Spectroscopy on medium and heavy neutron-rich nuclei via two-step Coulomb excitation at intermediate energies

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Past, Present,

and Future of shell model

Past

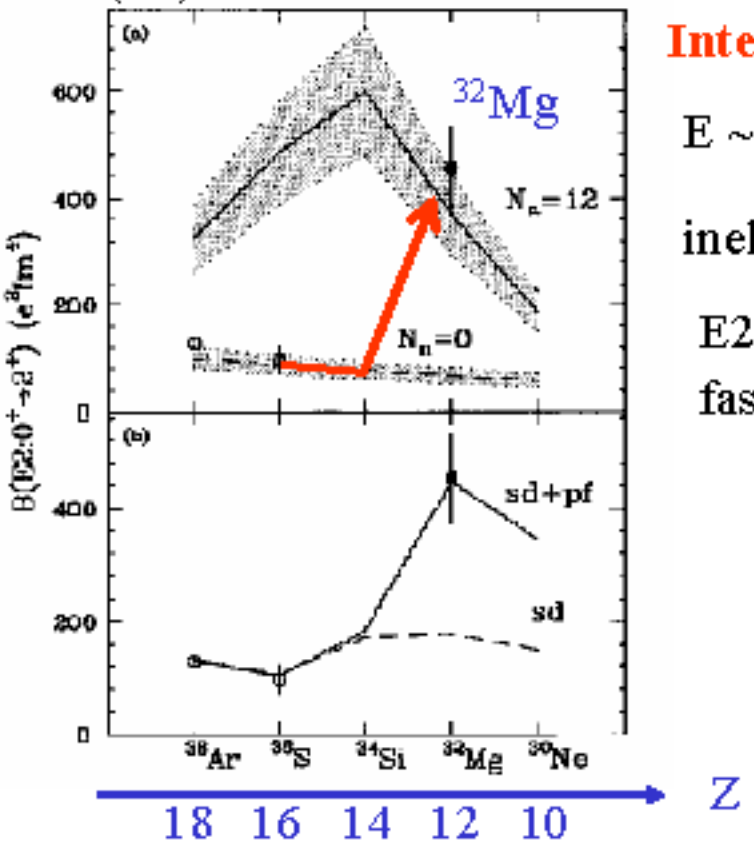
Physics of the 2^+ state

Large B(E2) observed for ^{32}Mg

The dawn of in-beam γ spectroscopy with fast RI beams

T. Motobayashi, et al., PLB 346, 9 (1995)

B(E2) for the N=20 isotones



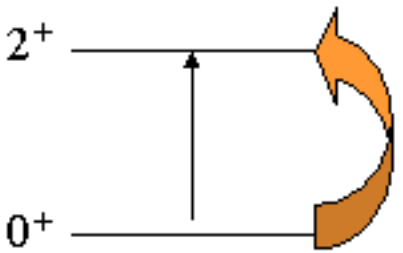
Intermediate energy Coulomb excitation

E ~ 50A MeV >> Coulomb barrier ~ 5A MeV

inelastic scattering on heavy target such as Pb

