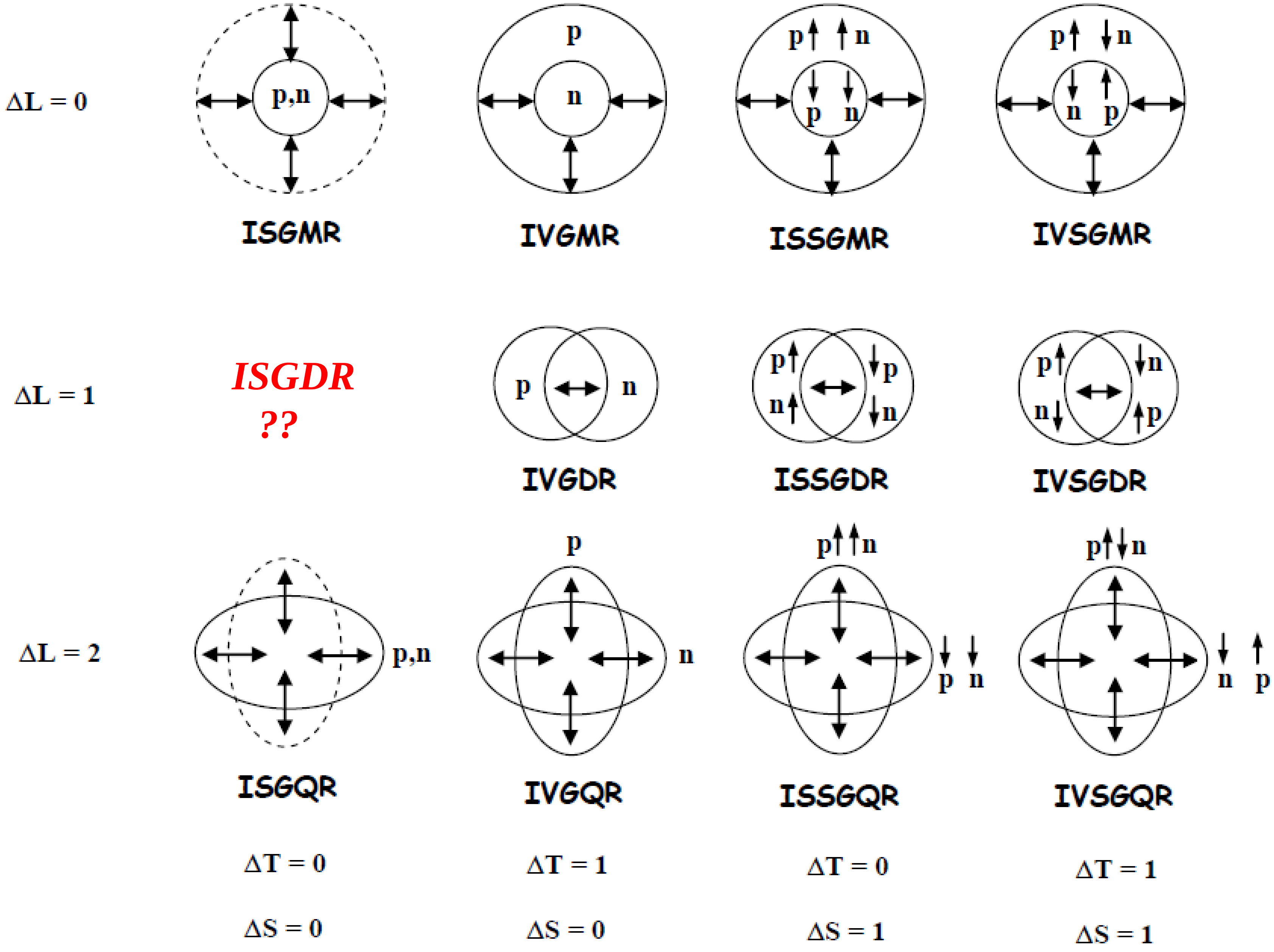
COLLECTIVE EXCITATIONS OF ATOMIC NUCLEI

Muhsin N. Harakeh

KVI-CART, Groningen & GANIL, Caen

Collective Motion of Nuclei under Extreme Conditions (COMEX 5)

