クーロン励起による質量数250領域原子核のガンマ線核分光

井手口　栄治
大阪大学・核物理研究センター

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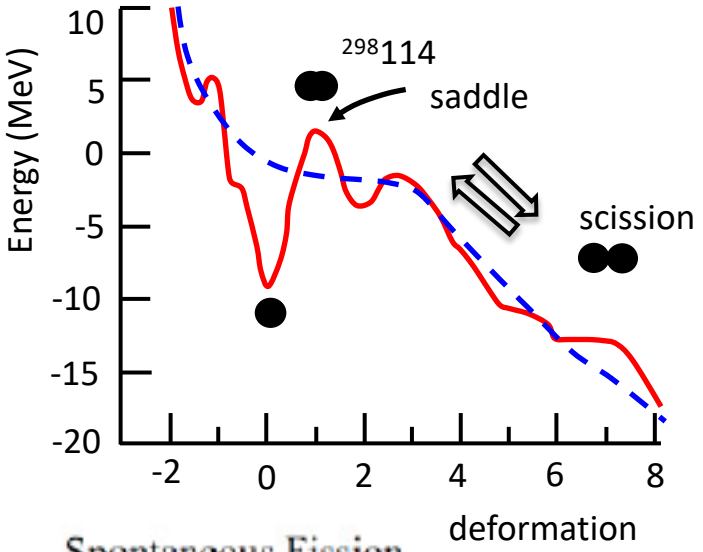
- G.de Angelis (INfN-LNL Legnaro)
- K.Rykaczewski (ORNL)

Scientific Motivation

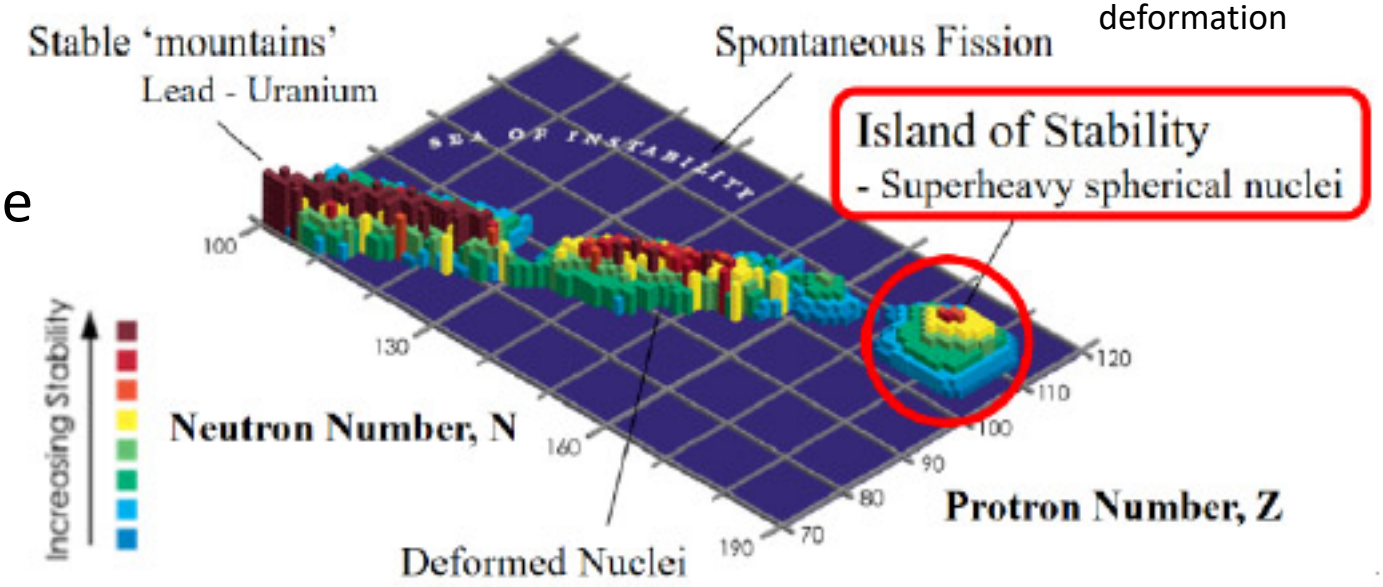
- The limit of nuclear stability

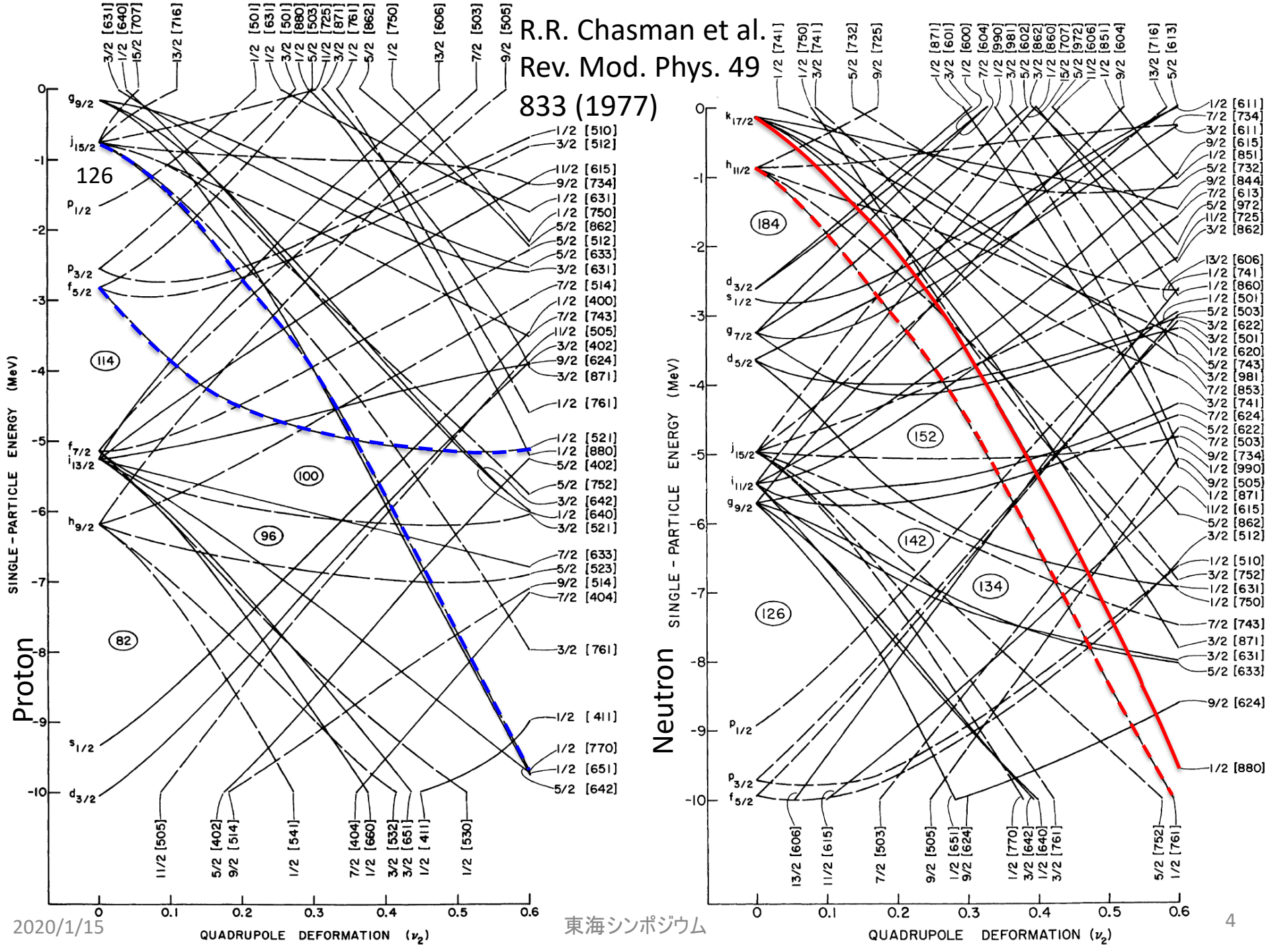
Nuclear shell structure is essential to stabilize against fission in large Z nuclei

- Predicted shell structure at Z～114, 120, 126, N～184



Single-particle structure




R.R. Chasman et al.
Rev. Mod. Phys. 49
833 (1977)
Proton
Neutron
SINGLE-PARTICLE ENERGY (MeV)
QUADRUPOLE DEFORMATION (ν_2)
126
114
100
96
82
184
152
142
134
126

Scientific Motivation

- The limit of nuclear stability
- Predicted shell structure at Z～114, 120, 126, N～184
- Single particle orbitals: $\pi f_{5/2}$, $j_{15/2}$, $\nu h_{11/2}$, $k_{17/2}$

→ lowering near Fermi surface in deformed Z～100, N～154

- ^{254}Es(Z=99, N=155) is in deformed region
- To understand shell structure, single-particle orbitals