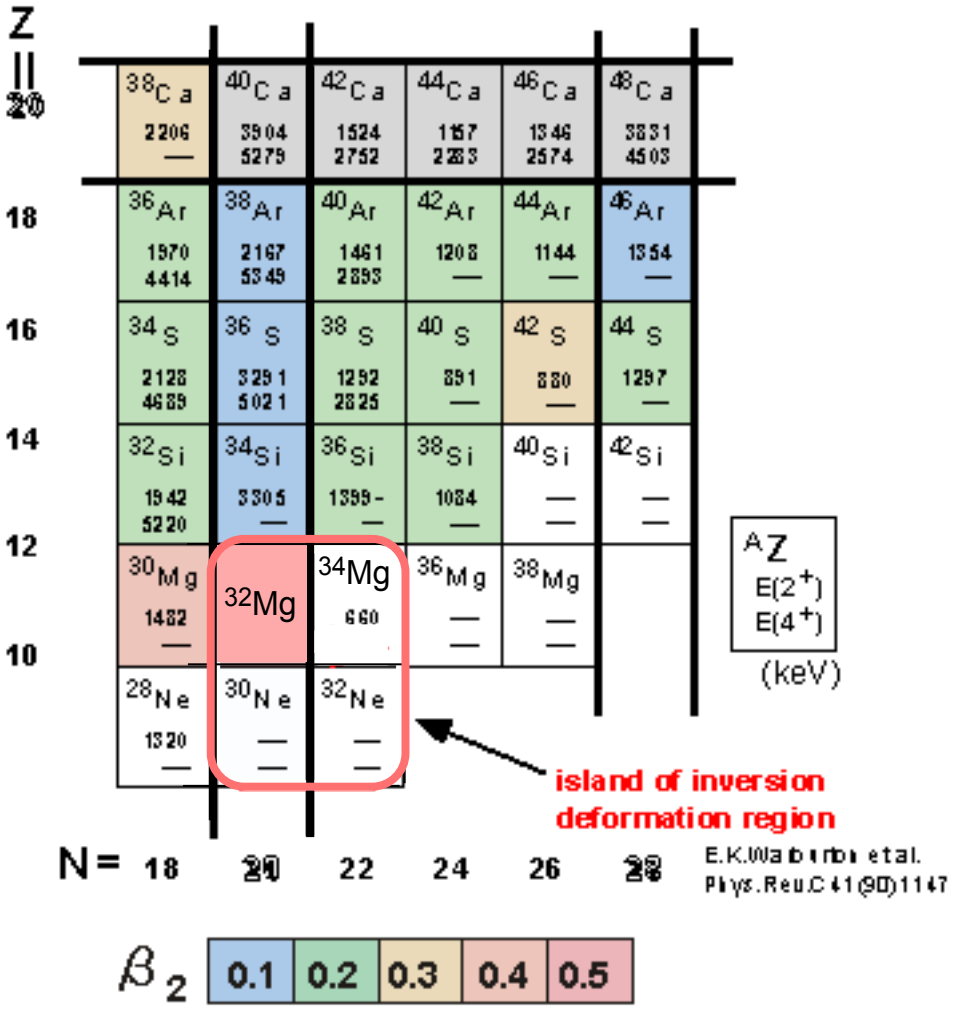
E2 excitation: Coulomb dominant if Z>10

fast interaction -> single step excitation



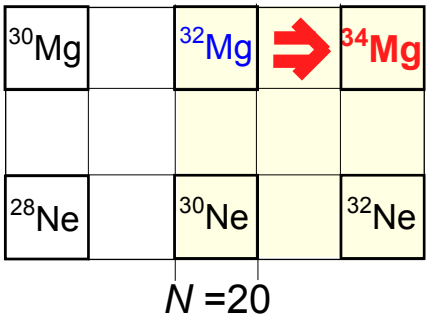
$\sigma \propto B(E2)$

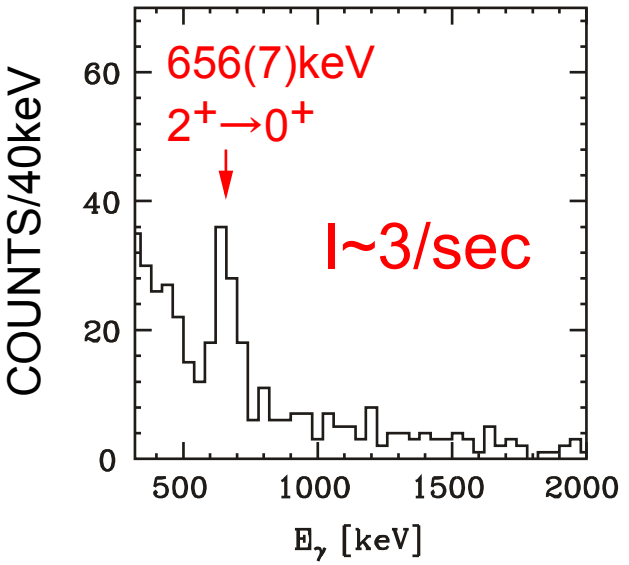
B(E2) measurements of the sd, pf shell nuclei

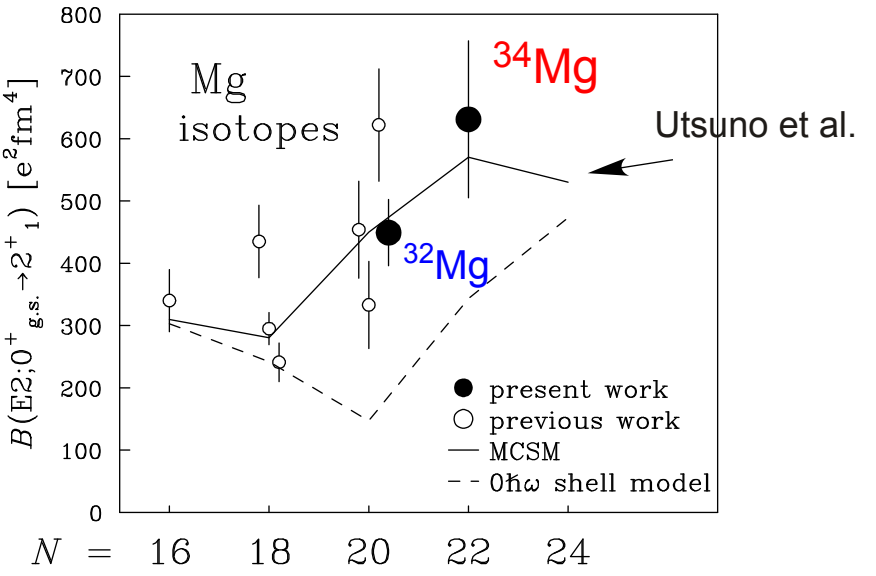


Coulomb excitation of ^{34}Mg

H. Iwasaki et al.
Phys.Lett.B 522(01)227







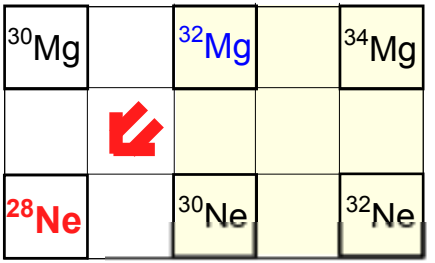
B (E2;$0^+ \rightarrow 2^+$) = 631(126) e^2fm^4
$\beta 2 \sim 0.58$!!

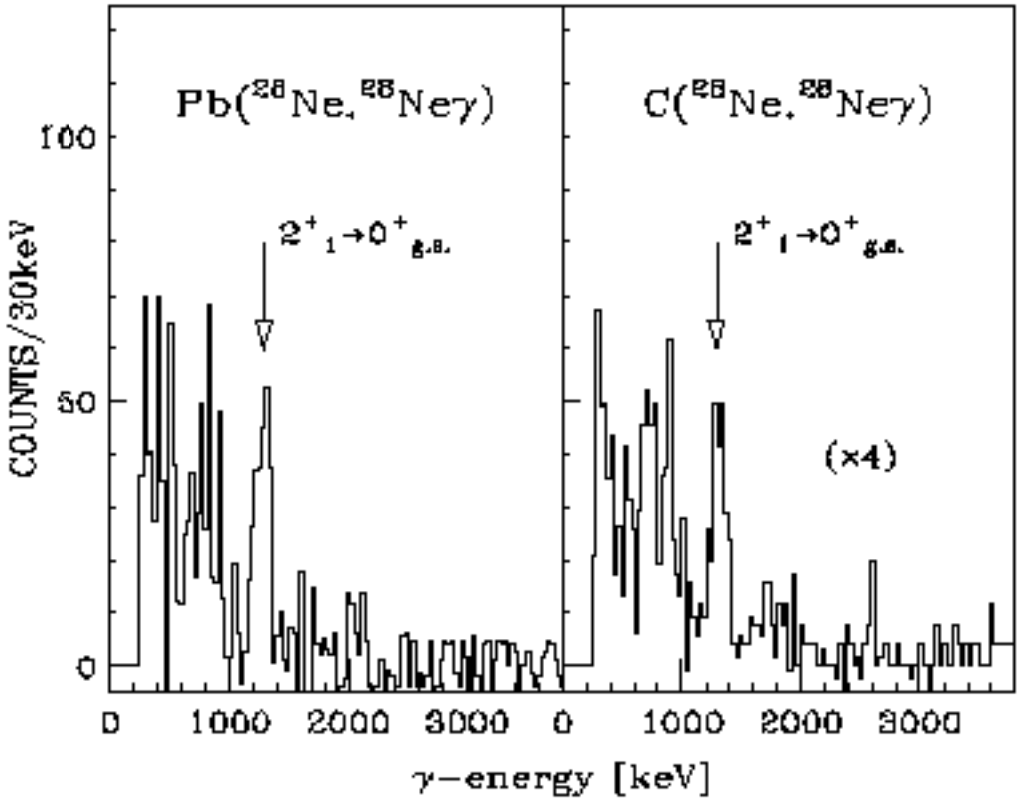
MCSM Utsuno et al.,
Phys. Rev. C 60(1999)054315