Kraków, Poland


ΔL = 0
p,n
ISGMR
p
n
IVGMR
p n
p n
ISSGMR
p n
n p
IVSGMR
ΔL = 1
ISGDR
??
p
n
IVGDR
p
p
n
n
ISSGDR
p
n
n
p
IVSGDR
ΔL = 2
p,n
ISGQR
p
n
IVGQR
p n
p n
ISSGQR
p n
n p
IVSGQR
ΔT = 0
ΔS = 0
ΔT = 1
ΔS = 0
ΔT = 0
ΔS = 1
ΔT = 1
ΔS = 1

Microscopic picture: GRs are coherent (1p-1h) excitations induced by single-particle operators.

- **Excitation energy depends on**

  ***i*) multipole *L* (*L*ħω, since radial operator ∝ r^L; except for ISGMR and ISGDR, 2ħω & 3ħω, respectively),**

  ***ii*) strength of effective interaction and**

  ***iii*) collectivity.**
- **Exhaust appreciable % of EWSR**
- **Acquire a width due to coupling to continuum and to underlying 2p-2h configurations.**

Microscopic structure of ISGMR & ISGDR

Transition operators:

$$O^{L=0} = \sum_i r_i^0 Y_0^0 + \frac{1}{2}\sum_i r_i^2 Y_0^0 + \ldots$$

Constant **Overtone**

2ħω excitation

$$O^{L=1} = \sum_i r_i^1 Y_0^1 + \frac{1}{2}\sum_i r_i^3 Y_0^1 + \ldots$$

Spurious c.o.m. motion **Overtone**

3ħω excitation (overtone of c.o.m. motion)

Nucleus → **Many-body system with a finite size**

Vibrations → **Multipole expansion with r, Y_{lm}, τ, σ**

	ΔS=0, ΔT=0	ΔS=0, ΔT=1	ΔS=0, ΔT=1	ΔS=1, ΔT=1	ΔS=1, ΔT=1
L=0: Monopole	ISGMR r^2Y_0	IAS τY_0	IVGMR τr^2Y_0	GTR $\tau\sigma Y_0$	IVSGMR $\tau\sigma r^2Y_0$
L=1: Dipole	ISGDR r^3Y_1 $(-5/3\langle r^2\rangle rY_1)$		IVGDR τrY_1		IVSGDR $\tau\sigma rY_1$
L=2: Quadrupole	ISGQR r^2Y_2		IVGQR τr^2Y_2		IVSGQR $\tau\sigma r^2Y_2$
L=3: Octupole	LEOR, HEOR r^3Y_3				

