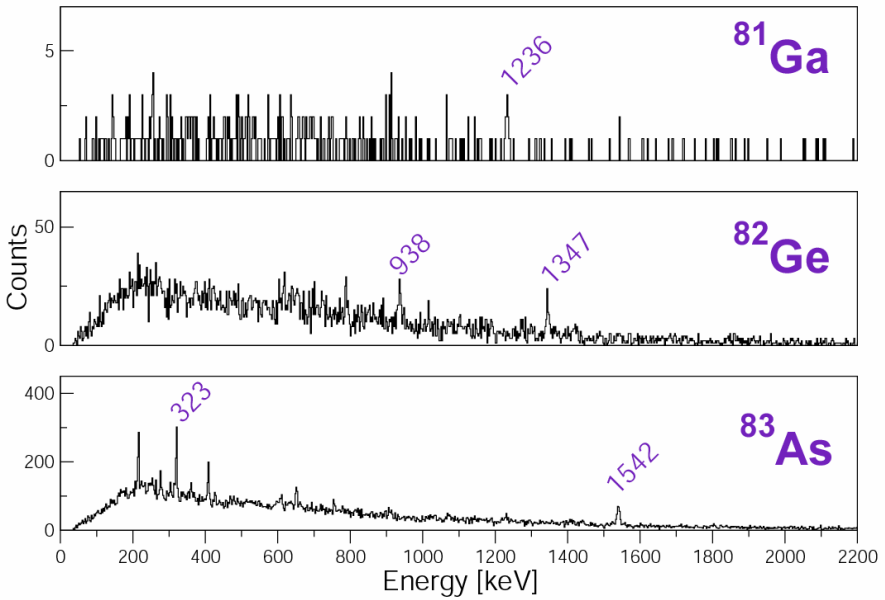
$^{64}Ni+^{238}U$ Spectroscopy of deformed neutron rich A ~ 60 nuclei

S.M.Lenzi, Padova, S.J.Freeman, Manchester

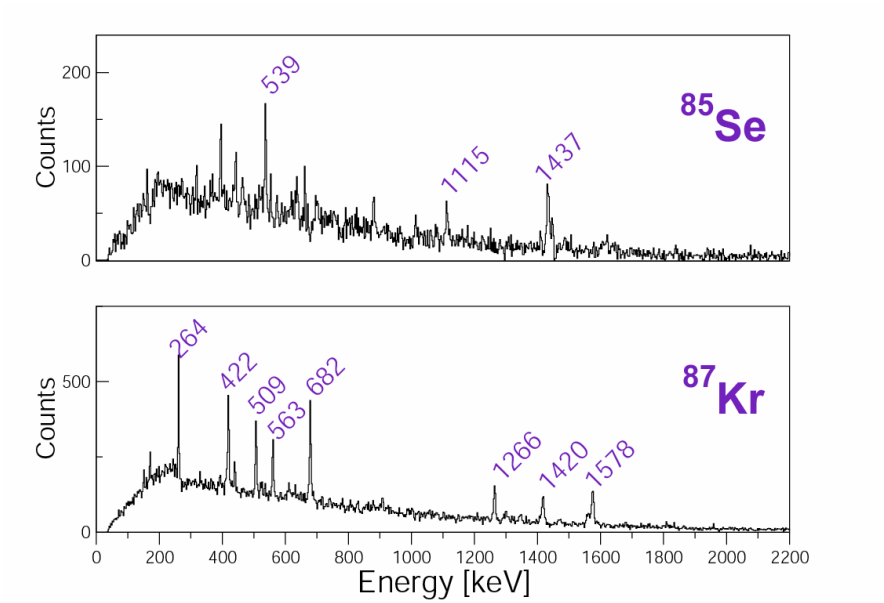
Spectroscopy of the lightest N=50 isotones

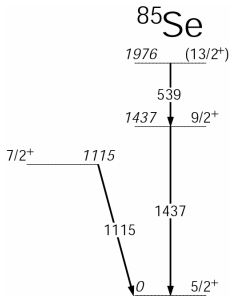
^{82}Se(500 MeV) + ^{238}U

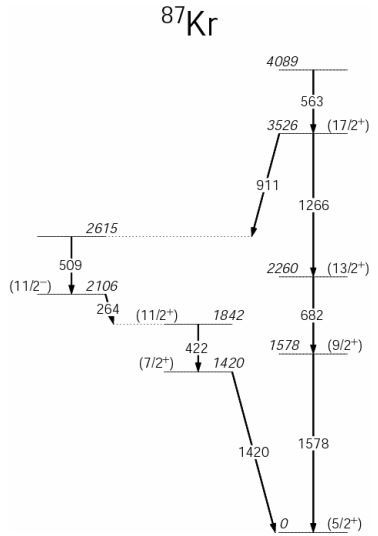
- First observation of γ rays from the decay of ^{81}Ga
- The excitation energy of the 4^+ state in ^{82}Ge firmly established
- First observation of the yrast levels of ^{83}As