large deformation of ^{34}Mg

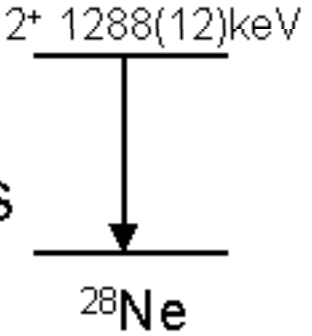
Coulomb excitation of ^{28}Ne

H. Iwasaki et al.
Phys.Lett.B 620(05)118





I of ^{28}Ne ≈100cps



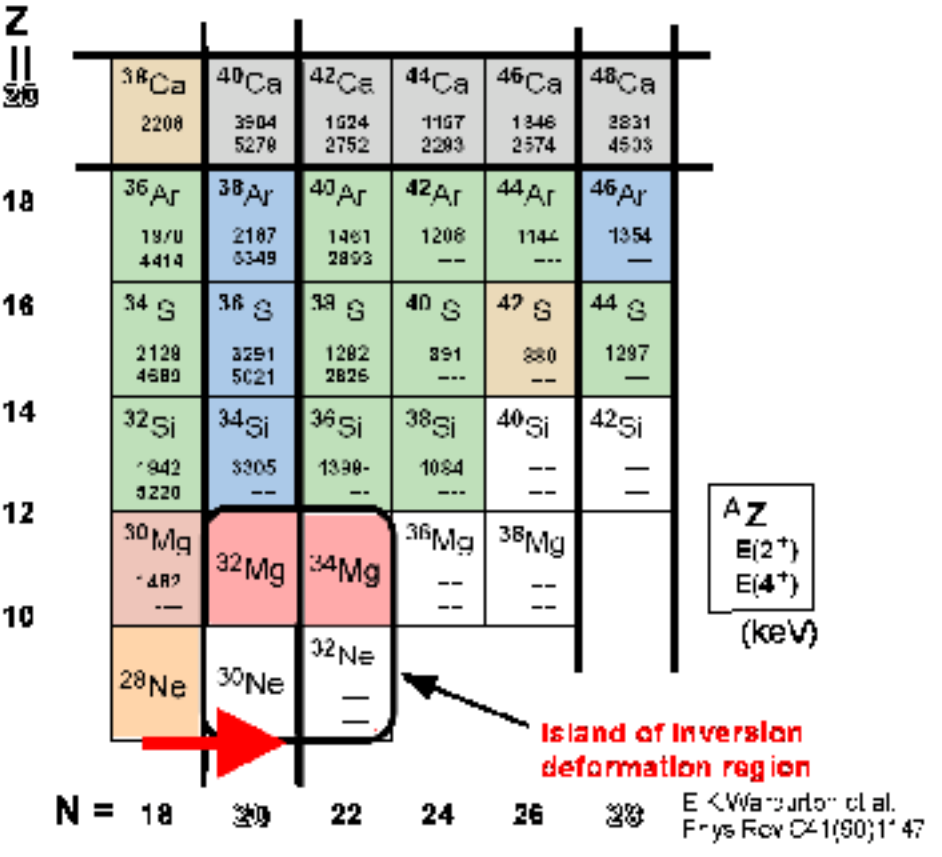
B(E2)= 132(23)e^{2}fm^4

previous
269(136)e^{2}fm^4
B.V.Pritychenko et al.
PLB461(99)322

β C = 0.36(3)

β N = 0.34-0.38

How is the region extended ?
toward lower Z and larger N
—– ^{30}Ne case —–



β_2 0.1 0.2 0.3 0.4 0.5

E(2⁺) measurement for ^{30}Ne via (p,p')

Yanagisawa et al., Phys. Lett. B566 ,84 (2003)

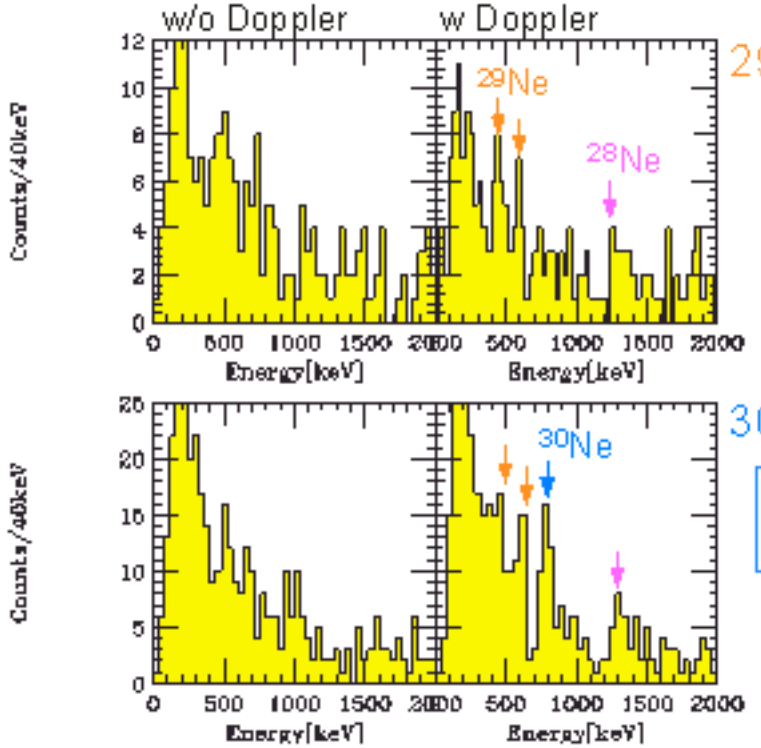
(p,p') liquid hydrogen target ~200mg/cm²

