Lifetime measurements of neutron-rich nuclei around the doubly-magic ^{48}Ca, using multi-nucleon transfer reactions

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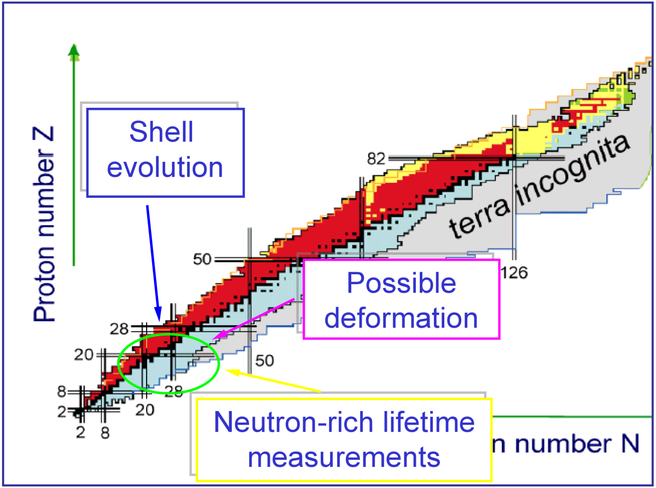
European Gammapool Workshop, Paris
May 27th÷30th, 2008

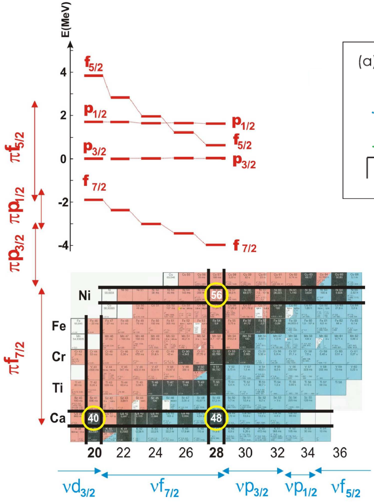
Outline

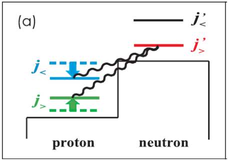
Motivation

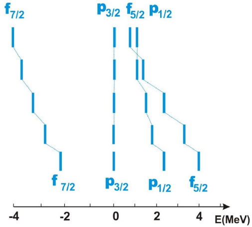

Proton number Z
Shell evolution
82
50
28
20
8
2
2
8
20
28
50
126
terra incognita
Possible deformation
Neutron-rich lifetime measurements
n number N

Shell evolution

migration of single particle orbitals



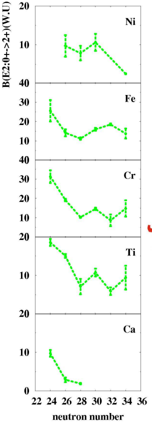


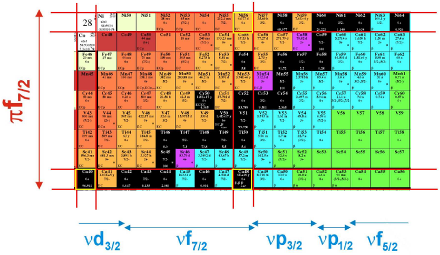


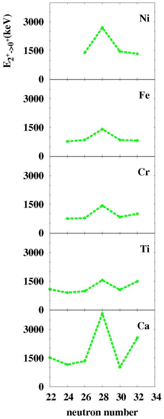
T. Otsuka et al., Phys. Lett. 95 (2005) 232502, B. Fornal contrib. to AGATA-WEEK 2007.

INFN

Motivation


B(E2:0+->2+)(W.U)
Ni
Fe
Cr
Ti
Ca
neutron number


πf7/2
νd3/2
νf7/2
νp3/2
νp1/2
νf5/2


E2+->0+(keV)
Ni
Fe
Cr
Ti
Ca
neutron number

Goals

Need for lifetime measurements

Complete spectroscopic information, constraint nuclear model in this region, nuclear structure evolution.