IVGDR

$\tau r Y_1$

$\Delta N = 1$ **E1 (IVGDR)**

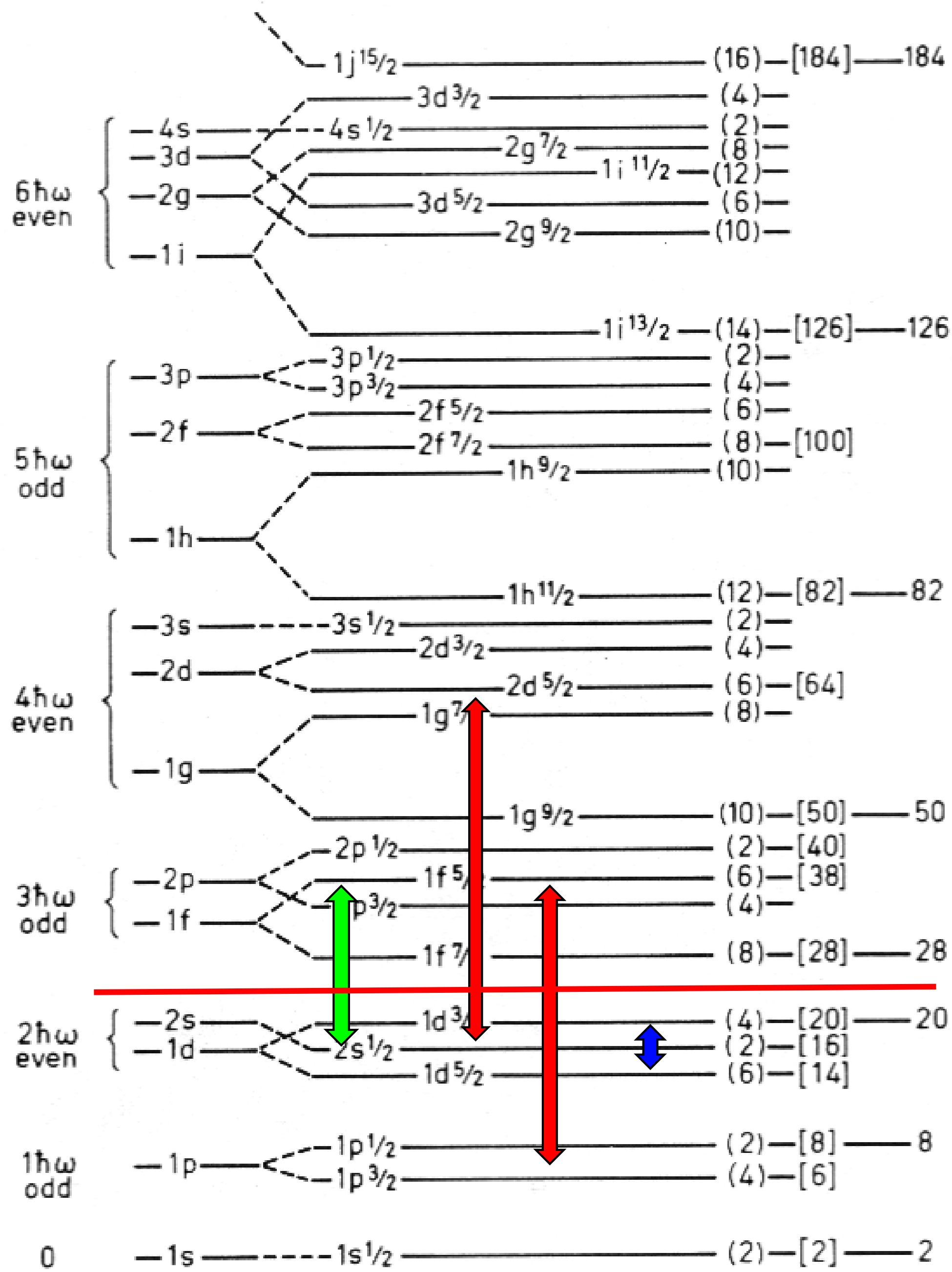
$\Delta N = 2$ **E2 (ISGQR)**

&

$\Delta N = 0$ **E0 (ISGMR)**

ISGMR $r^2 Y_0$

ISGQR $r^2 Y_2$



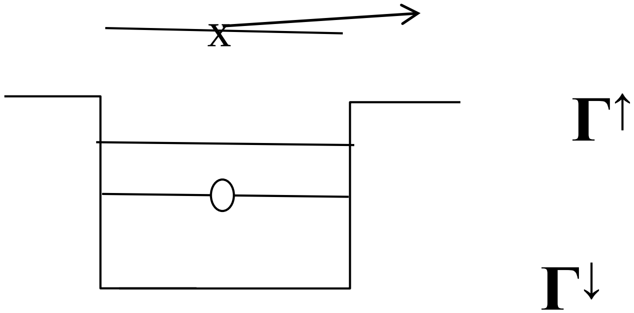
Decay of giant resonances

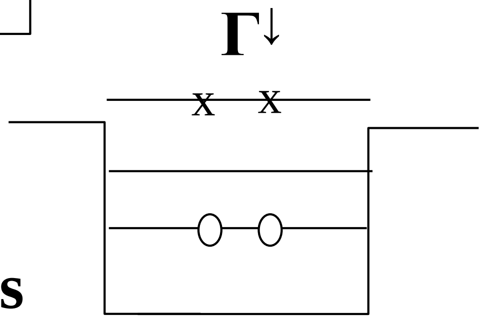
- **Width of resonance**

  $\Gamma, \Gamma^{\uparrow}, \ \Gamma^{\downarrow} \ (\Gamma^{\downarrow\uparrow}, \Gamma^{\downarrow\downarrow})$

  - **$\Gamma^{\uparrow}$: direct or escape width**
  - **$\Gamma^{\downarrow}$: spreading width**

  $\Gamma^{\downarrow\uparrow}$: pre-equilibrium, $\Gamma^{\downarrow\downarrow}$: compound