Number of target nuclei

$$\frac{t[g/cm^2]}{A} \times N_a$$

hydrogen A = 1

Pb target A = 208



^{29}Ne beam

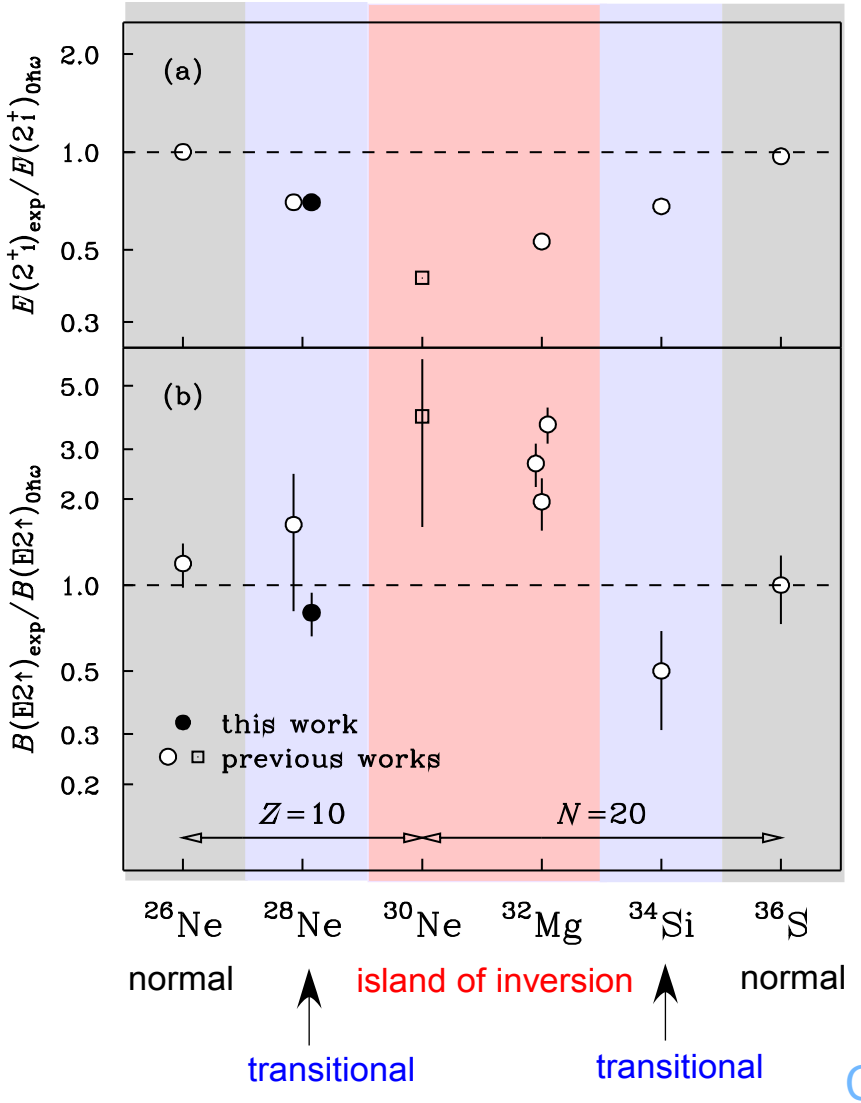
^{30}Ne beam I~0.3/sec

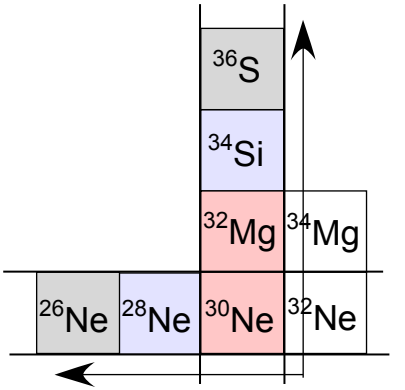
$E(2^+) = 790 \pm 10 \pm 20$ keV (stat. sys.)

cf ^{32}Mg 890 keV

model dependent B(E2)=460(270) e^2fm^4

the evolution of $E(2^+)$ and B(E2) across the region of the `island of inversion'





0hw shell model

for Ne
E.Caurier, et al. PRC58(98)2033
for N=20
R.W.Ibbotson et al. PRL80(98)2081

How does shape transition occur around the `island of inversion' ?

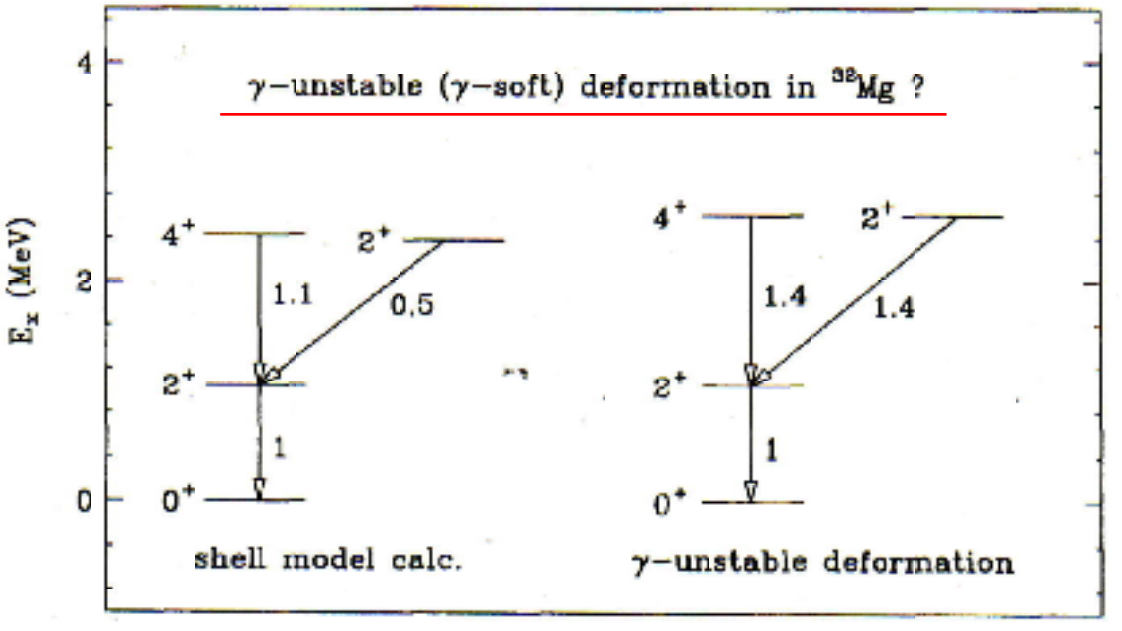


Fig. 6 Energy spectra and relative B(E2) values of ^{32}Mg. The left part is the result of the present shell model calculation [15] (see the text), while the right part is the typical pattern of the γ-unstable nucleus.