Spectroscopy of odd-A N=51 isotones





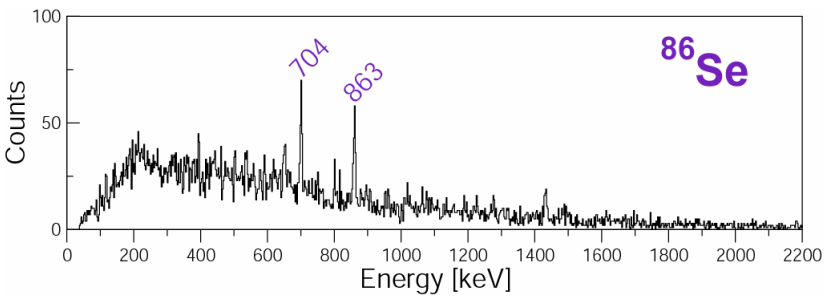


- First identification of yrast states in ^{85}Se and ^{87}Kr

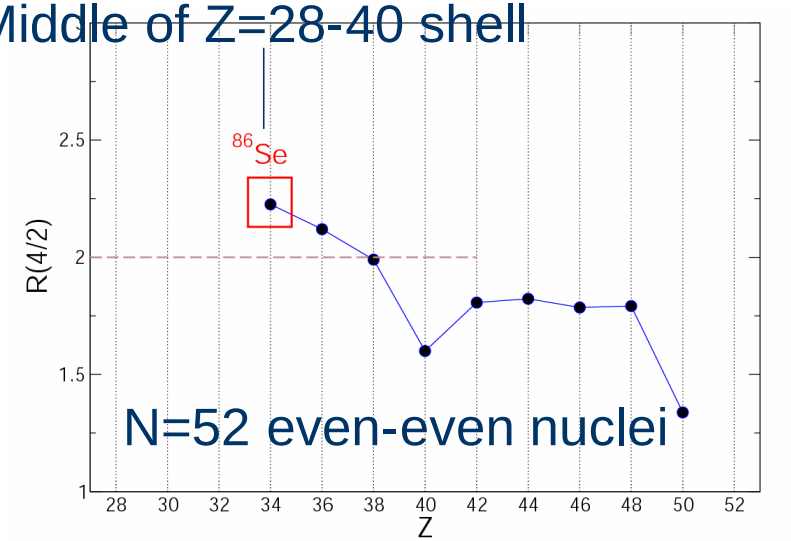
^{82}Se(500 MeV) + ^{238}U

Evolution of collectivity in light N=52 nuclei

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



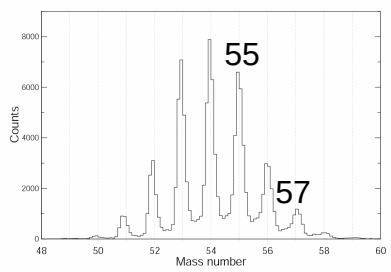
Middle of Z=28-40 shell



- First observation of the 4^+ ? 2^+ transition in ^{86}Se
- The systematic of R(4/2) ratio in N=52 even-even nuclei indicates an increase of collectivity going towards lower Z