Lifetime estimation

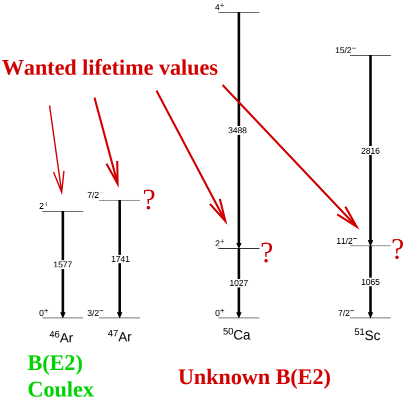
Shell model calculations for ^{50}Ca, ^{51}Sc, ^{47}Ar.

A. Poves *et al.*, Nucl. Phys. **A694** (2001) 157 and private com.

Measured B(E2:$2^+ \rightarrow 0^+$) in ^{46}Ar

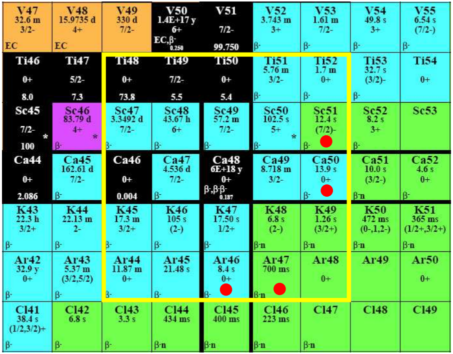
Absolute measurement based on intermediate energy Coulomb excitation. Adopted B(E2) 218(31) e^2fm^4.

A. Gade *et al.*, Phys. Rev. **C68** (2003) 014302.



Region

Around the doubly-magic nucleus ^{48}Ca



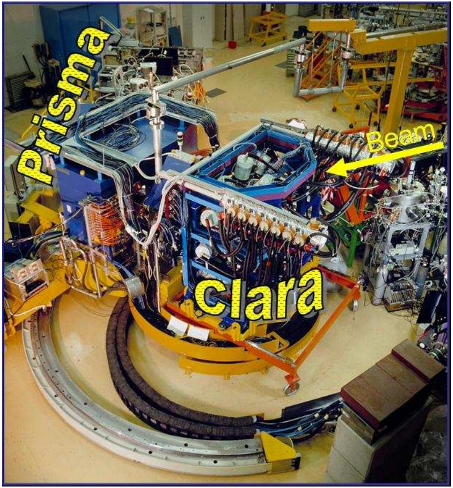
- Evolution of nuclear structure along isotopic chains through BE2s.
- Extension of the knowledge towards nuclei with larger isospin values.
- Subshell closure N=32 (Z=20).
- Persistence of N=28: ^{46}Ar, ^{44}S, ^{42}Si.

Experiment
Details

Details

- *beam*: ^{48}Ca @ 310 MeV provided by TANDEM ALPI ($\sim$1.5 pnA current) accelerator complex;
- *target*: 1 mg/cm^2 stretched ^{208}Pb (1 mg/cm^2 Ta backing) ;
- *degrader*: 4 mg/cm^2 ^{nat}Mg;
- PRISMA(49° grazing angle)+CLARA.
- Distances: 30 μm, 100 μm, 300 μm, 1240 μm, 220 μm
- 8-days beam-time

CLARA-PRISMA set-up



CLARA: 25 Euroball clovers

- Efficiency $\sim$ 3% (E_γ 1.3 MeV) $\rightarrow$ 1%
- P/T $\sim$ 45%
- FWHM $\sim$ 10 keV (v/c=10%) $\rightarrow$ 6 keV

A. Gadea *et al.*, Eur. Phys. J. **A20** (2004) 193.

PRISMA: magnetic spectrometer

- Solid angle $\sim$ 80 msr
- Mom. acceptance $\pm$ 10%
- Maximum rigidity1.2 Tm
- Energy resolution 1/1000
- Mass resolution 1/300 FWHM

A.M. Stefanini *et al.*, Nucl. Phys. **A701** (2002) 109c.