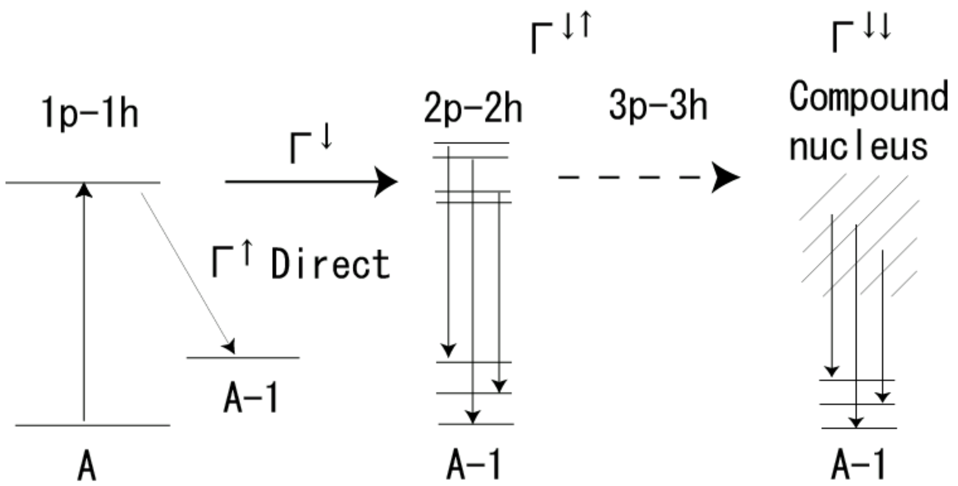




- **Decay measurements**

  ⇒ Direct reflection of damping processes

  Allows detailed comparison with theoretical calculations



The collective response of the nucleus
Giant Resonances

Electric giant resonances

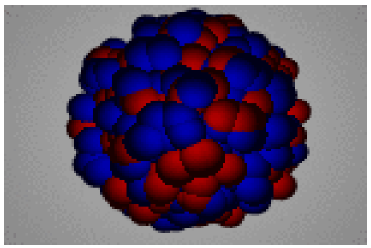