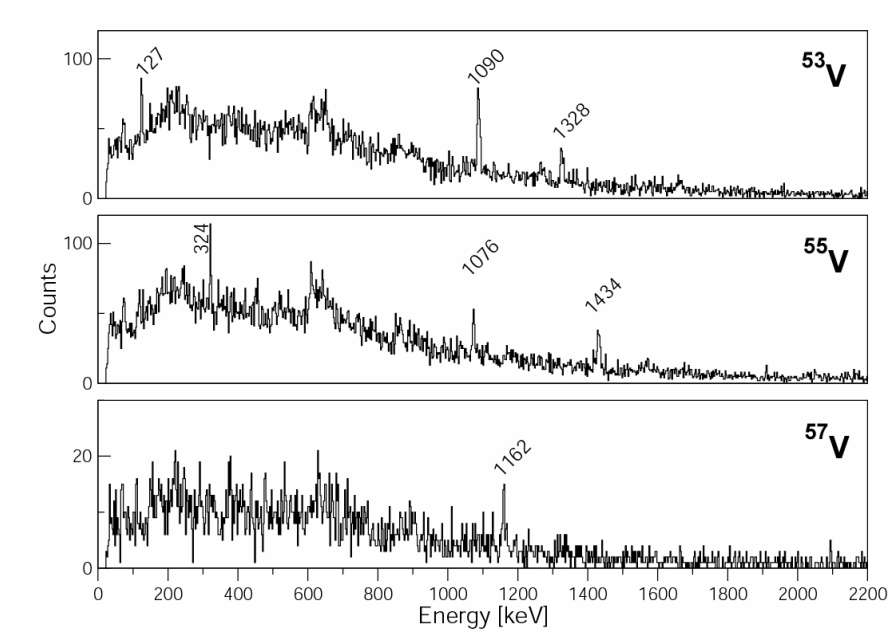
Spectroscopy around N=32 shell closure

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

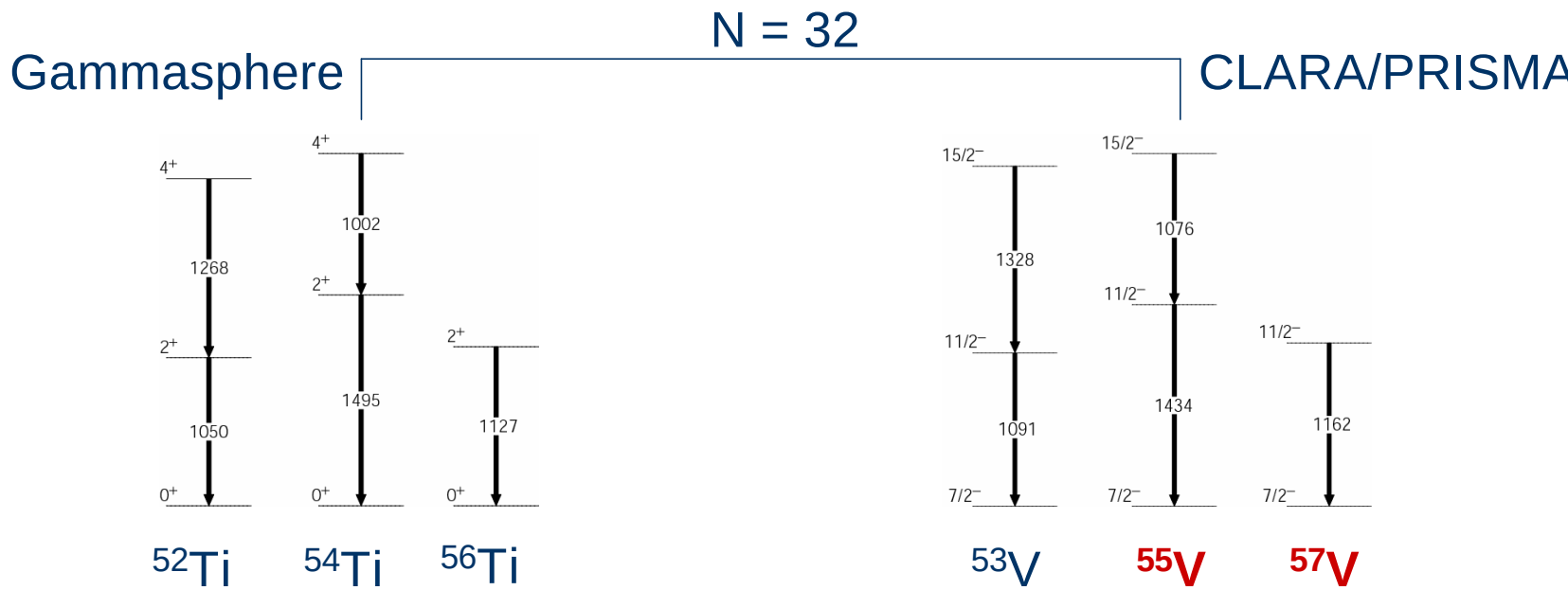


First identification of yrast states in heavy odd-A Vanadium isotopes ^{55}V and ^{57}V

- N=32 shell closure previously observed in ^{52}Ca and ^{54}Ti
- Possible N=34 shell closure theoretically predicted by the shell-model GXPF1 interaction, *M. Honma et al., Phys. Rev C 69, 034335(2004)*