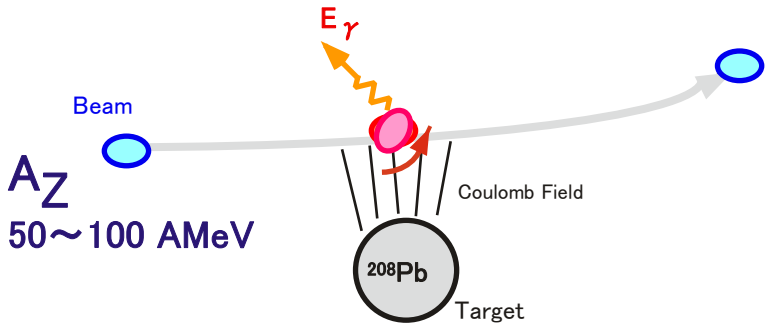
T.Otsuka NPA616(97)406c

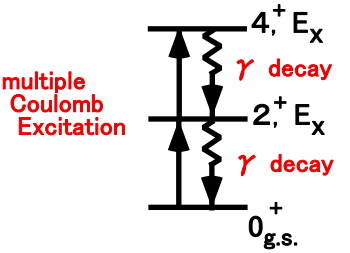
Present

Physics beyond the 2^+ state

two-step Coulomb excitation with RI beams at intermediate energies

…$2^+_{1,2}$ and 4^+_1 states in neutron-rich nuclei can be excited by heavy-ion scattering at intermediate energies





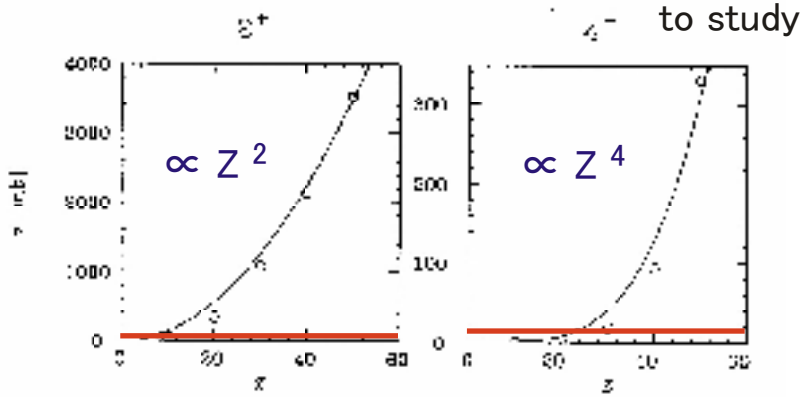
Coulomb excitation cross section σ_c

$\sigma_c(0^+ \rightarrow 2^+) \propto B(E2) \propto Z^2$

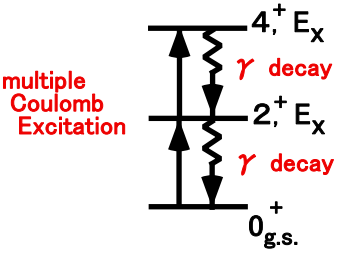
$\sigma_c(0^+ \rightarrow 2^+ \rightarrow 4^+) \propto B(E2)^2 \propto Z^4$

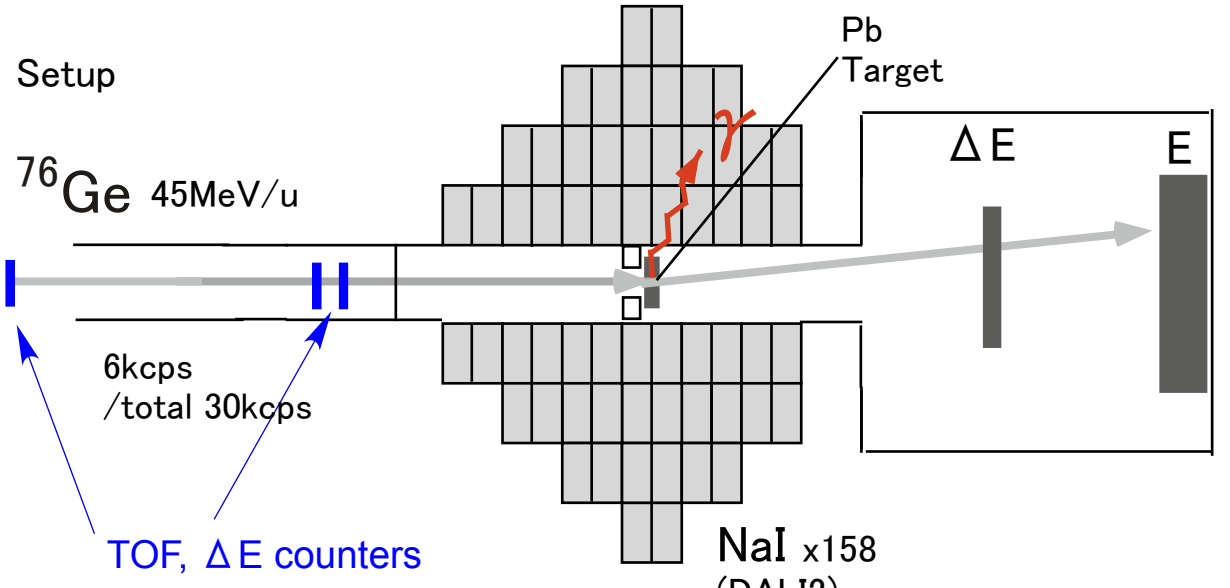
Z (β_2=0.3) + Pb 50AMeV

Z >30 possible to study 4^+ state



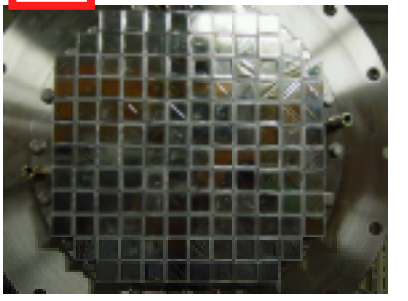
Experiment at RIPS
w/ neutron-rich Ge isotope beam





SSD x16

NaI x132



Identification of beams

TOF ∝ A/Z
ΔE ∝ Z^2/v^2 } measured by beam line counters
Bρ ∝ Av/Q
+
E ∝ Av^2 } measured by downstream NaI particle detectors