  → systematic studies of excited levels, spin and parity, deformation

By Coulomb excitation, study excited states and deformation

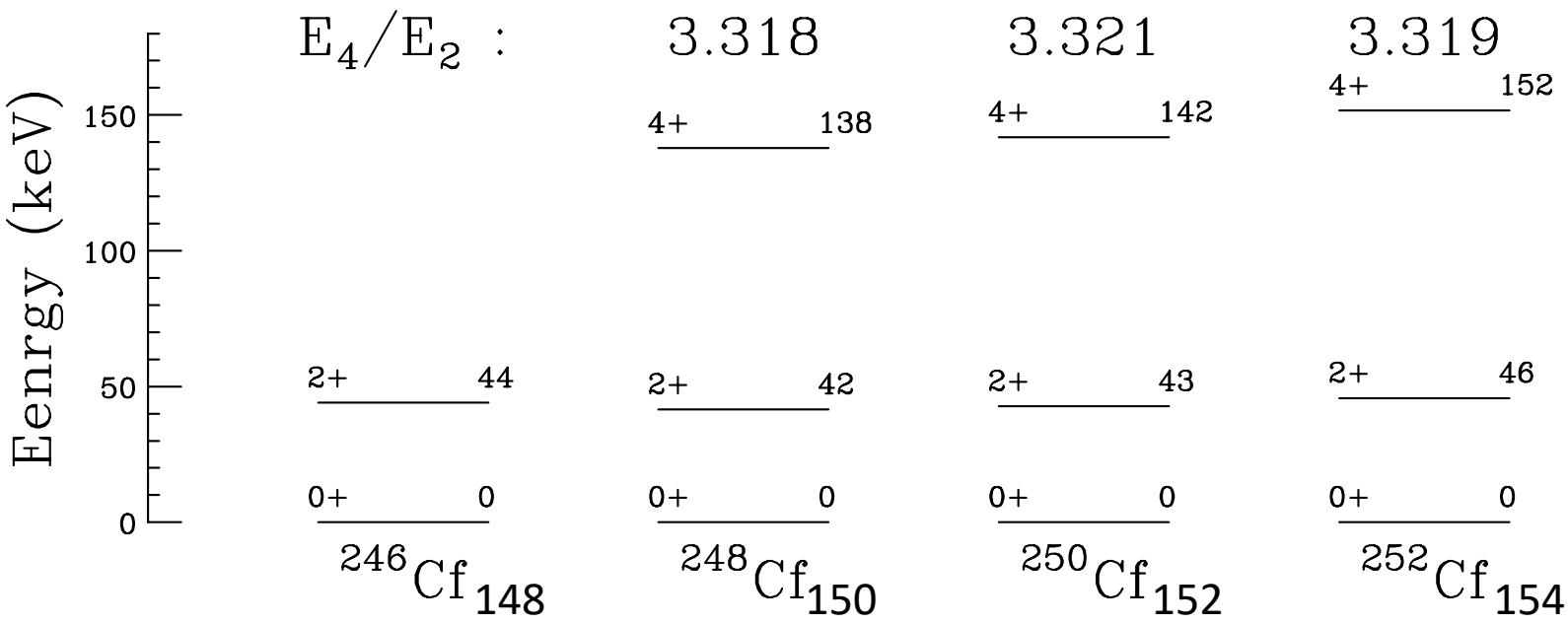
→ ^{249}Cf(Z=98,N=151) as one of systematic studies in this region

^{254}Es Coulex will be performed soon

Systematics of Cf isotopes

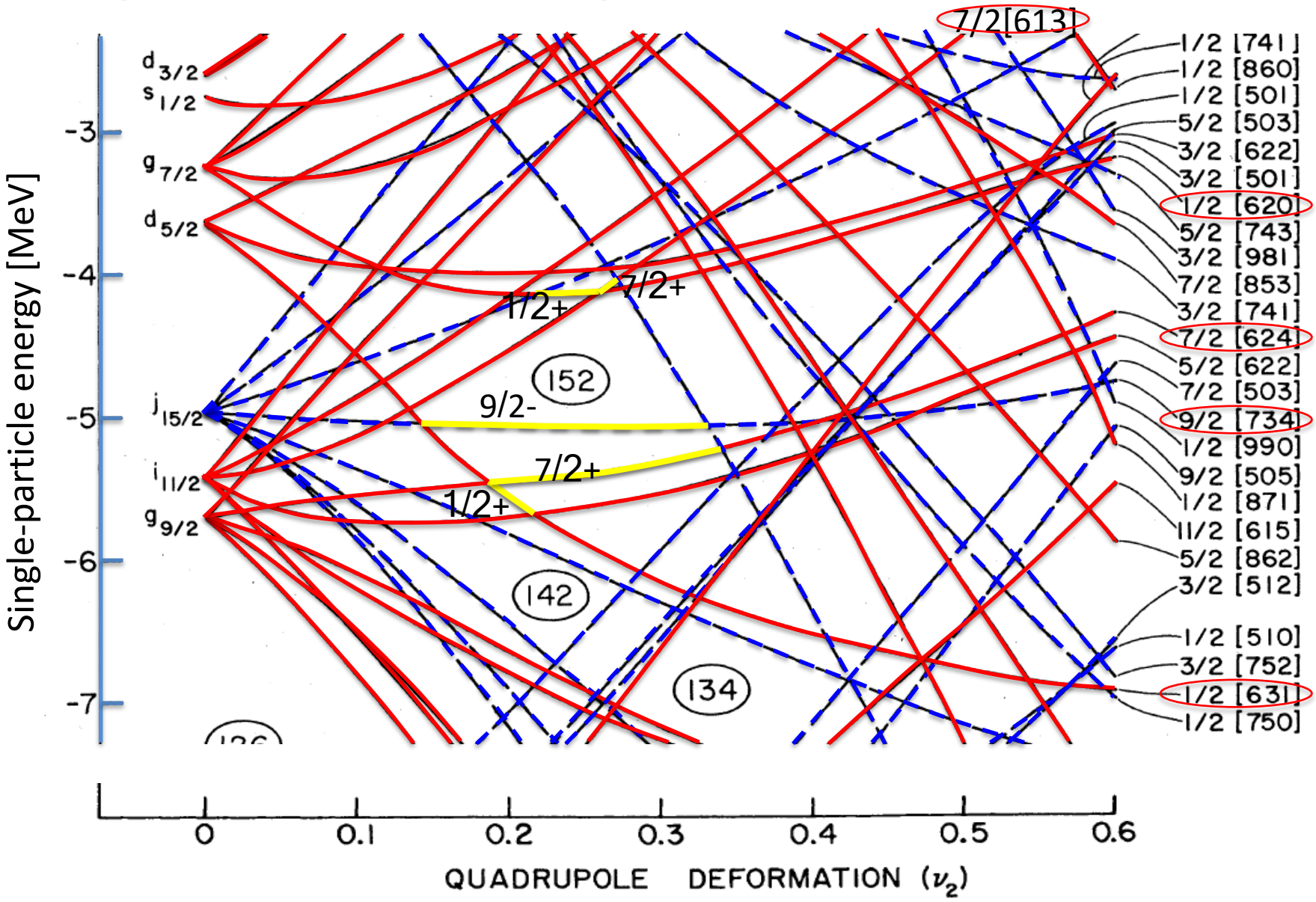
$^{245}Cf_{147}$ $^{247}Cf_{149}$ $^{249}Cf_{151}$ $^{251}Cf_{153}$ $^{253}Cf_{155}$