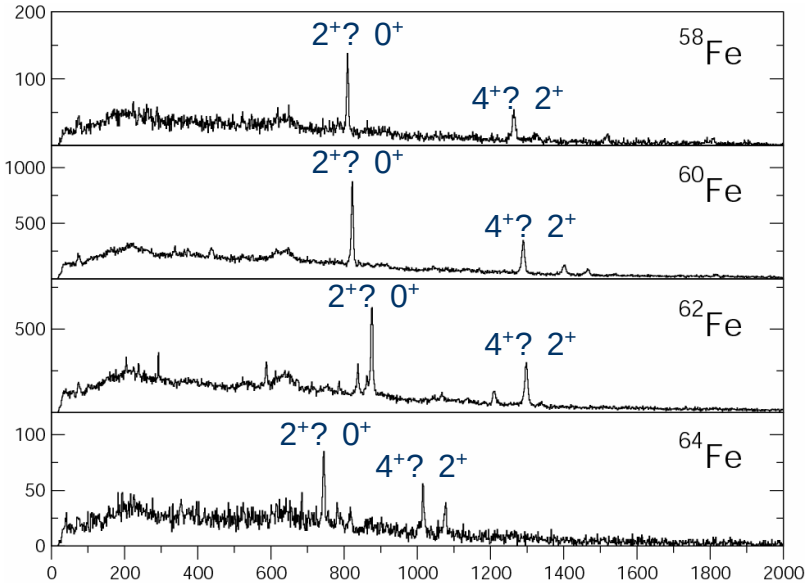


Predicted shell closures at N=32 and N=34

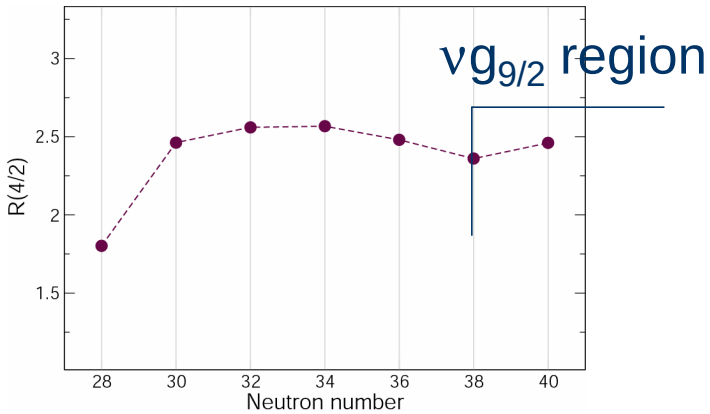


- First experimental observation of the $1\pi f_{7/2}$ band in $^{55,57}V$
- The predicted shell closure at N=34 is not confirmed by experimental data

Onset of deformation towards N=40



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

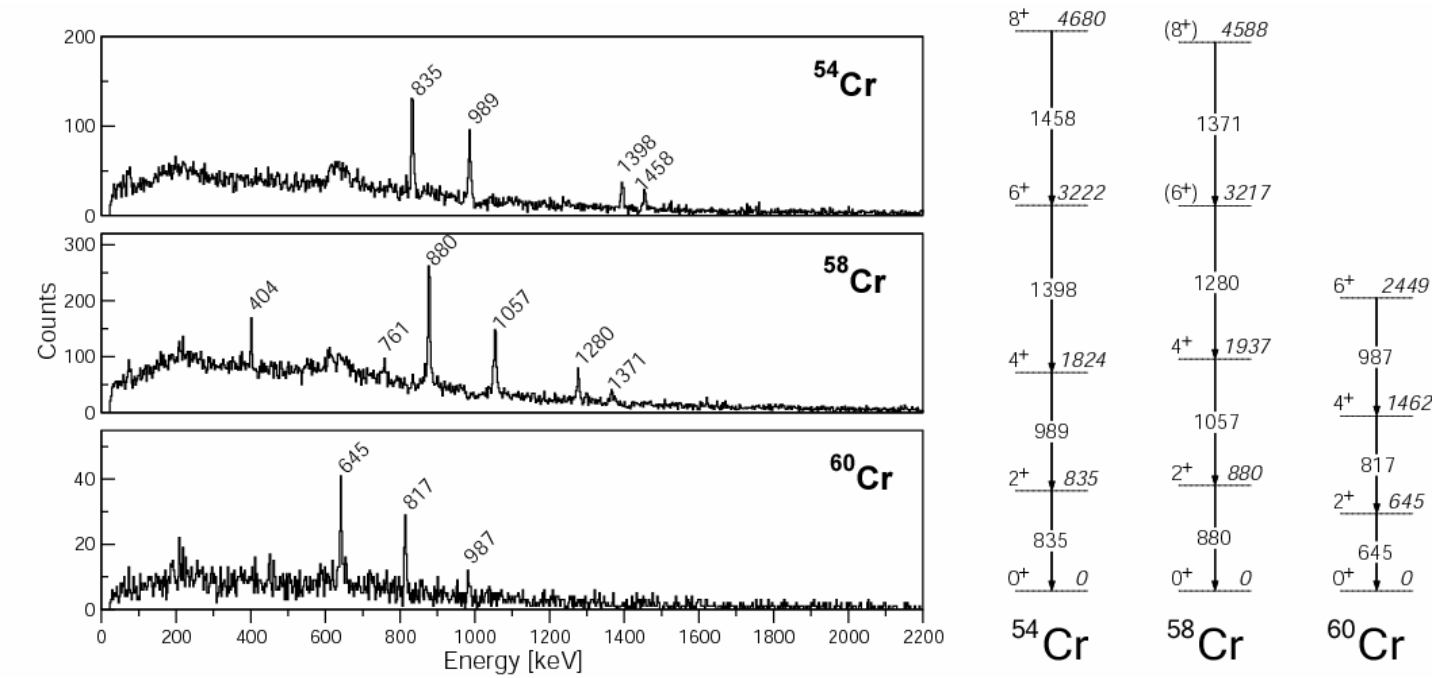


- First identification of 4^+ and possibly 6^+ states in ^{64}Fe
- The onset of deformation towards N=40 is confirmed by experimental data
- Shell-model calculations predicts that the $\nu g_{9/2}$ orbit has strong influence on the structure of even-even Fe isotopes with N=38
- The experimental R(4/2) ratio indicates a structure change for N=38