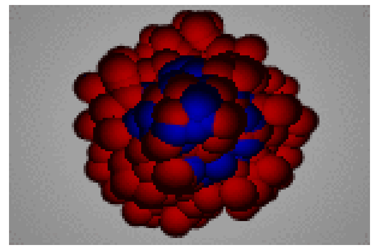
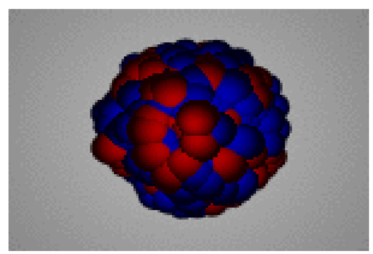
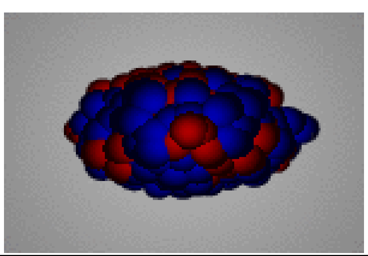
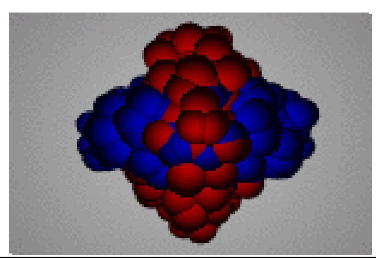
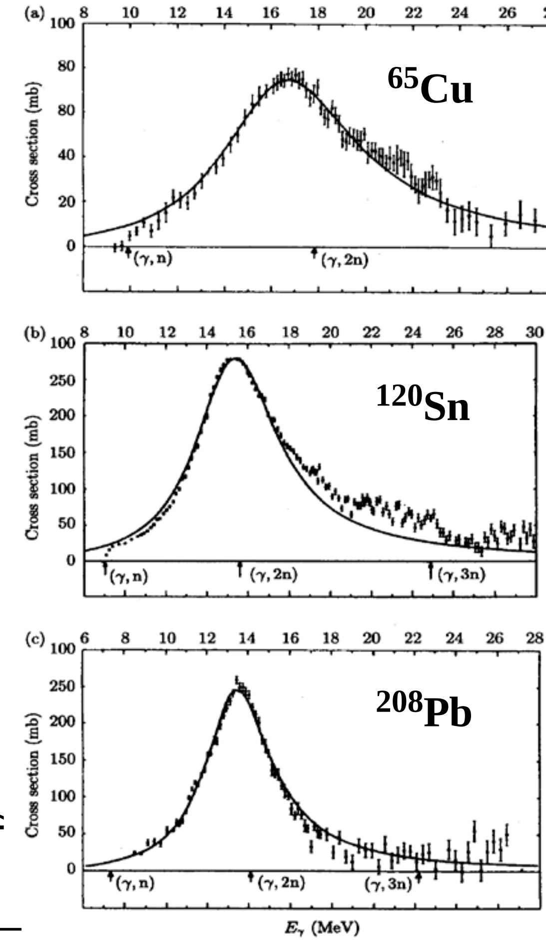
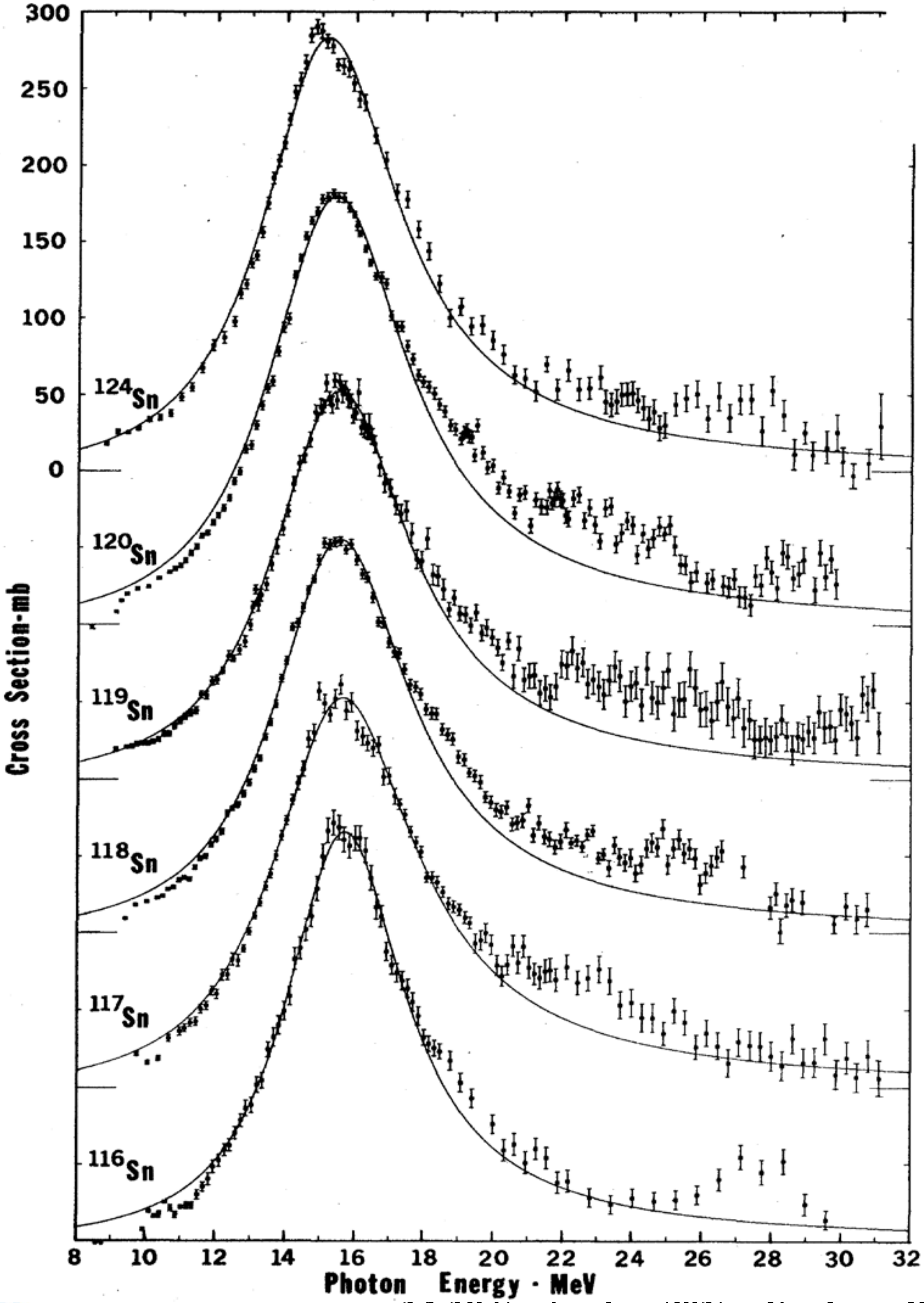
	Isoscalar	Isovector
Monopole (GMR)		
Dipole (GDR)		
Quadrupole (GQR)		