$1/2^+$ $(7/2^+)$ $9/2^-$ $1/2^+$ $(7/2^+)$

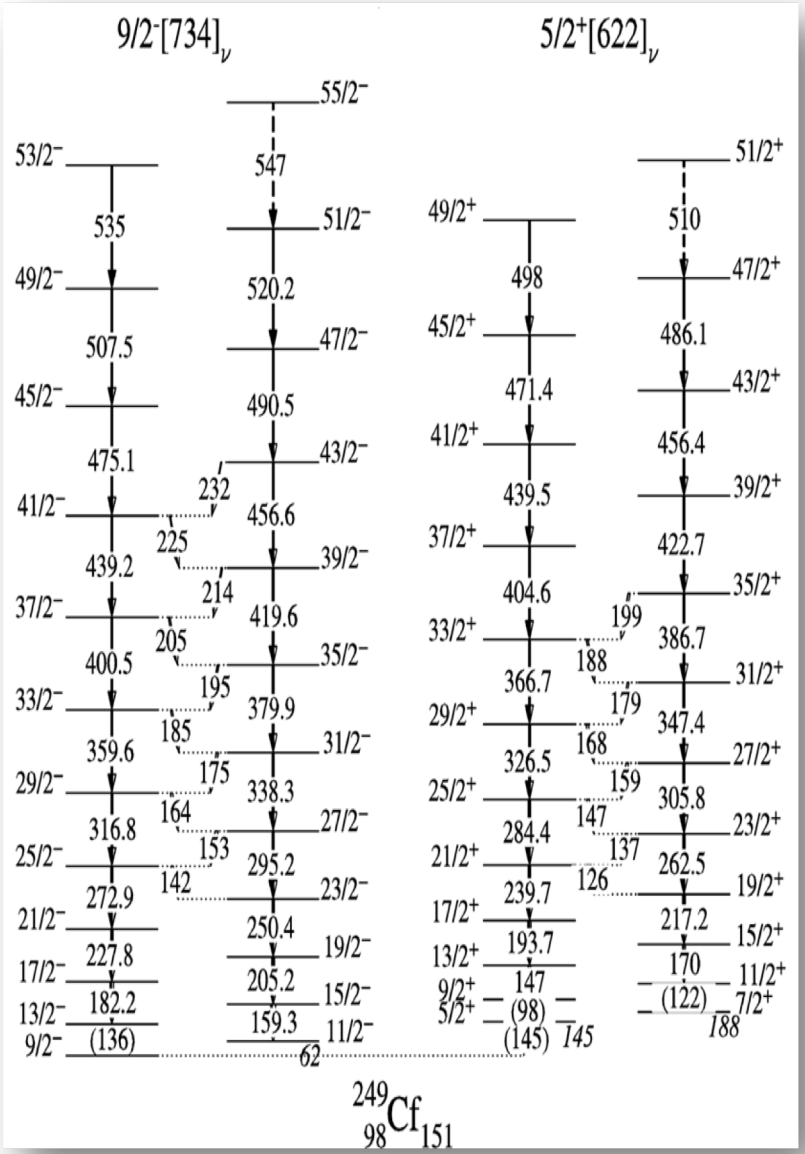


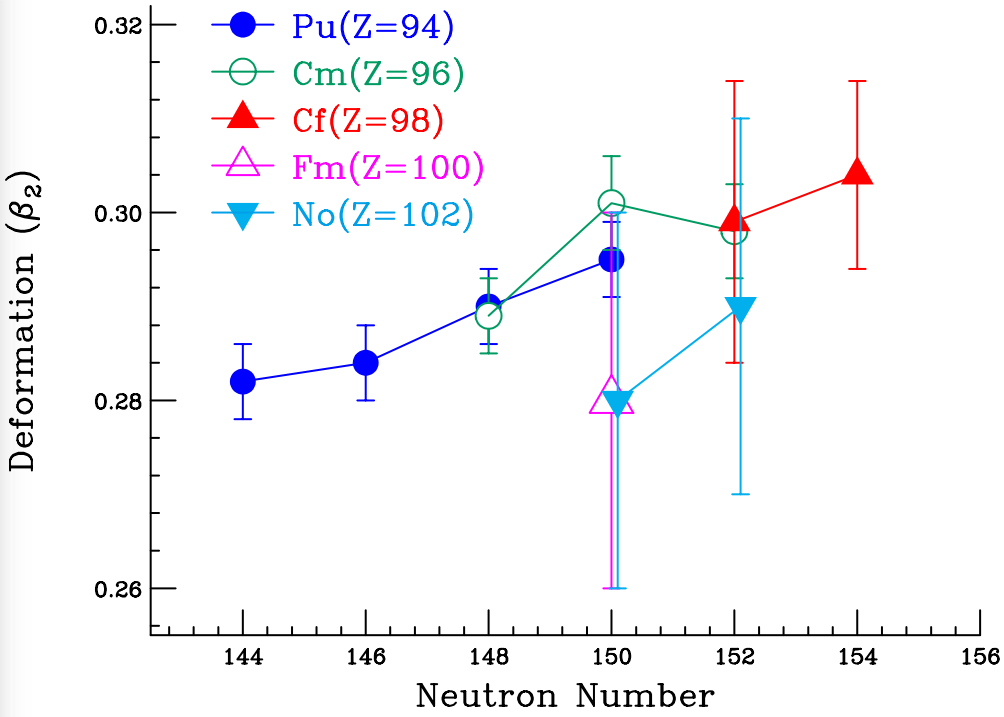
Single-particle diagram

R.R. Chasman et al.
Rev. Mod. Phys. 49, 833 (1977)



^{249}Cf(Z=98,N=151)





From B(E2)
→the quadrupole deformation of ^{249}Cf.

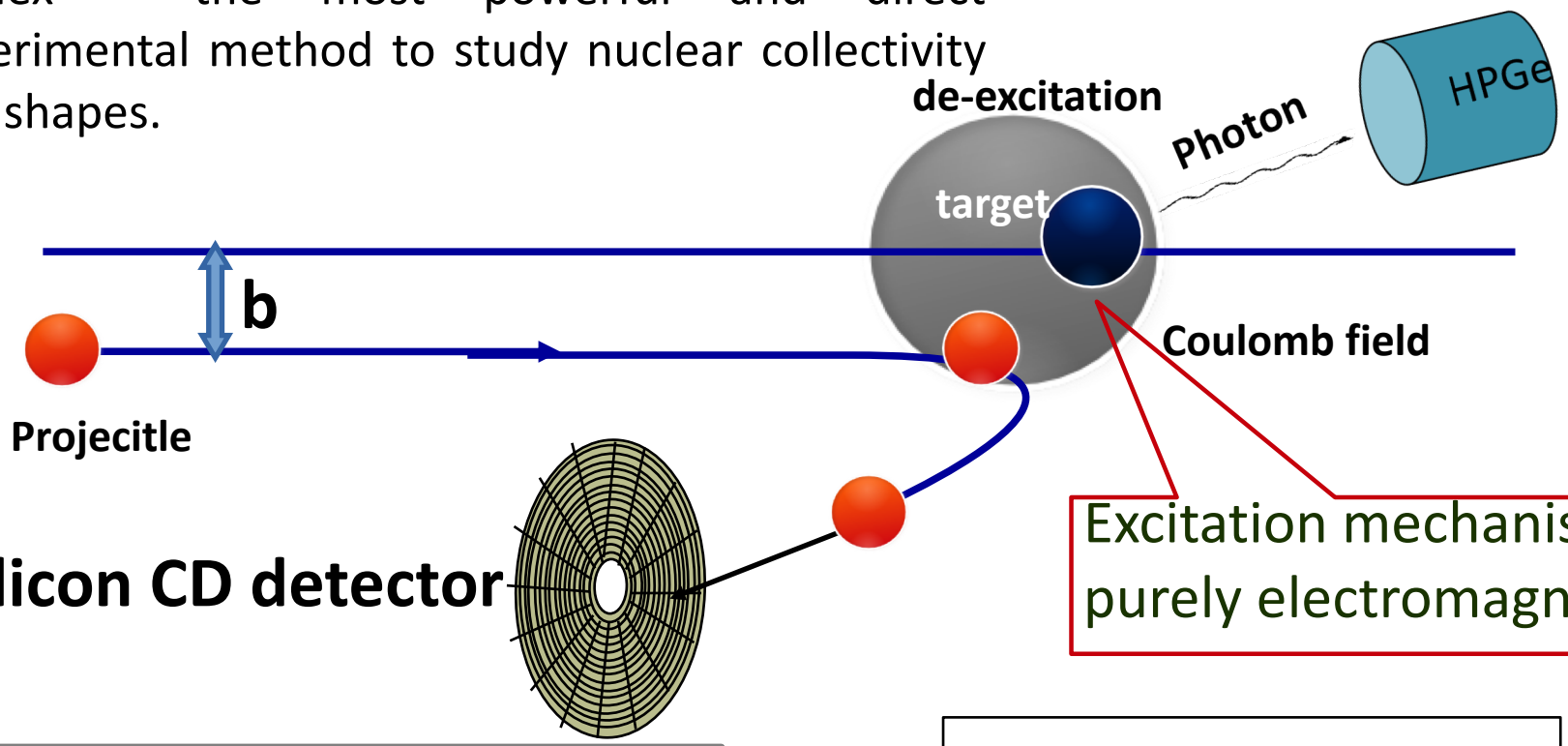
Fm, No: E(2+) energy
→ Grodzins systematics:$\tau \propto E^{-4}Z^{-2}A$ → β_2
PRC73, 024308, PRC65, 014303

S.S. Hota, et al., Phys. Lett. B 739 (2014) 13

^{249}Cf+^{208}Pb $\nu j_{15/2}$ band

Coulomb excitation (particle-gamma coincidence)

Coulex – the most powerful and direct experimental method to study nuclear collectivity and shapes.



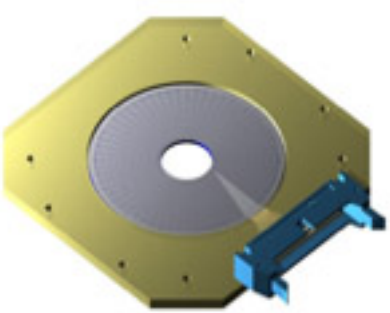
Excitation mechanism – purely electromagnetic

$$E_b(\theta_{cm}) = 0.72 \cdot \frac{Z_p Z_T}{D_{min}} \cdot \frac{A_p + A_t}{A_t} \cdot \left[1 + \frac{1}{\sin\left(\frac{\theta_{cm}}{2}\right)}\right] [\mathrm{MeV}]$$

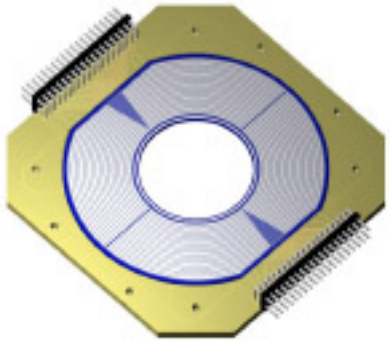
"safe" energy
70MeV(^{18}O)
225MeV (^{58}Ni)

Detector system

Distance to the target : 20 mm
Forward : 16 rings (50^o – 67^o)
Backward : 15/24 (120^o – 135^o)