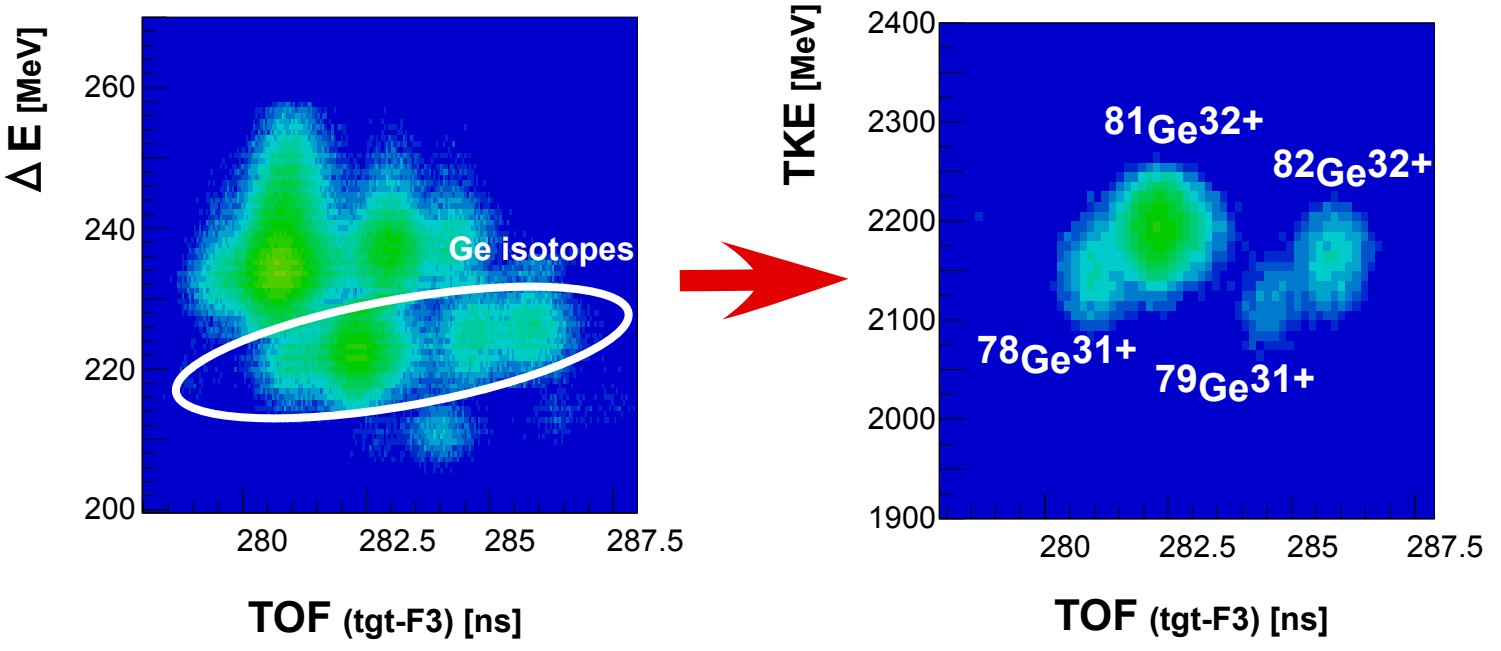
⇒ A,Z,Q

Identification of scattered paticles

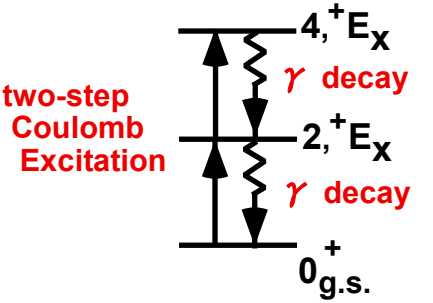
ΔE - E method
⇒ atomic number

advanced scheme of

cocktail beam (Z,A,Q)

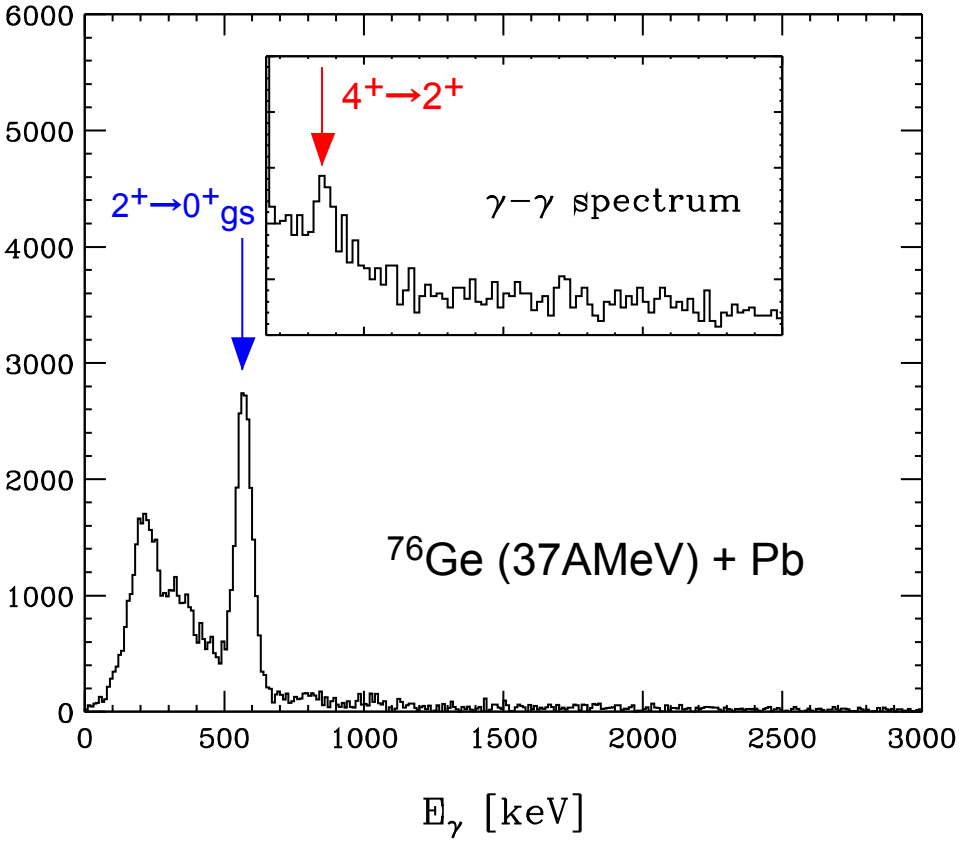


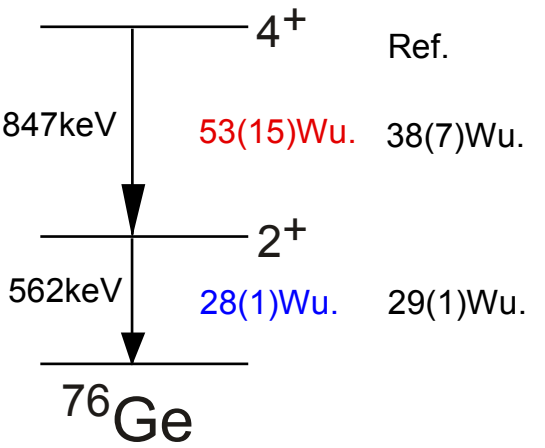
Intermediate-Energy two-step Coulomb excitation