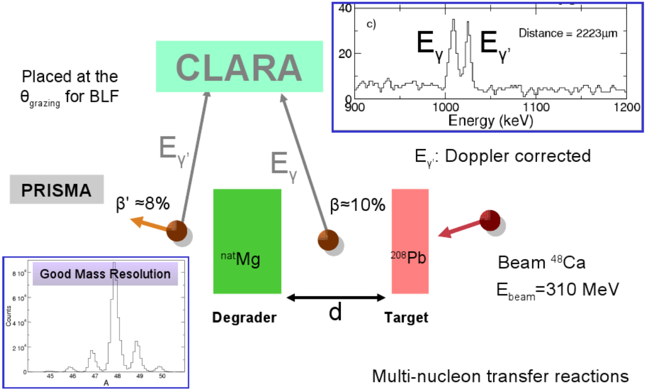
RDDS-target

plunger set-up

Remarks

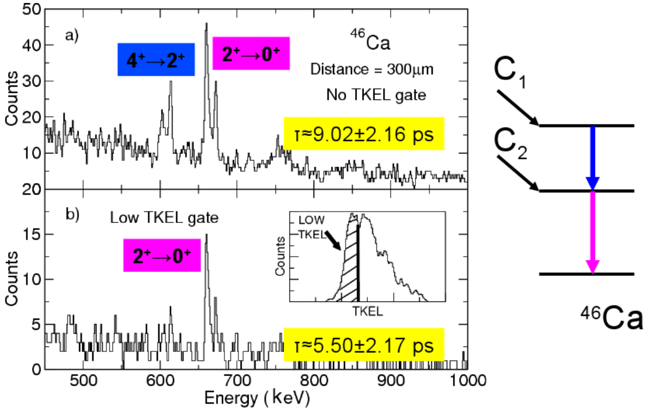
- Ring stack to set distances
- (stretched) Target: Ta 1 mg/cm^2, ^{208}Pb 1 mg/cm^2
- (stretched) Degrader: ^{nat}Mg 4 mg/cm^2
- Self-made plunger assemblying
- Cooling system for beam current increase

Working principle



J.J. Valiente, D. Mengoni et al., LNL An.Rep. 2007.

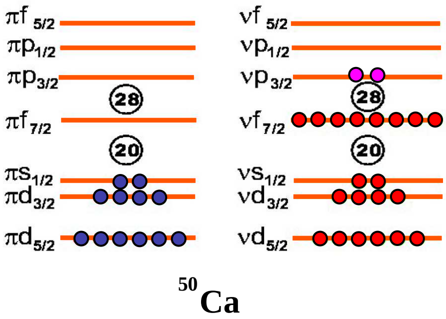
Differential plunger method

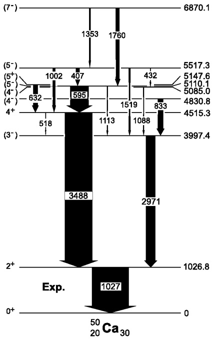


τ = 5.24±0.54 ps. M. Bini et al., Nuovo Cimento Lett. 5 913 (1972).

^{50}Ca isotope

Spectroscopic information

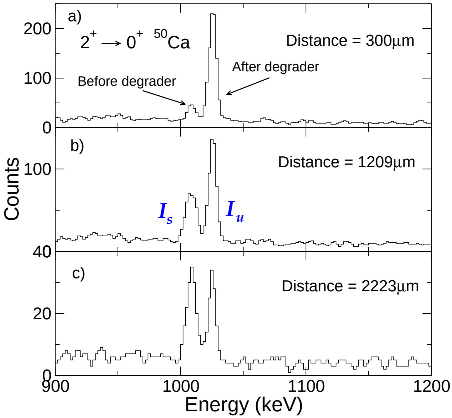




- Yrast structure N=30 isotones.
- Shell-model calculations only consider excitations involving neutron orbitals; proton core excitations possibly need to be included.
- Indication for N=32 subshell closure from the E(4+)/E(2+) energy ratio.