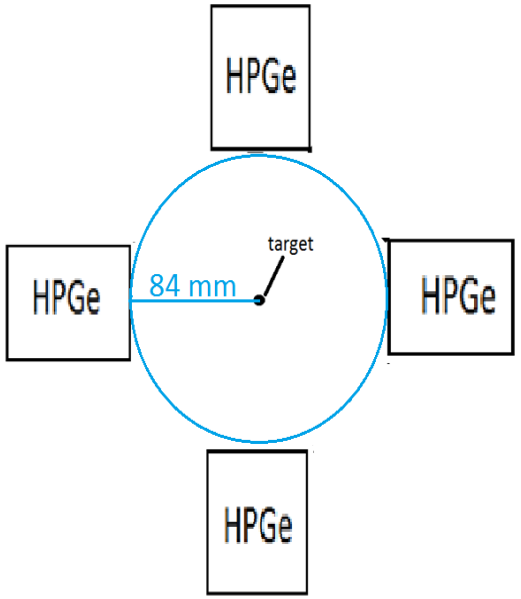


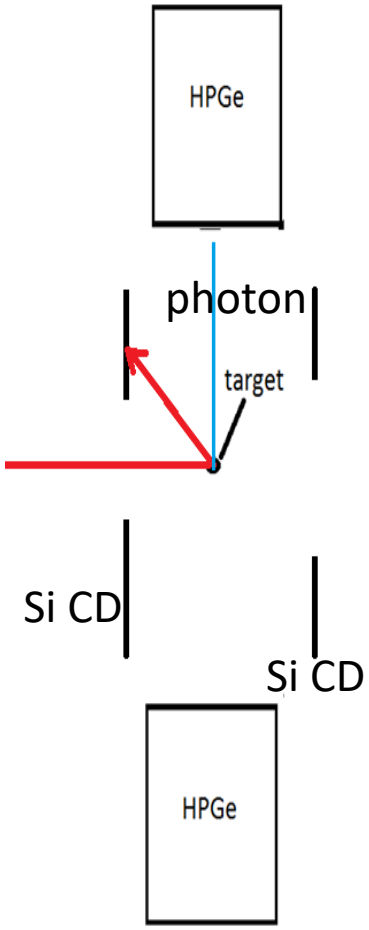
Backward



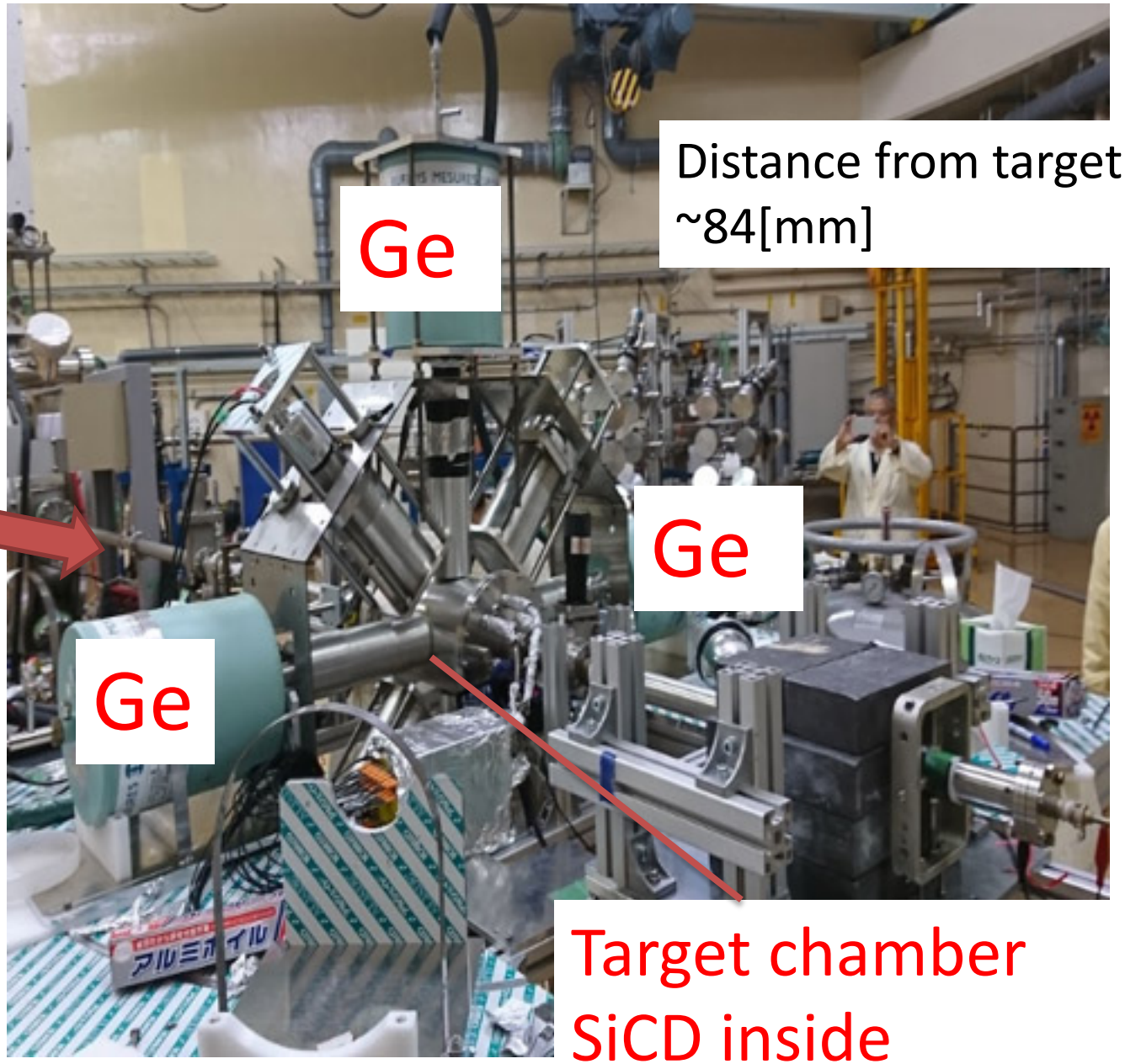
Forward

4 HPGe detectors
Φ66.1mm x 75.2 mm



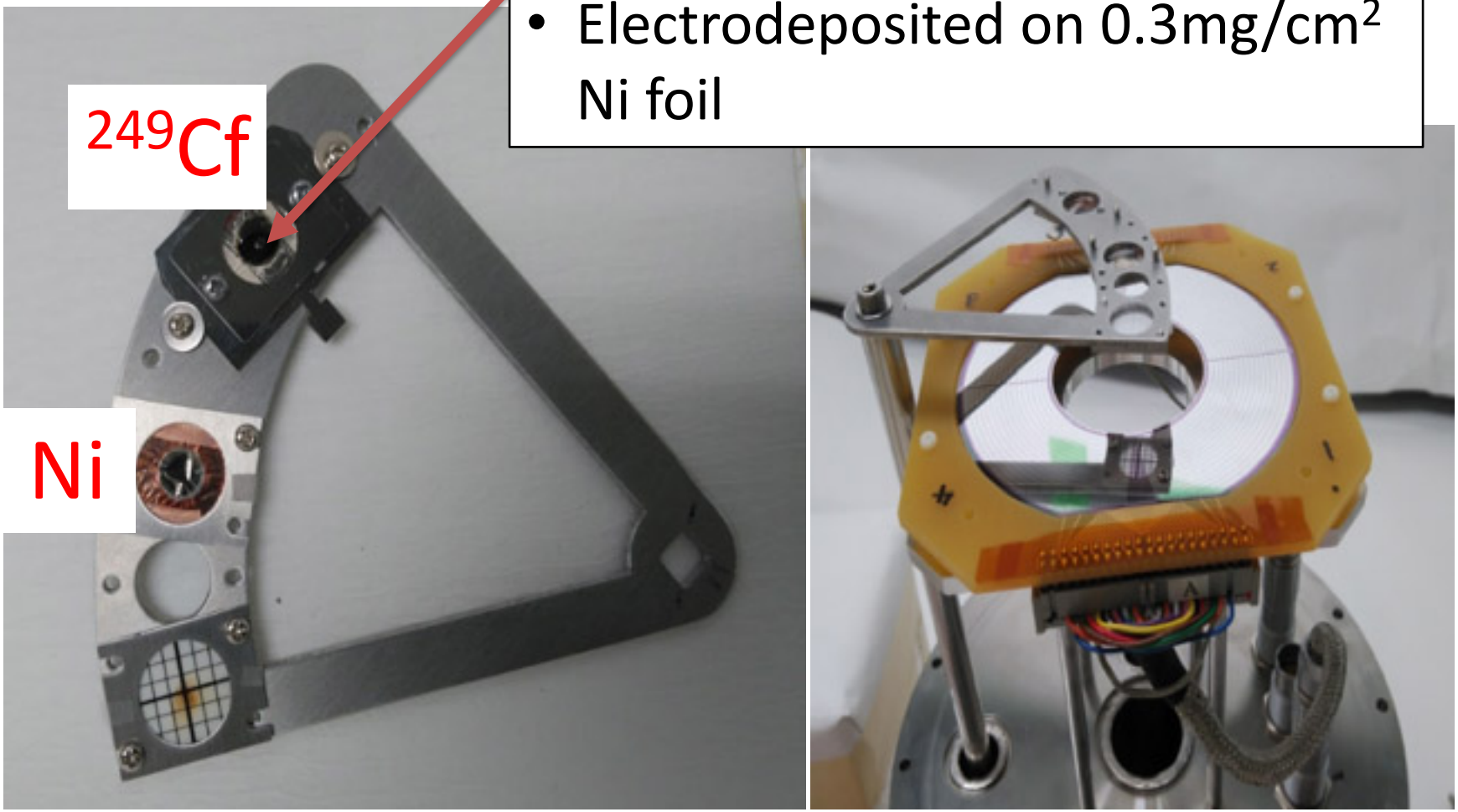


Scheme of detector system


Distance from target to Ge:
~84[mm]
Ge
Ge
Ge
Beam
Target chamber
SiCD inside