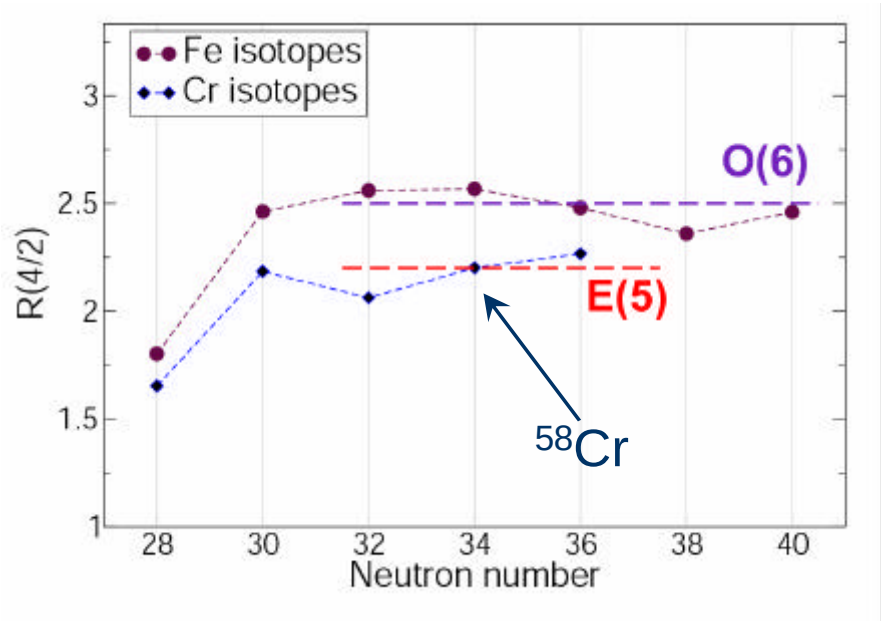
Spectroscopy of heavy Cr isotopes

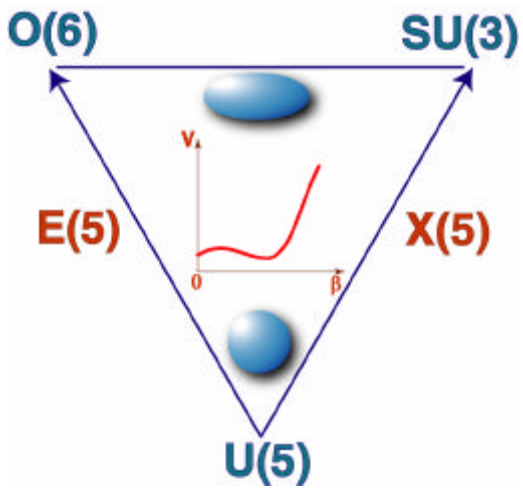
^{64}Ni(404 MeV) + ^{238}U

First observation of γ rays from the yrast levels of ^{58}Cr



g-softness in heavy Cr and Fe isotopes



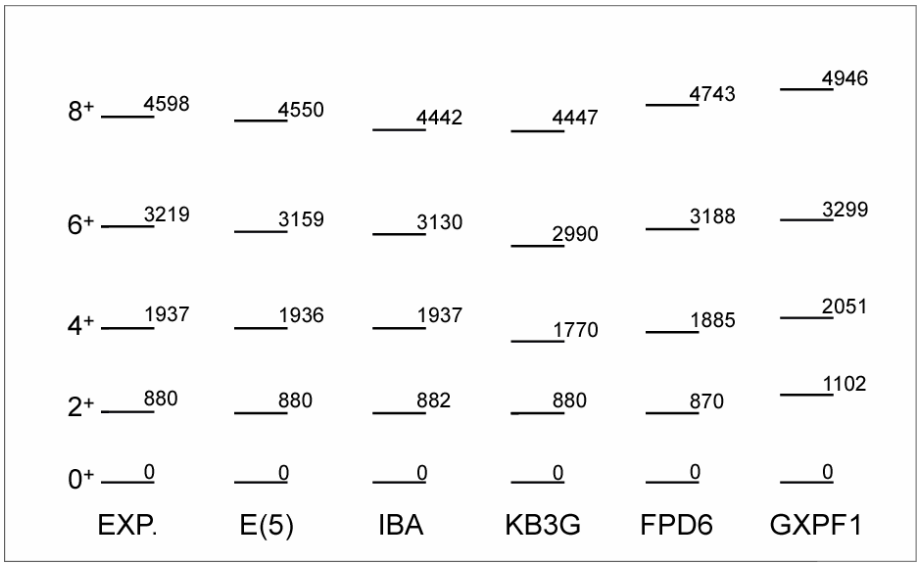


- The R(4/2) ratio in Fe isotopes is very close to the value of 2.50 specific to γ-soft rotors
- The R(4/2) ratio in Cr isotopes is increasing towards the same value

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 ?