R. Broda *et al.*, Acta Phys. Pol. **B36** (2005) 1343.

Differential plunger method



Peak ratio

$$I_s = N_0(1 - e^{(-\frac{d}{v}\frac{1}{\tau})})$$

$$I_u = N_0 e^{-\frac{d}{v}\frac{1}{\tau}}$$

$$ln\left(\frac{I_u}{I_u + I_s}\right) = -\frac{d}{v}\frac{1}{\tau}$$

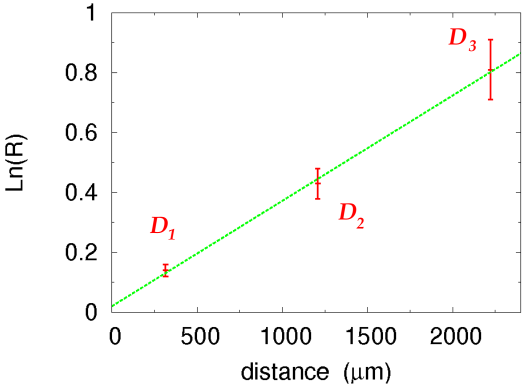
D. Mengoni, J.J. Valiente et al., LNL An. Rep. 2007.

v is the velocity before the degrader, while PRISMA measures the one after the degrader!

Method

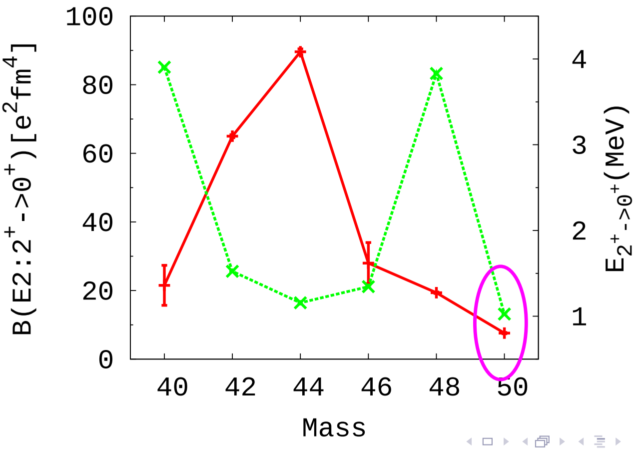
Velocity before the degrader β

$$\frac{E_{\gamma} + E_{\gamma'}}{E_{\gamma'}} = (\beta - \beta')cos\vartheta, \vartheta \rightarrow CLARA, \beta' \rightarrow PRISMA$$

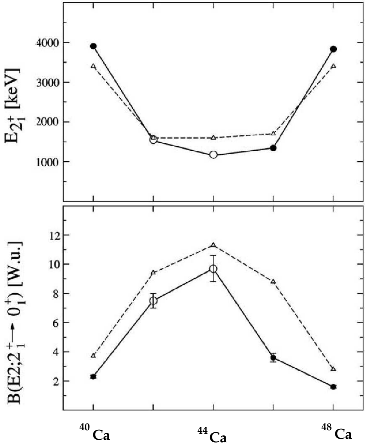


^{50}Ca reduced transition probability

With various gate on TKEL:
(96±3) ps lifetime → (7.5±0.2) e^2fm^4 B(E2↓)



Large shell model calculation



S. Schielke Phys. Lett. B571 29 (2003).

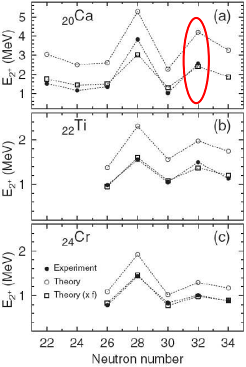
- Full fp shell calculations, using ^{40}Ca as inert core.
- KB3G(M), GXPF1A(M) effective interactions.
- Two set of effective charges: isoscalar (1.5, 0.5), dR (1.15, 0.8)

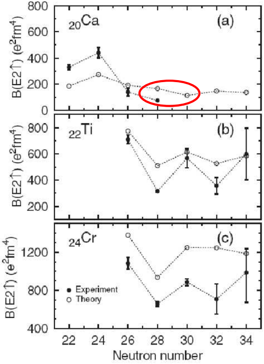
R. du Rietz et al., Phys. Rev. Lett. 93, 222501 (2004).