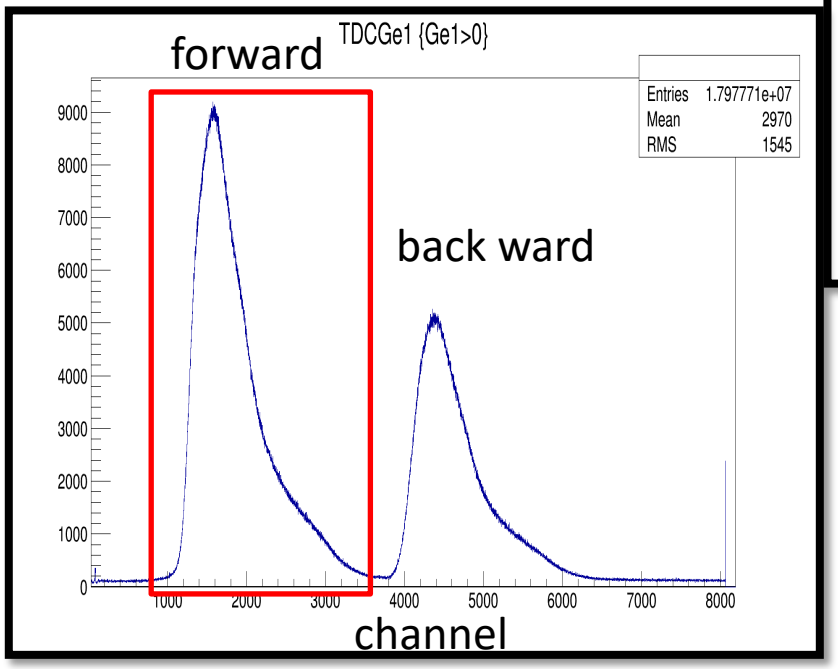
^{249}Cf Target

- 1mm diameter、
- 20μg/cm^2 thickness
- Electrodeposited on 0.3mg/cm^2 Ni foil



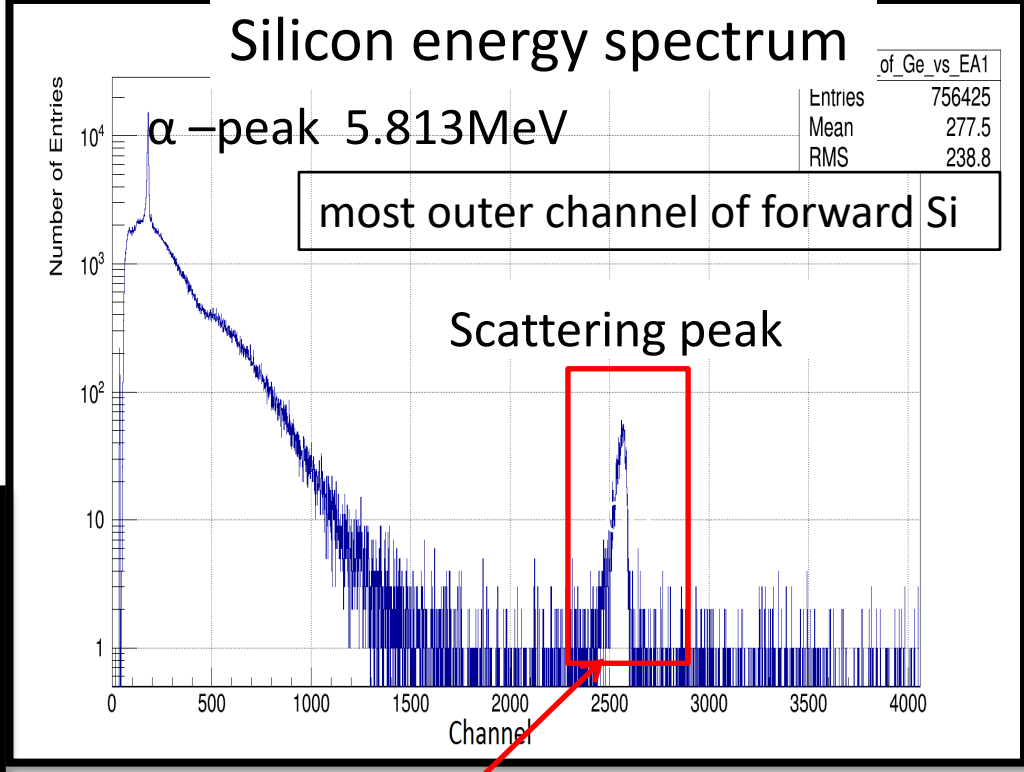
Particle-gamma coincidence analysis

Ge-Si TDC spectrum

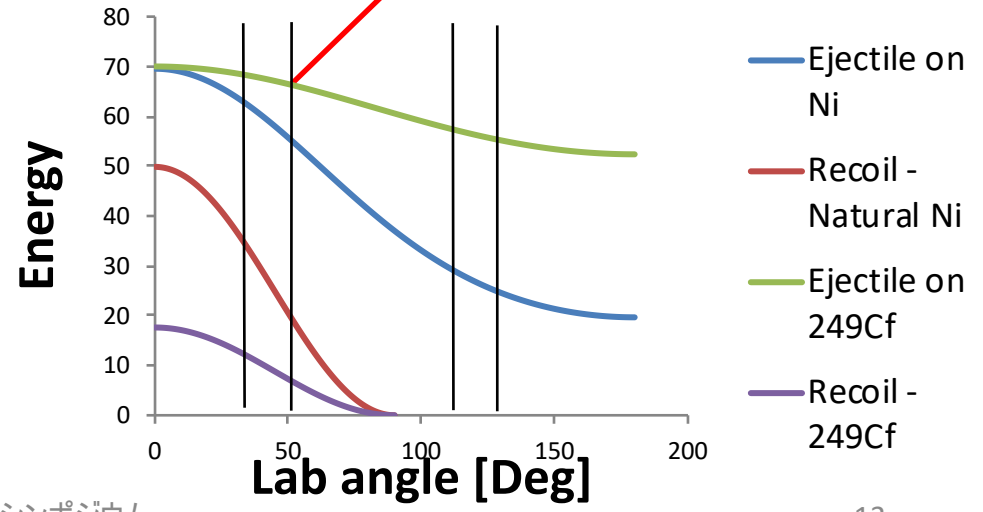


TDC range is 800ns with resolution of 8192 channels.