- 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



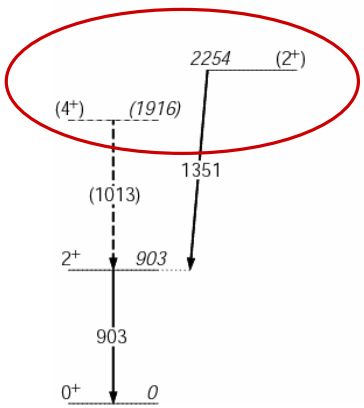
Experimental B(E2) values are needed to firmly demonstrate the existence of E(5) symmetry in ^{58}Cr

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

Collectivity above N=20 shell closure

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

First identification of yrast states in $^{34,36}Si$ and ^{40}S

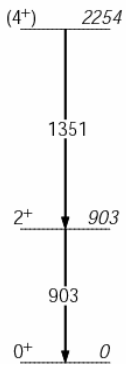


ß decay

NSCL-MSU

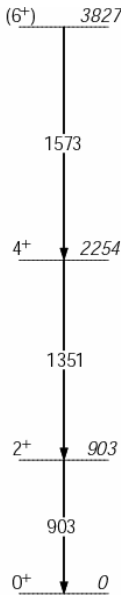
(1)

^{40}S

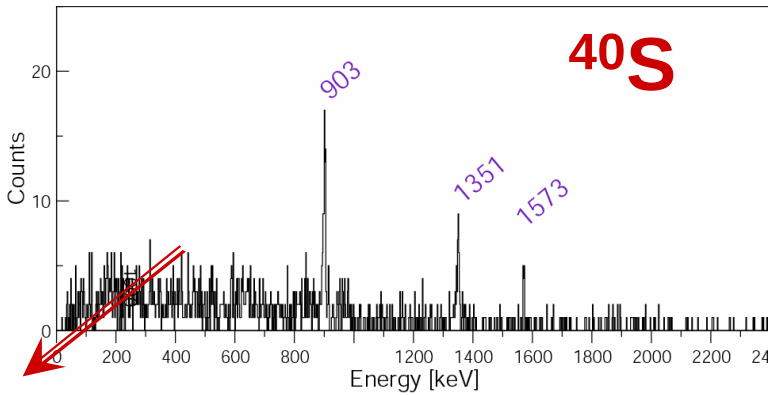


GANIL

(2)



CLARA/PRISMA



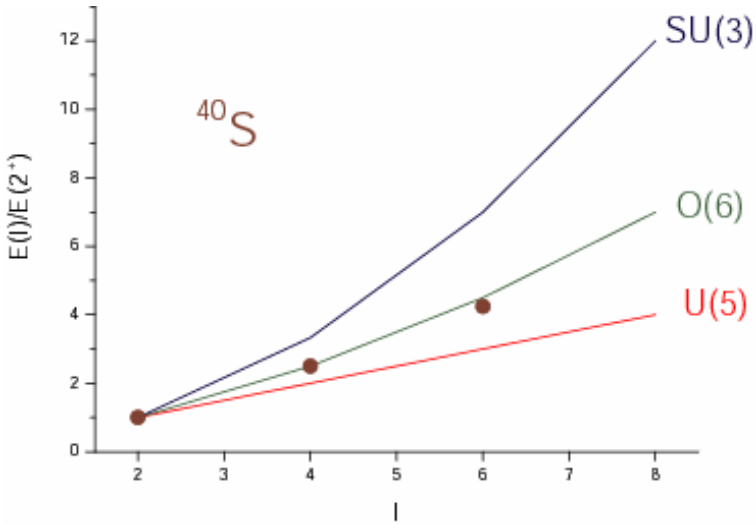
(1) J.A. Wigner et al.
Phys. Rev C 64(2001)064318