	E_γ (keV)	$B(E2, 2^+ \rightarrow 0^+)$ (e^2fm^4)	E_γ (keV)	$B(E2, 11/2^- \rightarrow 7/2^-)$ (e^2fm^4)
Exp.	1026	7.5(2)	1062	18(4)
KB3G (st)	1060	7.95	1141	17.03
KB3G (dR)		20.35		32.24
GXPF1A (st)	1187	8.10	1136	18.21
GXPF1A (dR)		20.74		33.64

Beyond mean-field

simmetry restoration





simmetry-conserving theory provided by projection technique:

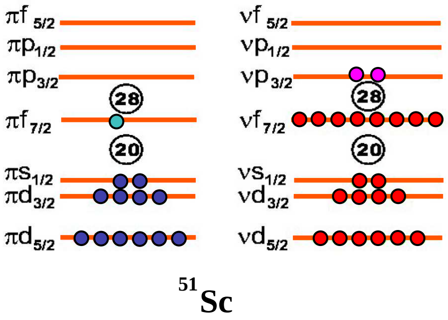
- angular momentum
- particle number

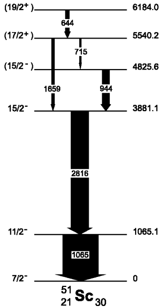
Applied to heavy nuclei, additional residual interaction required for lighter nuclei

no effective charge, good agreement with experimental data (trend)

T. Rodriguez, J.L. Egido Phys. Rev. Lett. 99, 062501 (2007).

^{51}Sc isotope
Spectroscopic information

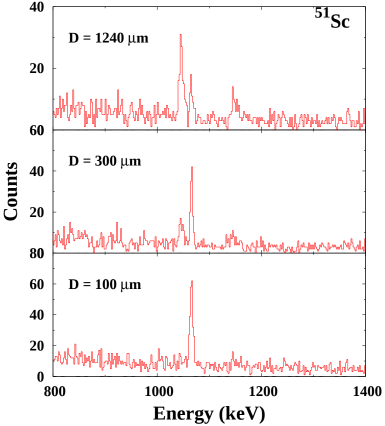




- Yrast structure N=30 isotones.
- Shell model calculations are restricted to the coupling of $f_{\frac{7}{2}}$ proton with neutron excitations.

R. Broda *et al.*, Acta Phys. Pol. **B36** (2005) 1343.

Method



- low Q_{val} gate
- lifetime: 34±7 ps
- B(E2↓): 18±4 e^2fm^4

fp shell effective charge

the polarization charge

The E2-polarization effect gives rise to an effective charge associated with the quadrupole processes:

$$(e_{eff})_{E2} = e(\tfrac{1}{2} - \tau_z) + (e_{pol})_{E2}, \qquad e_{pol} = (e_{pol})_{IS} + (e_{pol})_{IV}$$

π

$$(e_{eff})_{E2} = e + (e_{pol})_{E2}$$

ν

$$(e_{eff})_{E2} = (e_{pol})_{E2}$$

The core polarization can be understood in terms of the coupling between the particle and the collective oscillations associated with deformations of the core.

Effective charge
derivation

Lifetimes of the 2+ in ^{50}Ca and 11/2- ^{51}Sc will help to determine the effective charges in the fp shell.

- ^{50}Ca wave function of the 2+ $\rightarrow$ $(\nu p3/2)^2$
- ^{51}Sc wave function of the 11/2- $\rightarrow$ $(\nu p3/2)^2$, $\pi f7/2$

π

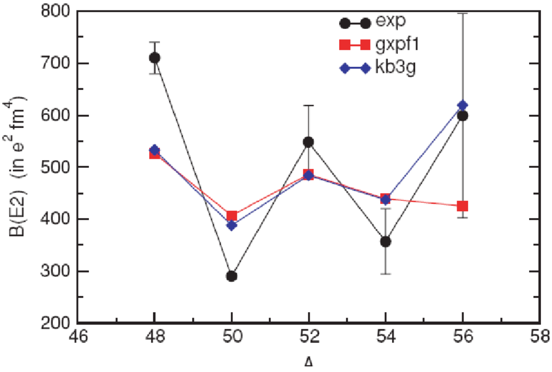
$e_{eff}(\pi) = 1.5$

ν

$e_{eff}(\nu) = 0.48$

Incomplete (t=5) LS shell model calculation have been performed to reproduce lifetime in ^{58}Ni and Ti staggering.