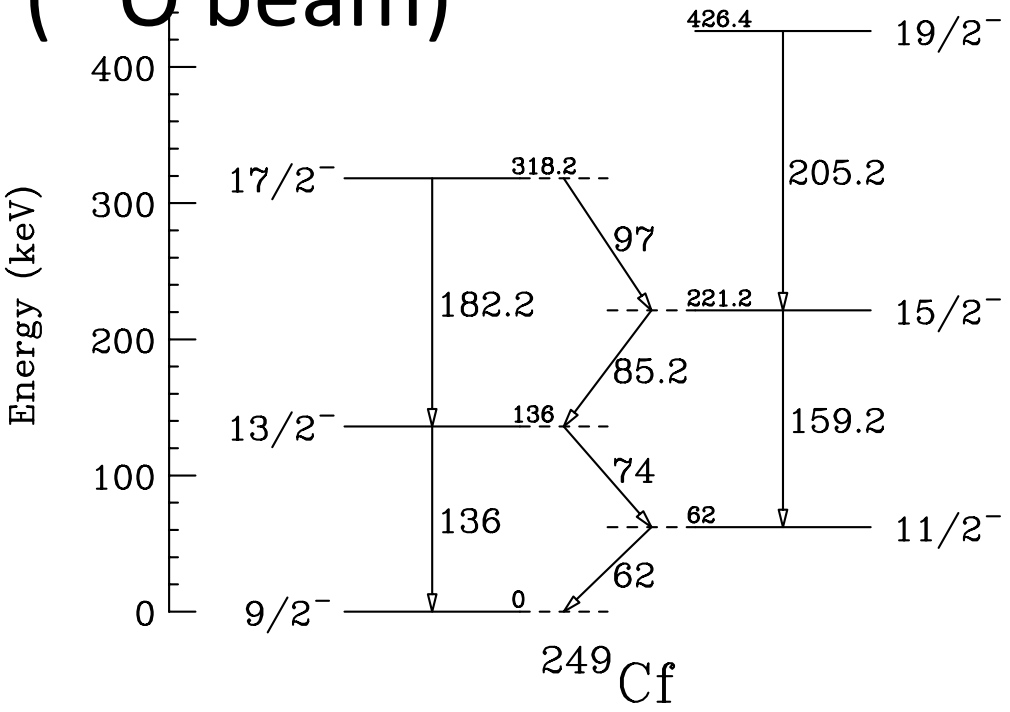
Silicon energy spectrum

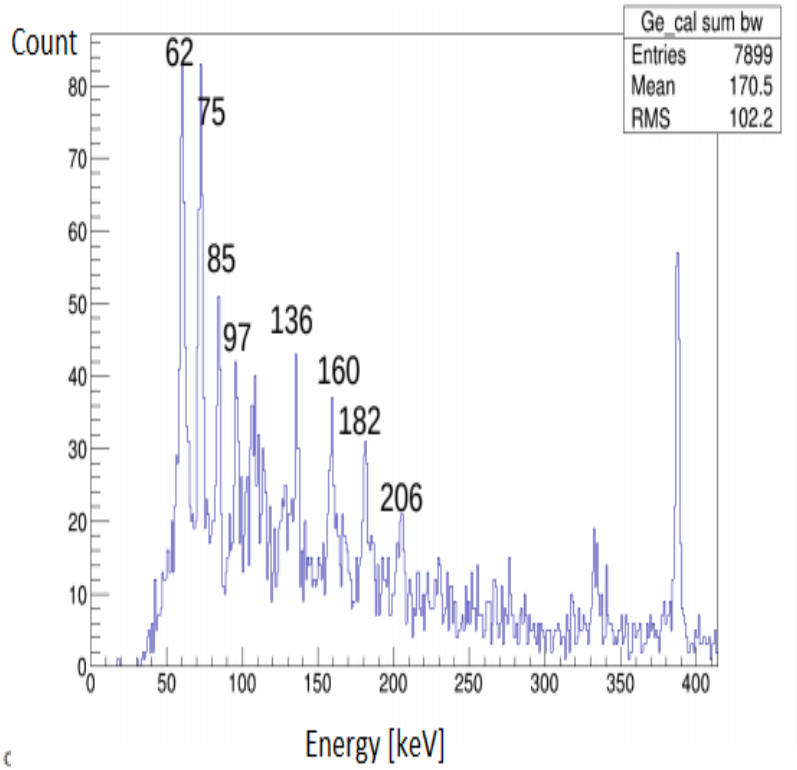


Energy calculation



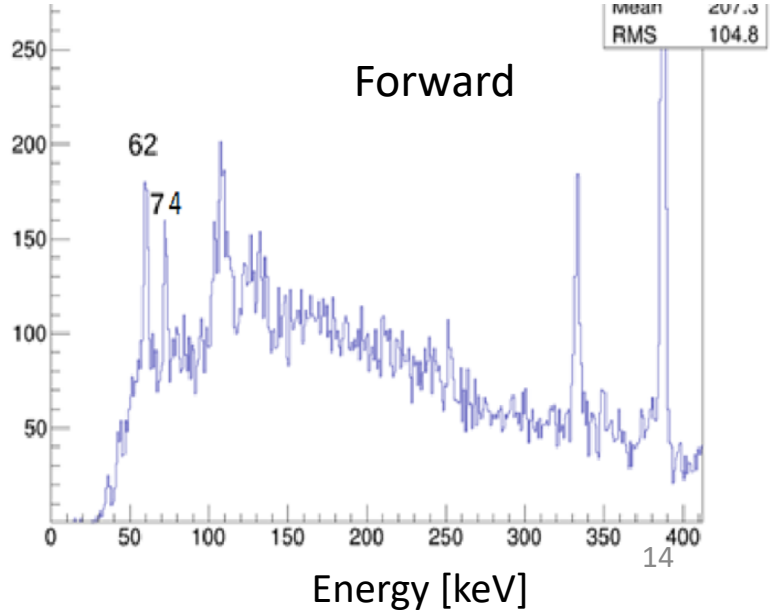
Gamma-ray spectrum (^{18}O beam)





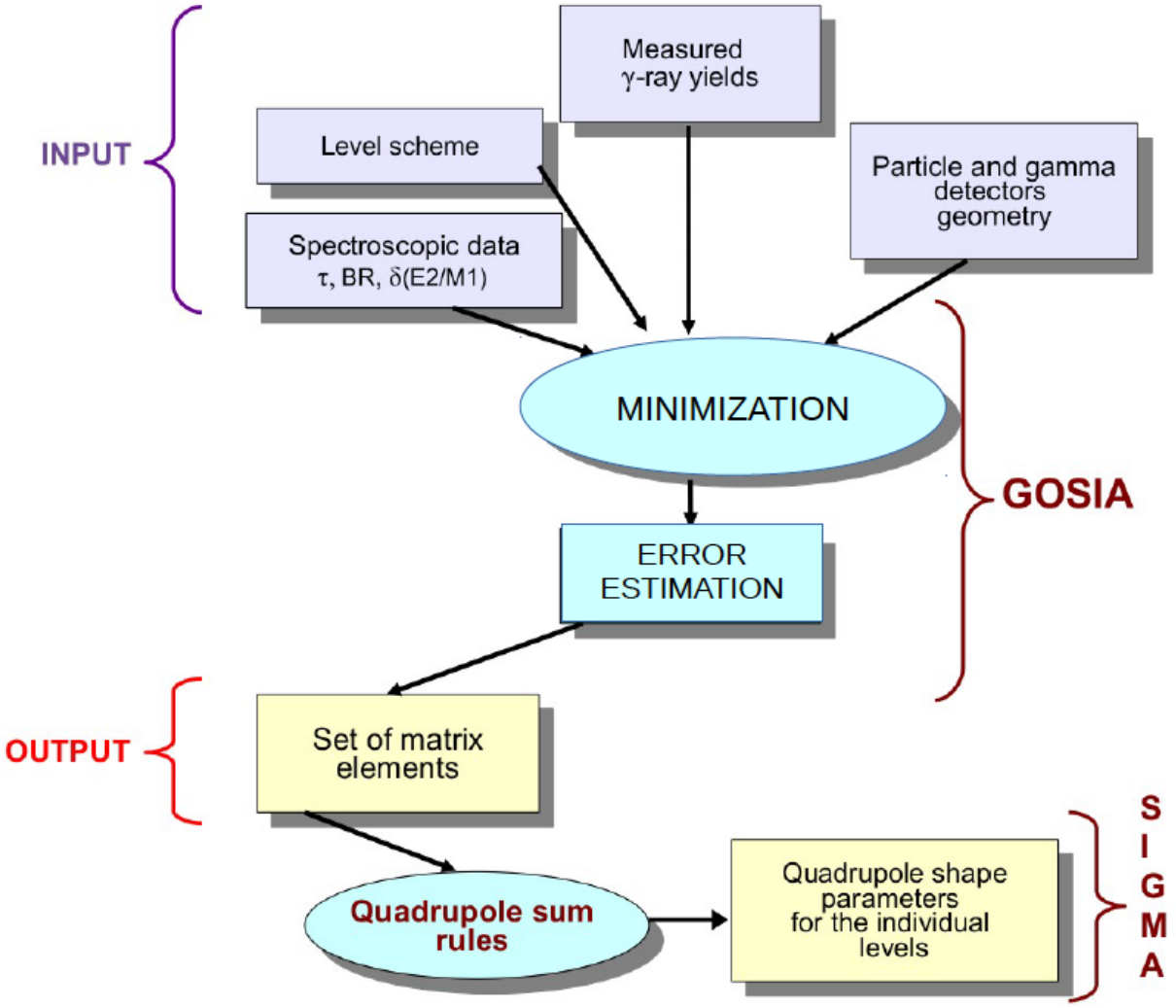
Experimental intensity: 74 keV, 136 keV, 182 keV
Branching ratio : 74 keV / 136 keV