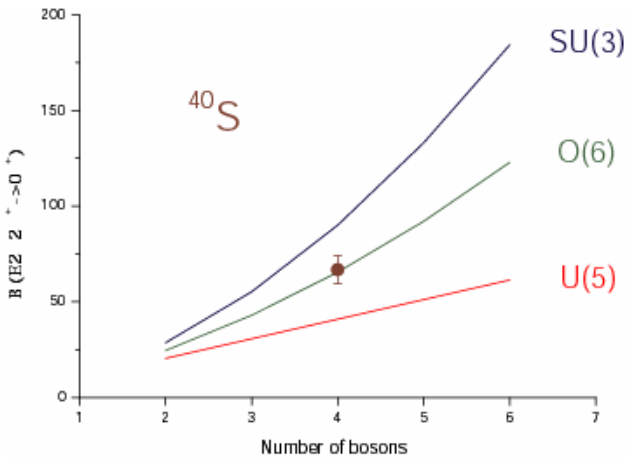
(2) D. Sohler et al.
Phys. Rev C 66(2002)054302

g-softness in heavy S isotopes

Analytic IBA formulas

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





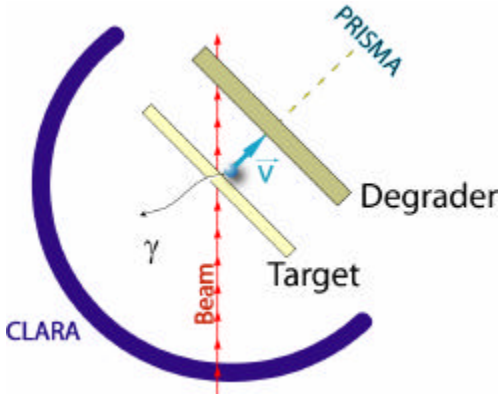
The level scheme and B(E2) value suggest a significant degree of γ-softness in ^{40}S

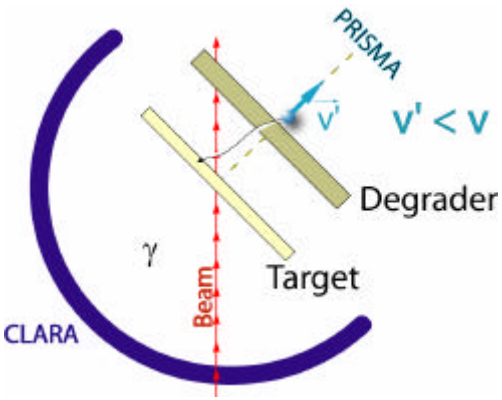
Development projects:

Differential plunger with CLARA/PRISMA

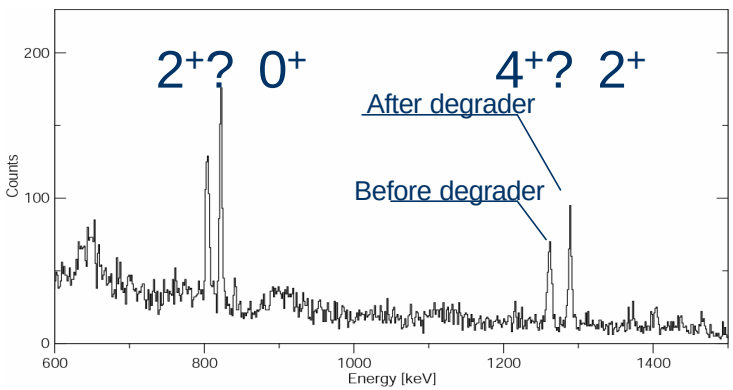
Collaboration with IKP-Köln

- 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





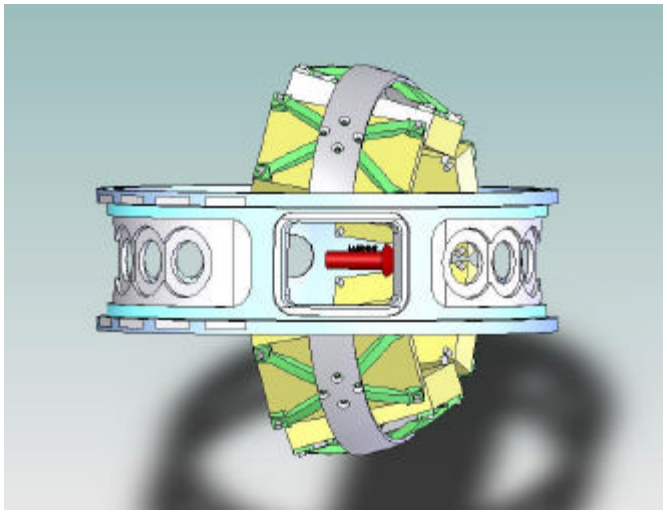
^{60}Fe – simulation based on existing experimental data