Effective charge
Ti staggering

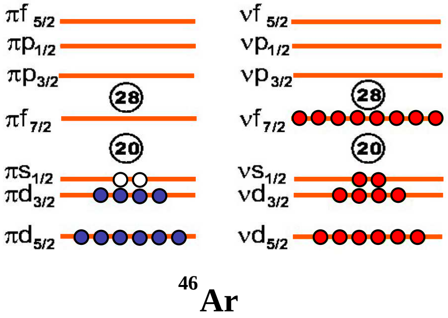


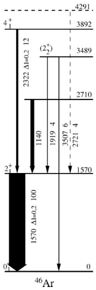
- For N=Z $e_{eff}(\pi)$=1.15, $e_{eff}(\nu)$=0.8
- A new computation of the effective charges is required for neutron-rich nuclei.
- ^{50}Ca e_π=1.08 and e_ν=0.569 can be deduced.

A. Poves et al., Phys. Rev. C 72, 047302 (2005).

^{46}Ar isotope

spectroscopic information

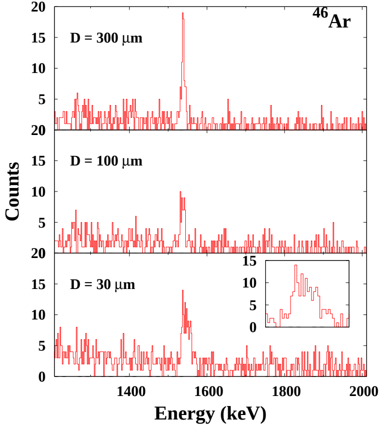




- Intermediate Coulomb energy determination of B(E2:$2^+ \rightarrow 0^+$).
- Deformation occurs near N=28 but the major shell gap persists in the slightly oblate vibrational nucleus ^{46}Ar.

A. Gade *et al.*, Phys. Rev. **C68** (2003) 014302.
H. Scheit *et al.*, Phys. Rev. Lett **77** (1996) 3967.
Zs. Dombrádi *et al.*, Nucl. Phys. **A727** (2003) 195.

Differential plunger method



- fully shifted peak ⇒ short lifetime
- increased emission in the degrader ⇒ peak broadening
- (preliminary) upper limit in the lifetime

N=28 major shell gap

possible deformation of ^{46}Ar?

Relativistic Coulomb Excitation:

B(E2) trantistion probability through disentanglement of the Coulomb cross section

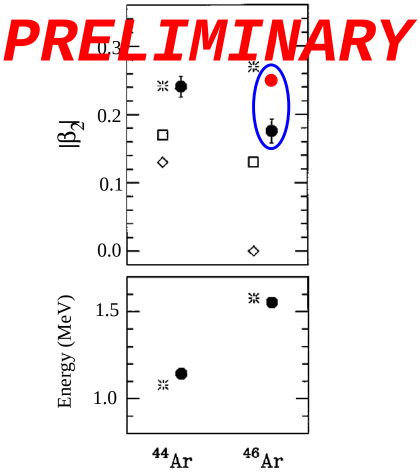
$0° - \theta_{lab}^{max}$		$0° - 1.9°$	$0° - 2.2°$	$0° - 2.5°$	$0° - 2.7°$	$0° - 2.9°$
$E(^{46}Ar)$ midtarget (MeV/nucleon)	73.2					
^{46}Ar beam purity (%)	$\geqslant 99$					
Target ^{197}Au (mg/cm^2)	209					
Typical intensity on target (kHz)	13					
Total run time (h)	≈ 9					
Integrated cross section σ (mb)		32(5)	43(6)	53(7)	60(8)	68(8)
b_{min} (fm)		18.8	16.2	14.3	13.2	12.3
R_{int} (fm)	13.3					
$B(E2;0_1^+ \rightarrow 2_1^+)(e^2\ fm^4)$		226(43)[a]	227(39)	220(35)	218(31)	212(30)
Adopted $B(E2\uparrow)(e^2\ fm^4)$	218(31)					
$B(E2\uparrow)(e^2\ fm^4)$ from Ref. [8]	196(39)					

[a] $B(E2)$ at $b_{min} = R_{int}$.