GOSIA input to deduce matrix element and deformation



GOSIA

T. Czosnyka, D. Cline, C.Y. Wu – Am. Phys. Soc. 28:745 (1983)

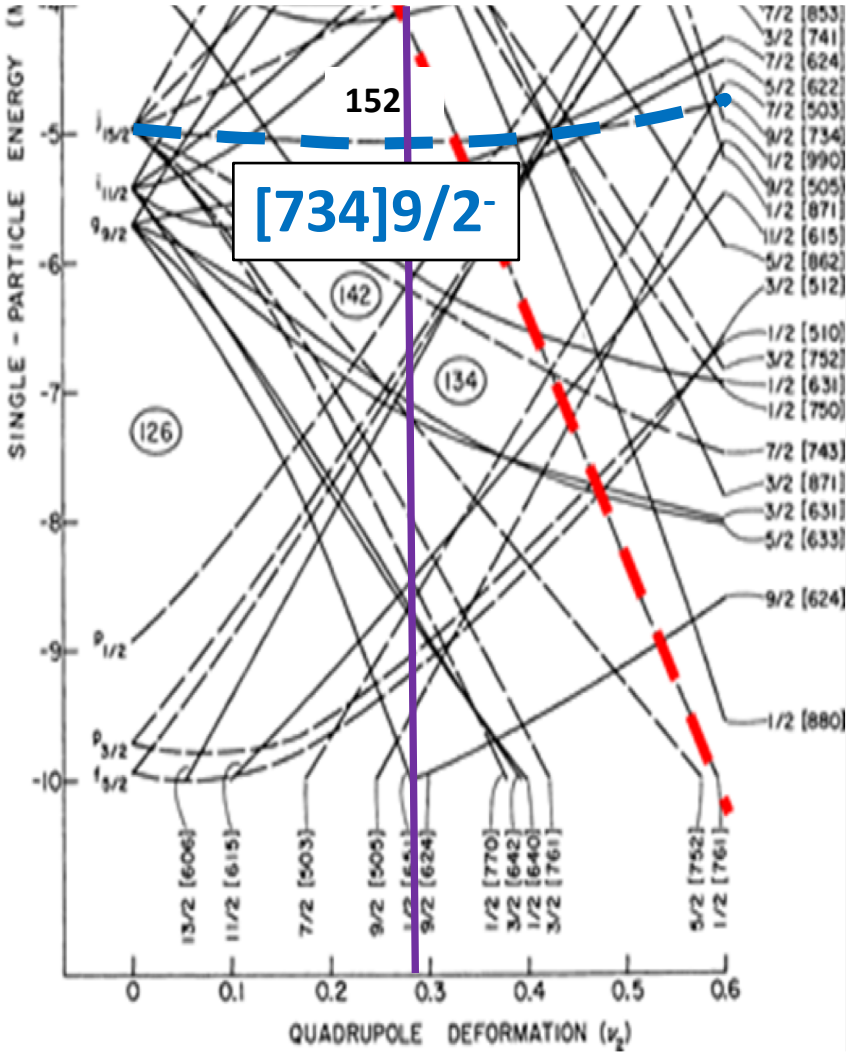


Result

$$\beta = 4\pi/(3ZR^2)\left[\frac{B(E2)_{\uparrow}}{e^2}\right]^{1/2}$$

where $R^2 = (1.2 * 10^{-13} A^{\frac{1}{3}} \mathrm{cm})^2$

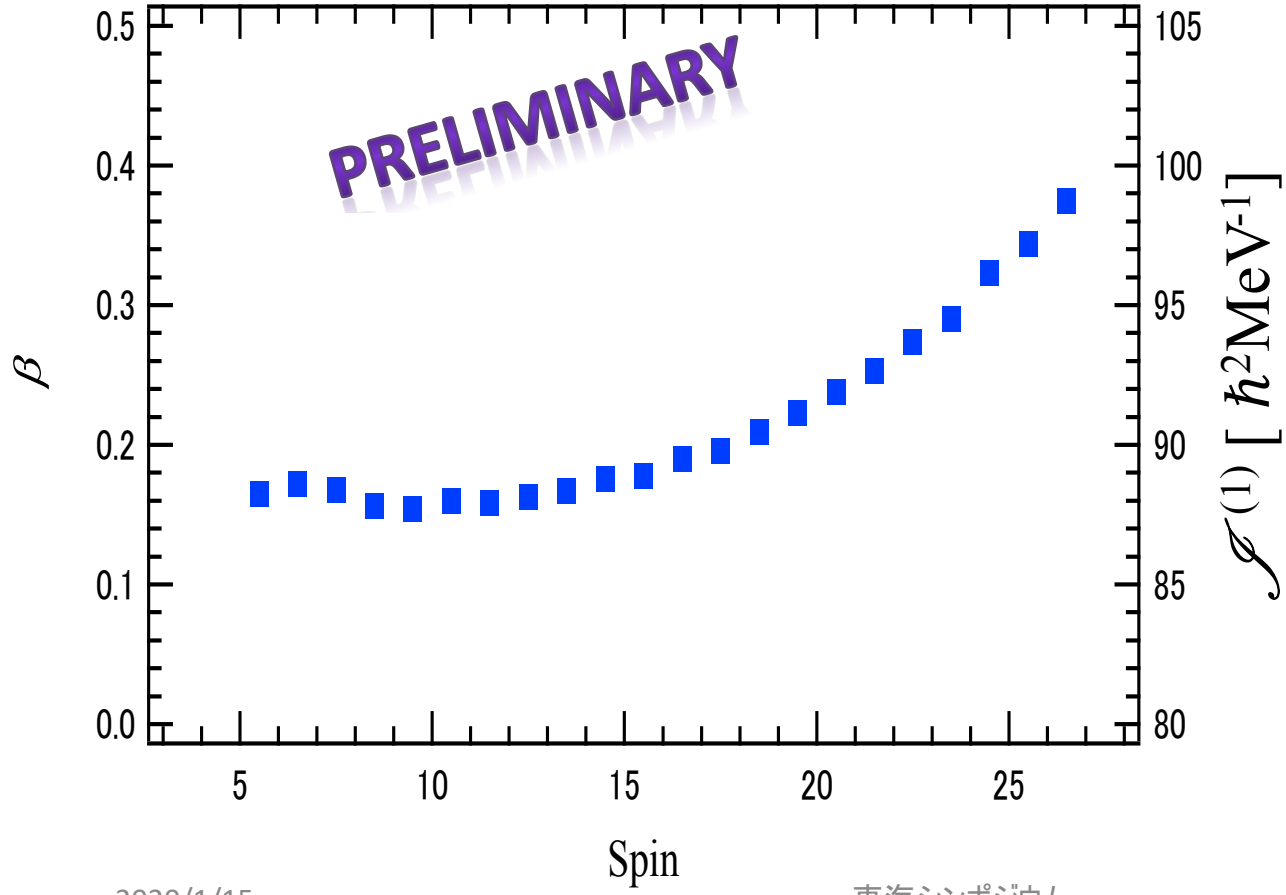
$= 0.0144 A^{2/3}\ \mathrm{b}$



Quadrupole deformation, Moment of inertia

Red: quadrupole deformation (left)
Blue: Moment of inertia (right)

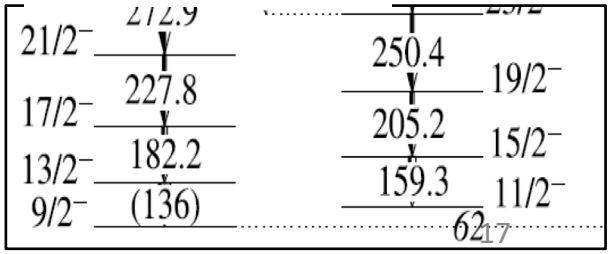
$$J^{(1)}(I-1)/\hbar^2 = \frac{2I-1}{E_\gamma(I \to I-2)}$$



Cranked Shell Model
Z.H.Zhang et al.:PRC83
Upbending due to πi13/2 proton alignment

$(\varepsilon_2, \varepsilon_4) = (0.248, 0.008)$

Exp.:



Summary

- Successfully performed Coulomb excitation gamma-ray spectroscopy of ^{249}Cf for the first time
- Analyzed the experimental intensity and branching ratio of low-lying states in ^{249}Cf using ^{18}O beam Coulex
- Higher-spin states studied by ^{58}Ni beam Coulex
-
-
- ^{254}Es Coulex is planned

  using CAGRA clover Ge detectors

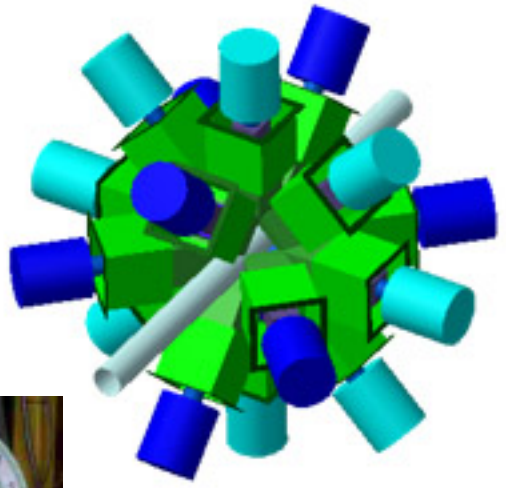
CAGRA array

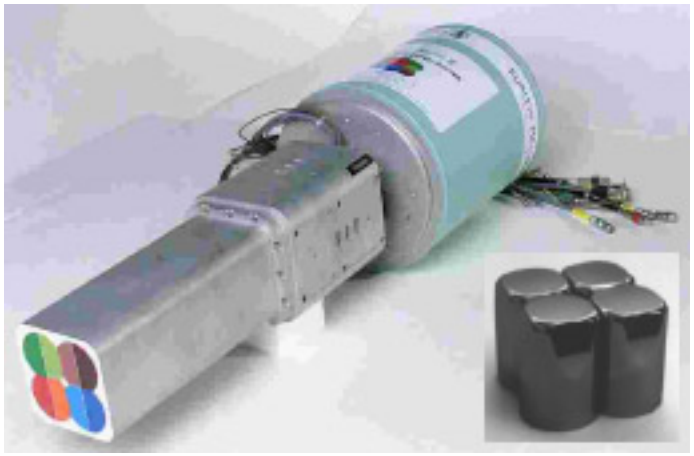
Clover **A**rray **G**amma spectrometer
at **R**CNP/RIBF for **A**dvanced research

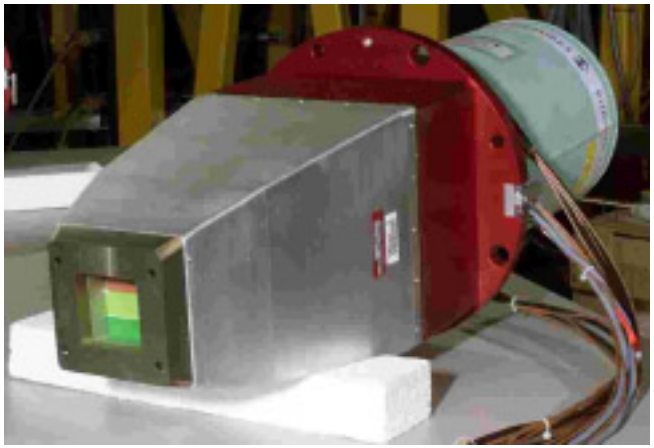
Construct Clover Array by US-Japan-China International collaboration