Development projects:
Position-sensitive MCP array DANTE

Collaboration with FLNR Dubna

- Variable-position MCP array, allowing complete covering of the grazing angle
- Will compensate the low level of statistics of γ-PRISMA coincidences



g-PRISMA : identification

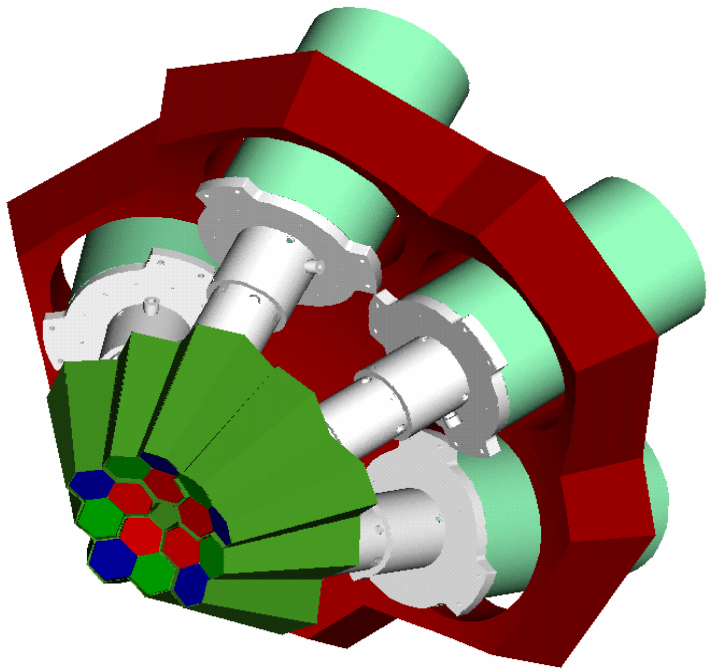
g-g-DANTE: build the level scheme

Talk of J.J. Valiente Dobon

AGATA Demonstrator at PRISMA

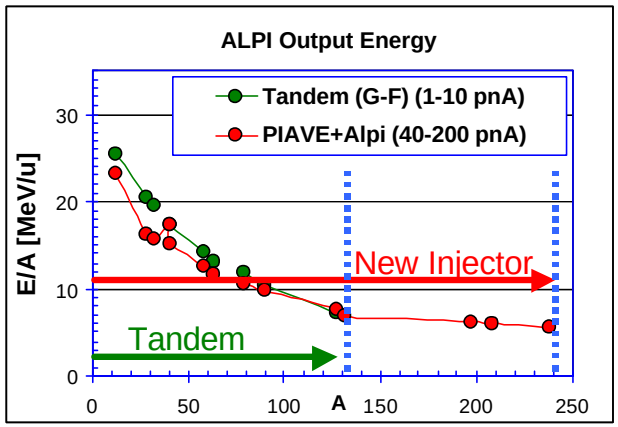
On the second half of 2007, the clover array CLARA will be replaced with the AGATA demonstrator

- **5 triple-clusters**
- 36-fold segmented crystals
- 540 segments



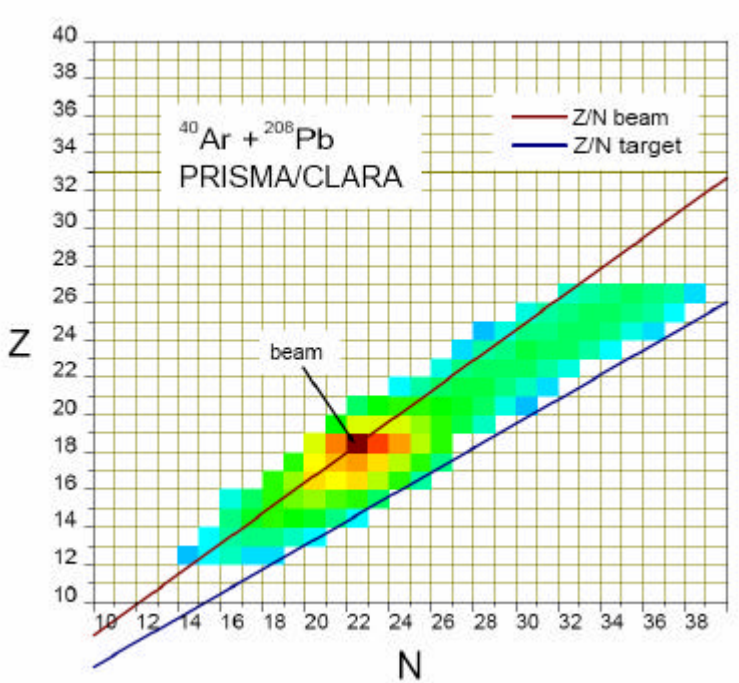
Talk of E. Farnea

Higher intensity beams: PIAVE/ALPI



- Test beams of ^{22}Ne and ^{40}Ar were already successfully delivered
- Higher beam intensities and heavier projectiles will become available with the entrance of PIAVE/ALPI complex in routine operation

^{40}Ar test beam, January 2006



Summary

- Spectroscopy with quasi-elastic multi-nucleon transfer and deep-inelastic collisions, using the CLARA-PRISMA setup and the medium-mass and heavy beams from LNL, provides valuable structure information on moderately n-rich nuclei
- Further developments include
  - the possibility to measure lifetimes with CLARA/PRISMA setup
  - higher granularity and γ detection efficiency (AGATA demonstrator)
  - More statistics for γ-recoil coincidences (DANTE)
  - Higher intensities and heavier beams (PIAVE/ALPI)