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

N=28 major shell gap

possible deformation of ^{46}Ar?

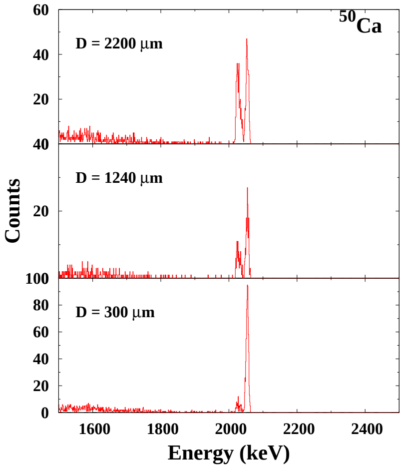


- non-zero deformation of ^{46}Ar
- the nuclues might be as deformed as ^{44}Ar
- shell model calculation (empirical interaction) predicts this trend!

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

Simulations

realistic CLARA-PRISMA simulation



- Event generator: vel distribution deduced from the exp, stopping power in the degrader
- Full Prisma reconstruction
- Geant4 Clara simulation (comparison with AGATA follows soon in Andres talk)
- lifetime 105±6 ps

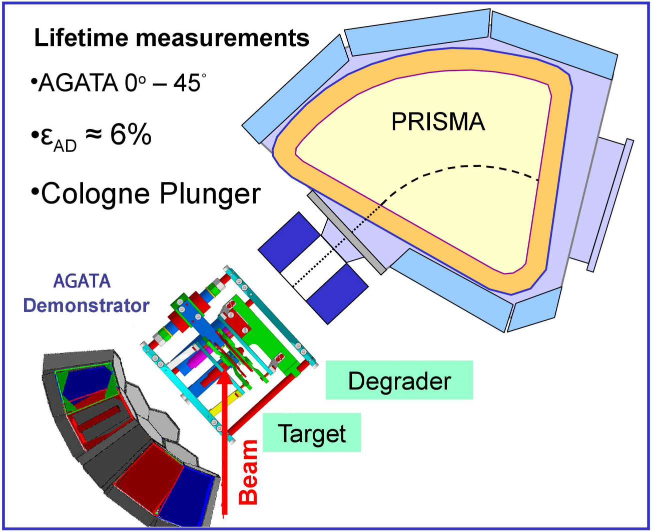
Summary

- Lifetime measurement performed via MNT and RDDS method, using CLARA gamma spectrometer coupled with PRISMA magnetic spectrometer.
- Preliminary results (experiment performed in december 2007) on the lifetime of the first excited states in the N=30 isotones ^{50}Ca and ^{51}Sc. This allows to determine the effective charges of the fp shell.
- Simulation in progress for ^{46}Ar (N=28).

Outlook and Conclusions

- Novel method for lifetime measurement in neutron-rich nuclei available.
- Feeding control through TKEL gate.
- Future at LNL: The AGATA demostrator coupled to PRISMA and the plunger from Cologne will open new possibilities due to its much higher efficiency (almost ten times CLARA for lifetime measurement).
- LoI to study ^{52}Ca with the AD + PRISMA + Köln Plunger