US(CloverShare) 10 set
Tohoku 6 set
＋
China（IMP) 3detectors

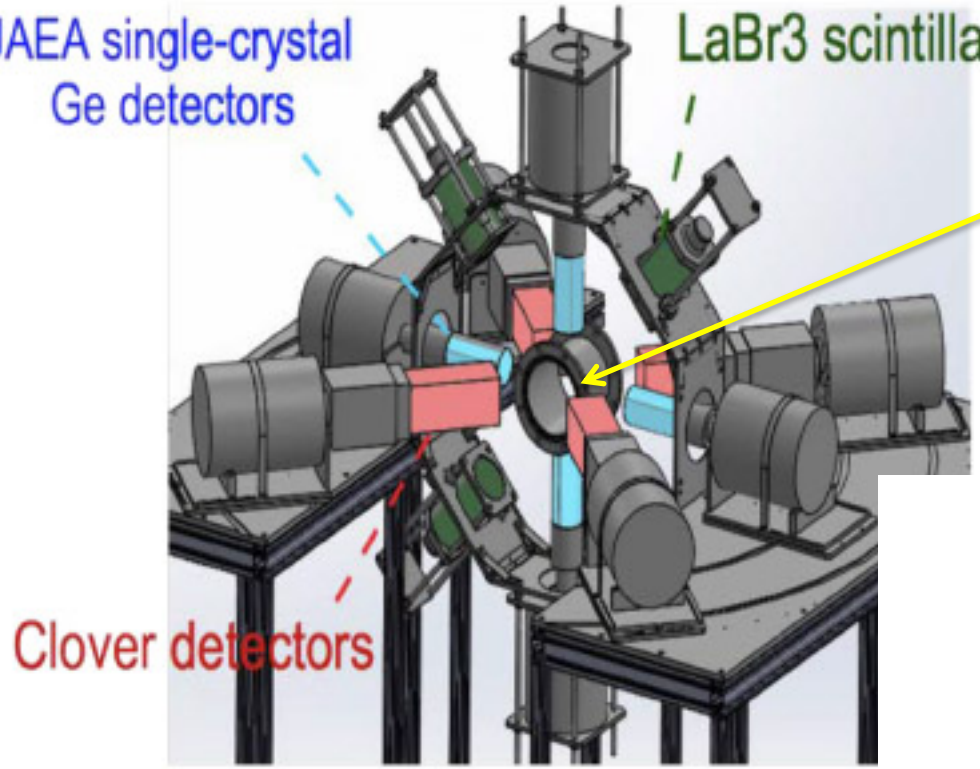
→ 16 BGOACS
Clover Ge Array

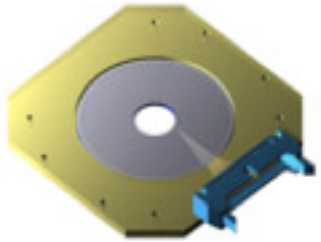


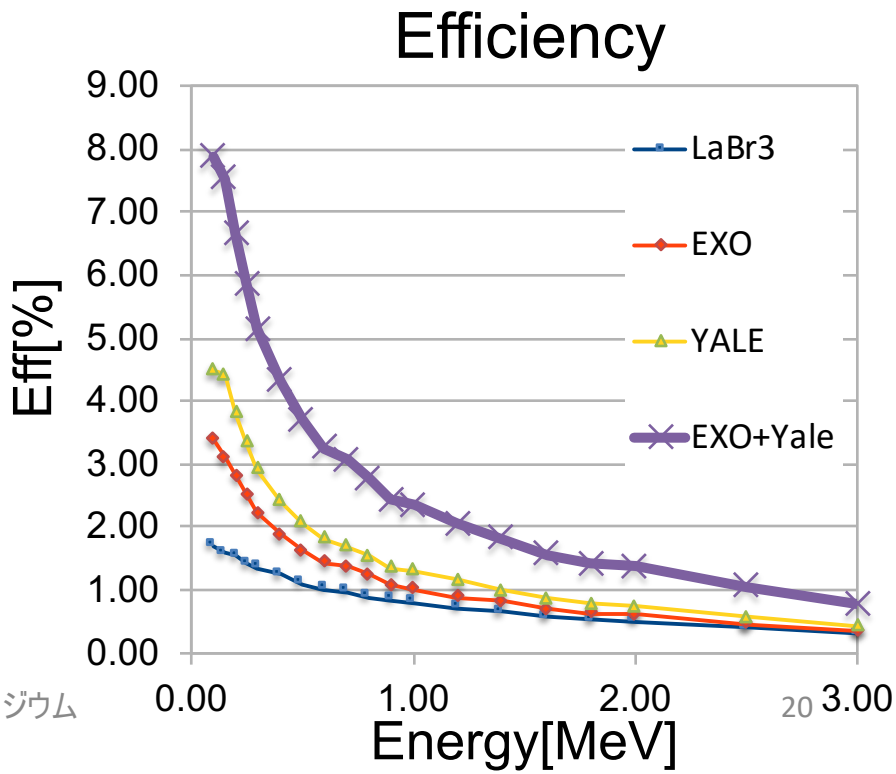


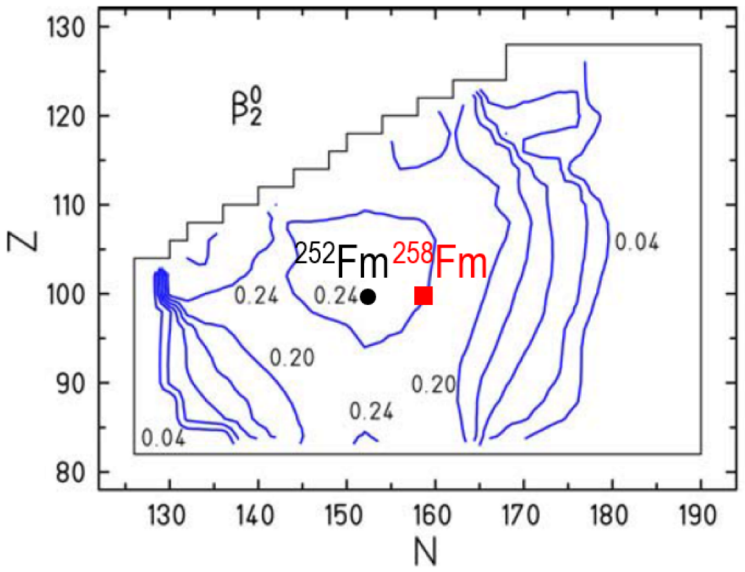


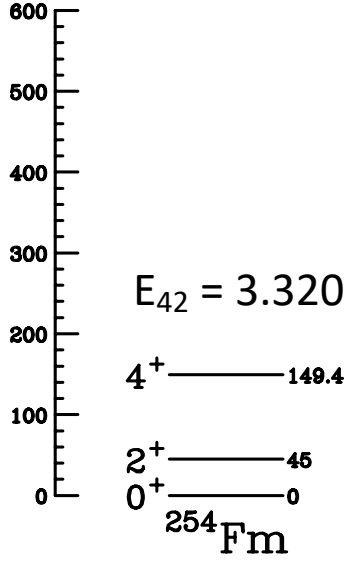
Experimental setup using CAGRA

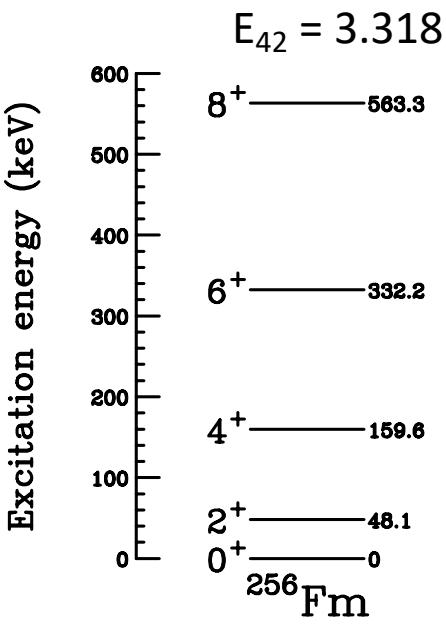


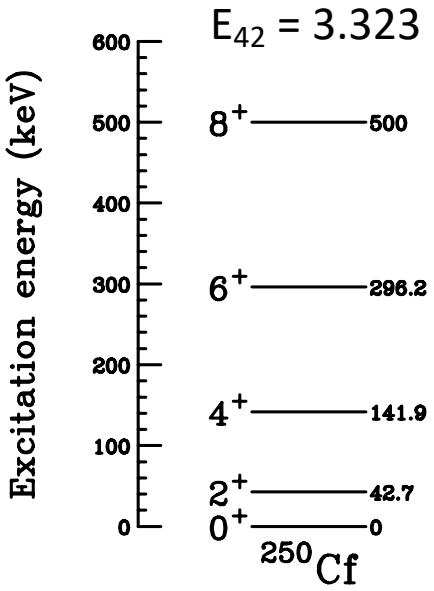


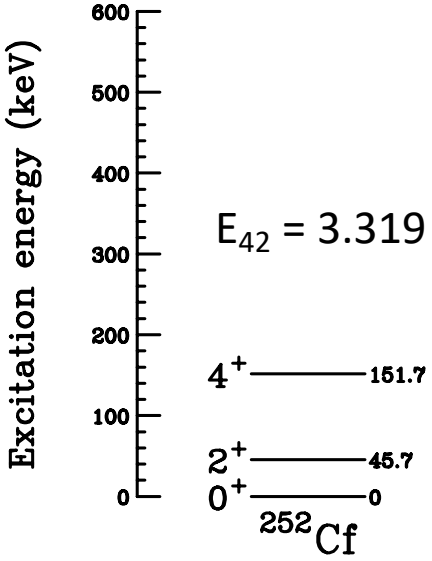


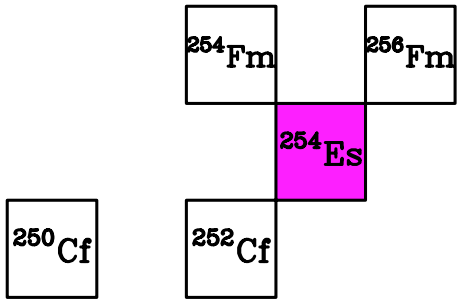

β_2^0
^{252}Fm
^{258}Fm
0.24
0.24
0.20
0.20
0.24
0.04
0.04
Z
N


E_{42} = 3.320
4^+ 149.4
2^+ 45
0^+ 0
^{254}Fm


E_{42} = 3.318
Excitation energy (keV)
8^+ 563.3
6^+ 332.2
4^+ 159.6
2^+ 48.1
0^+ 0
^{256}Fm


E_{42} = 3.323
Excitation energy (keV)
8^+ 500
6^+ 296.2
4^+ 141.9
2^+ 42.7
0^+ 0
^{250}Cf


E_{42} = 3.319
Excitation energy (keV)
4^+ 151.7
2^+ 45.7
0^+ 0
^{252}Cf


^{254}Fm
^{256}Fm
^{254}Es
^{250}Cf
^{252}Cf

End

Thank you for your attention