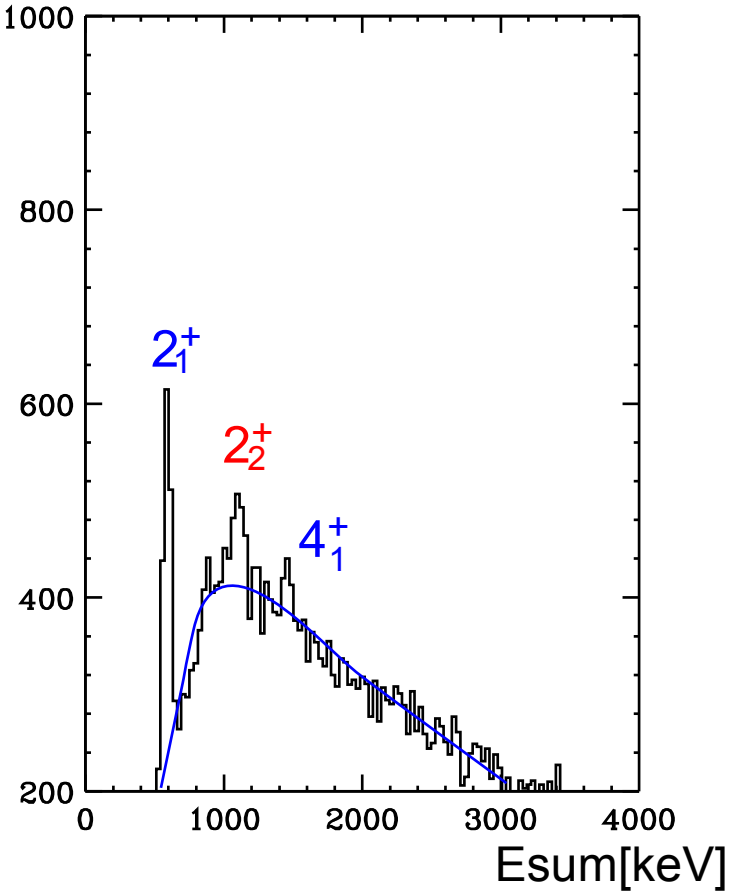
Coulex cross section σ_c

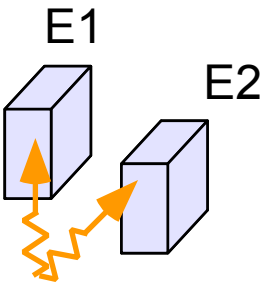
$\sigma_c(0^+ \rightarrow 2^+) \propto B(E2) \propto Z^2$, $\sigma_c(0^+ \rightarrow 2^+ \rightarrow 4^+) \propto B(E2)^2 \propto Z^4$