Köln plunger



Collaborators

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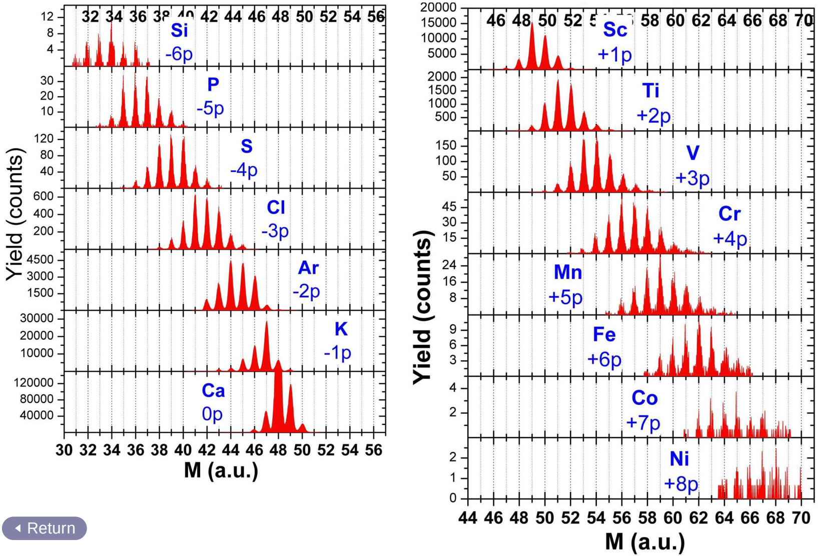
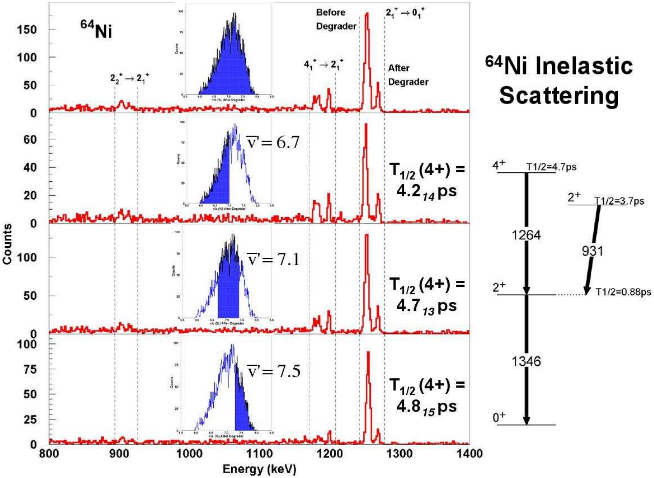
^{48}Ca(330 MeV)+^{238}U: mass distribution



Return

Inelastic channel feeding

^{64}Ni(400MeV) + ^{208}Pb



Return

Production rates

Isotopes production rates (counts/day) obtained from a previous ^{48}Ca + ^{238}U at 330 MeV experiment with CLARA-PRISMA, with an average ^{48}Ca beam intensity of 0.5 pnA, by Broda and collaborators.

	Mass							
	45	46	47	48	49	50	51	52
Sc	-	-	-	-	-	-	1.2×10^4	1.4×10^3
Ca	-	-	-	-	-	5.3×10^4	-	-
K	1.9×10^4	4.0×10^4	7.9×10^4	1.8×10^4	2.7×10^3	-	-	-
Ar	1.2×10^4	8.6×10^3	2.2×10^3	-	-	-	-	-

Known spectroscopic information

Thick target (80 mg/cm^2) DIHIR gamma coincidences:

1. GASP ^{48}Ca(210 MeV) + ^{48}Ca - Low fold gates for fusion
2. GAMMASPHERE ^{48}Ca(245 MeV) + ^{208}Pb
3. GAMMASPHERE ^{48}Ca(330 MeV) + ^{238}U

R. Broda., J. Phys. G: Nucl. Part. Phys. **32** (2006) R151.

MNT-DIHIR experiment:

1. PRISMA-CLARA ^{48}Ca(330 MeV) + ^{238}U

How we plan to proceed

- Based on the production rate for the various nuclides for Broda experiment),
- Beam current: $\sim$ 1 pnA to avoid the target to melt
- at least 100 counts in the photopeak transition
- $\sim$ 3 days/distance are estimated considering the lowest populated nucleus (^{47}Ar),
- thin (300 μg/cm^2) target to check PRISMA set-up.
- 3 distances from 30 $\div$ 300 μm to cover the 1$\div$10 ps time range: 300 μm then analisys.
- 3 ps lifetime of ^{46}Ca will be firstly checked.