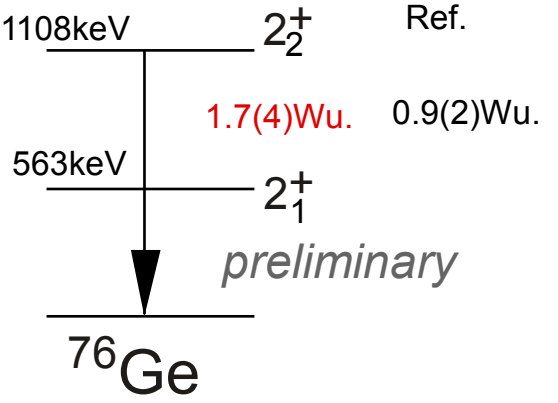


Observation of the 2^+_2 state

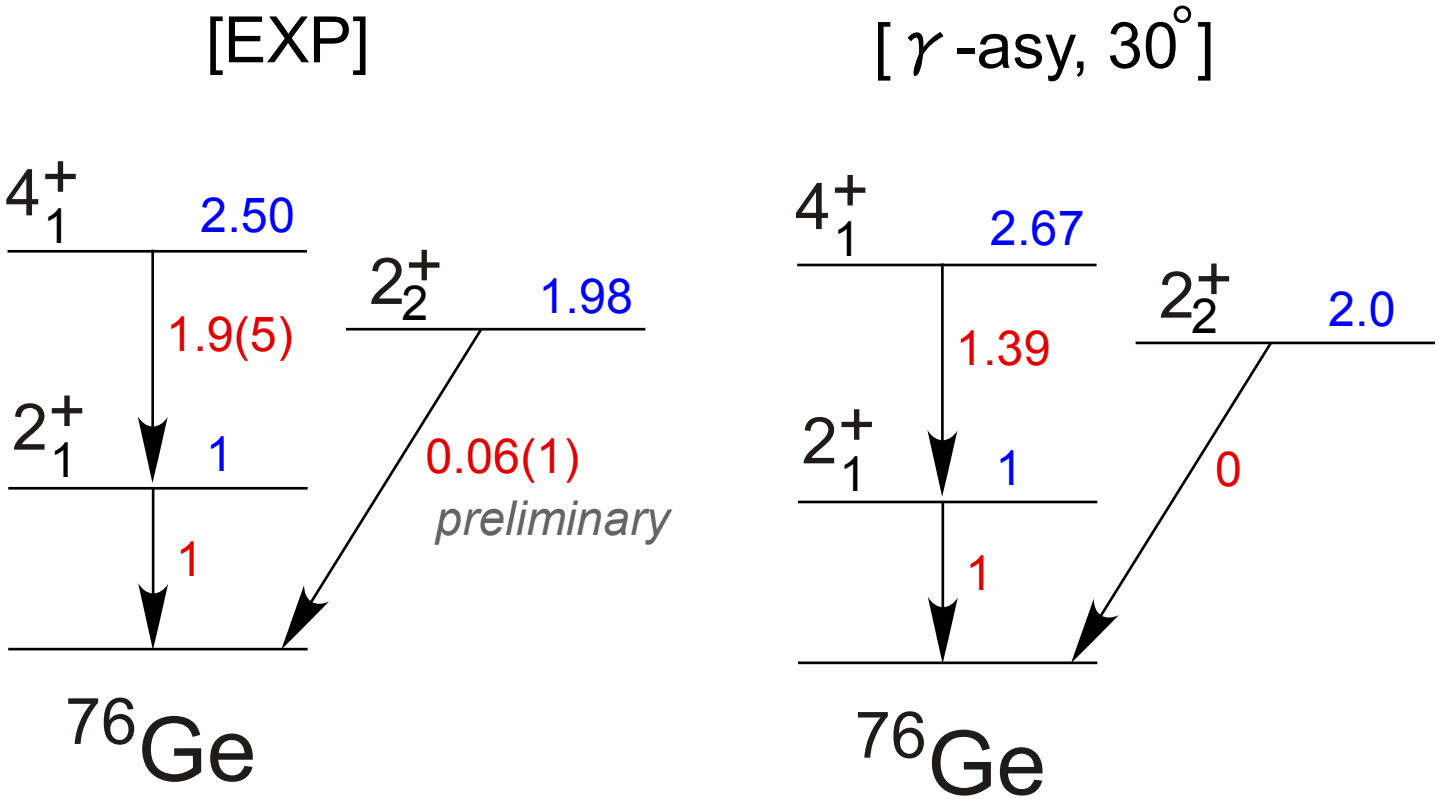




Esum = E1 + E2



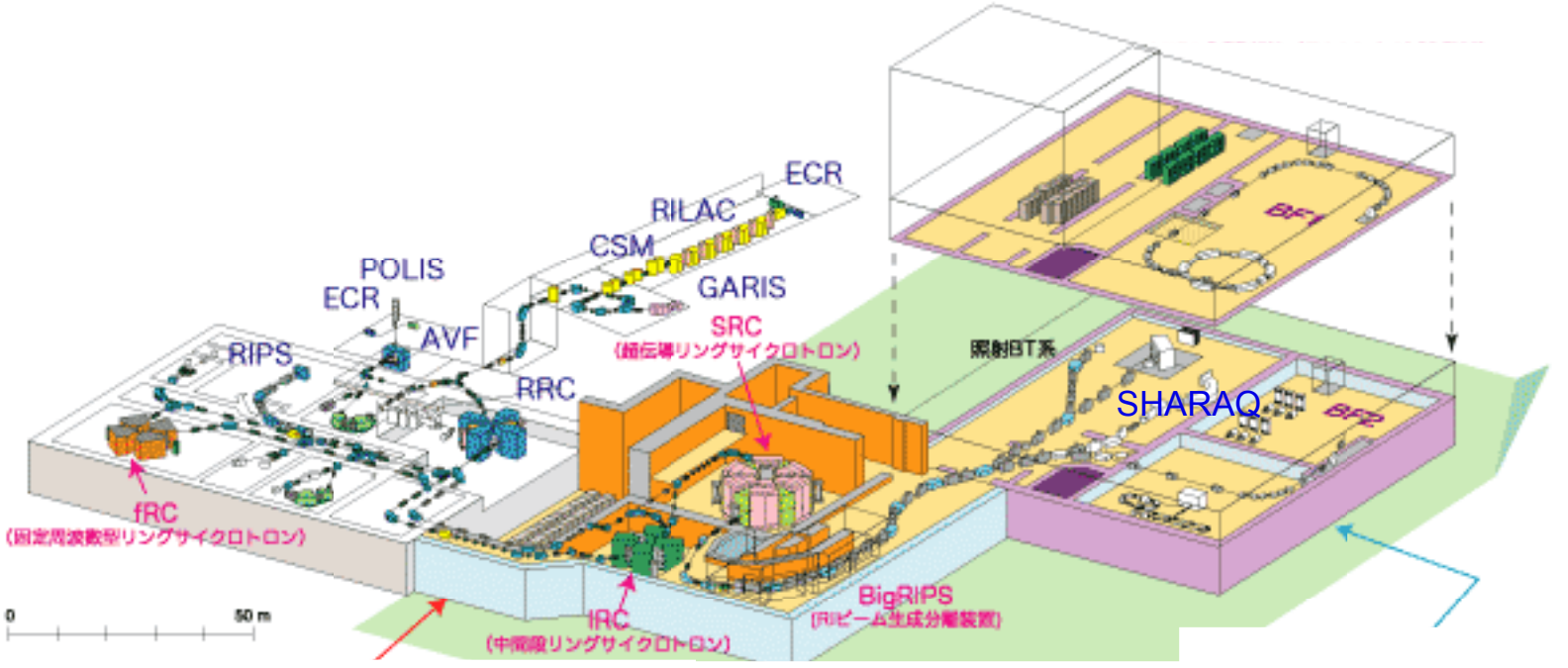
Comparison with model



Future

Physics at RIBF

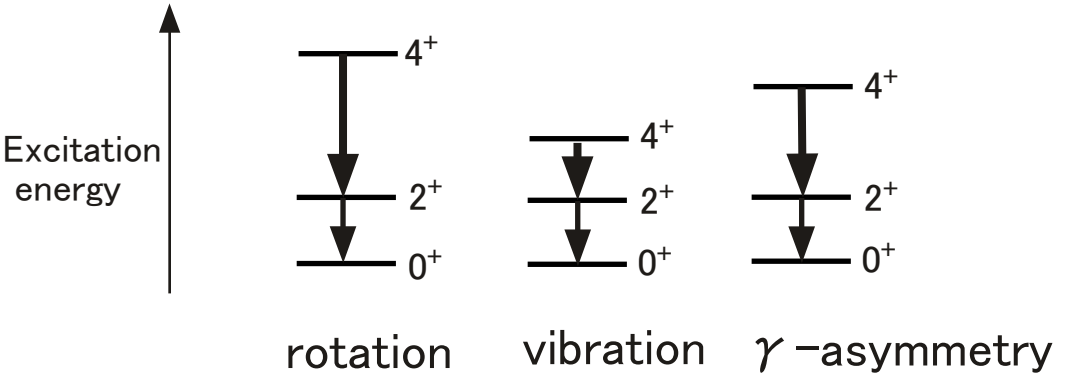
Layout of the RI Beam Factory (RIBF)



present
A<50
E/A = 50MeV

RIBF
A<200
E/A = 250MeV

How does nuclear shape changes towards the dripline ?



	rotation	vibration	γ −asymmetry
$E(4^+)/E(2^+)$	3.3	2.0	2.67
$\frac{B(E2;4^+\rightarrow 2^+)}{B(E2;2^+\rightarrow 0^+)}$	1.43	2.0	1.39

Example : Cd isotopes (Z=48)

	^{114}Cd	^{116}Cd	^{118}Cd	^{120}Cd	^{122}Cd	^{124}Cd	^{126}Cd	^{128}Cd	^{130}Cd
N =	66	68	70	72	74	76	78	80	82
$E(4^+)/E(2^+)$	2.3	2.4	2.4						
$\frac{B(E2;4^+\rightarrow 2^+)}{B(E2;2^+\rightarrow 0^+)}$	1.9	1.7	>1.8						

Summary

Past, present, and future of gamma-ray studies, to be discussed with shell model, are discussed.

It is demonstrated that
E2 properties of the 2_1^+, 2_2^+ , and 4_1^+ states
in medium-heavy n-rich nuclei can be studied via single-step and double-step Coulomb excitation at intermediate energies.