Photo-neutron cross sections



Berman and Fultz, Rev. Mod. Phys. 47 (1975) 47

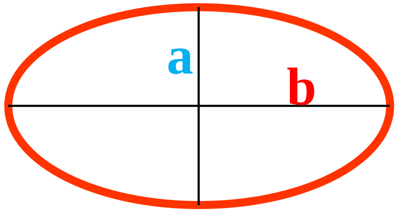


Measurement of the giant dipole resonance with mono-energetic photons

B.L. Berman and S.C. Fultz

Rev. Mod. Phys. 47 (1975) 713

Nucleus	Centroid (MeV)	Width (MeV)
^{116}Sn	15.68	4.19
^{117}Sn	15.66	5.02
^{118}Sn	15.59	4.77
^{119}Sn	15.53	4.81
^{120}Sn	15.40	4.89
^{124}Sn	15.19	4.81

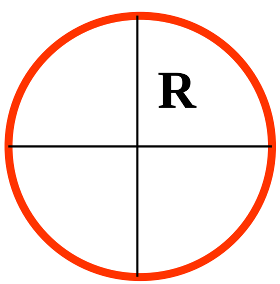


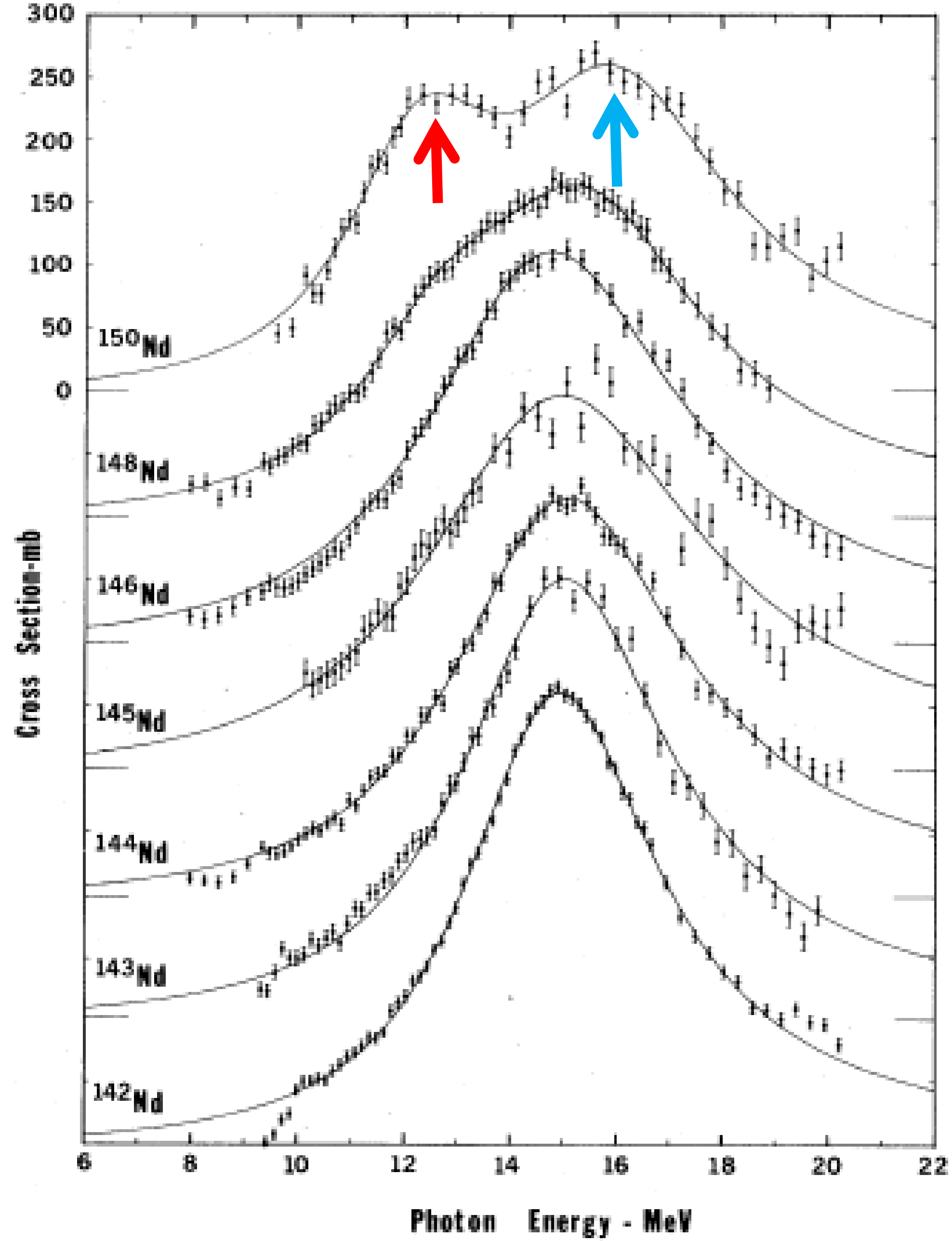
Quadrupole deformation:
$\beta_2 = 0.275$

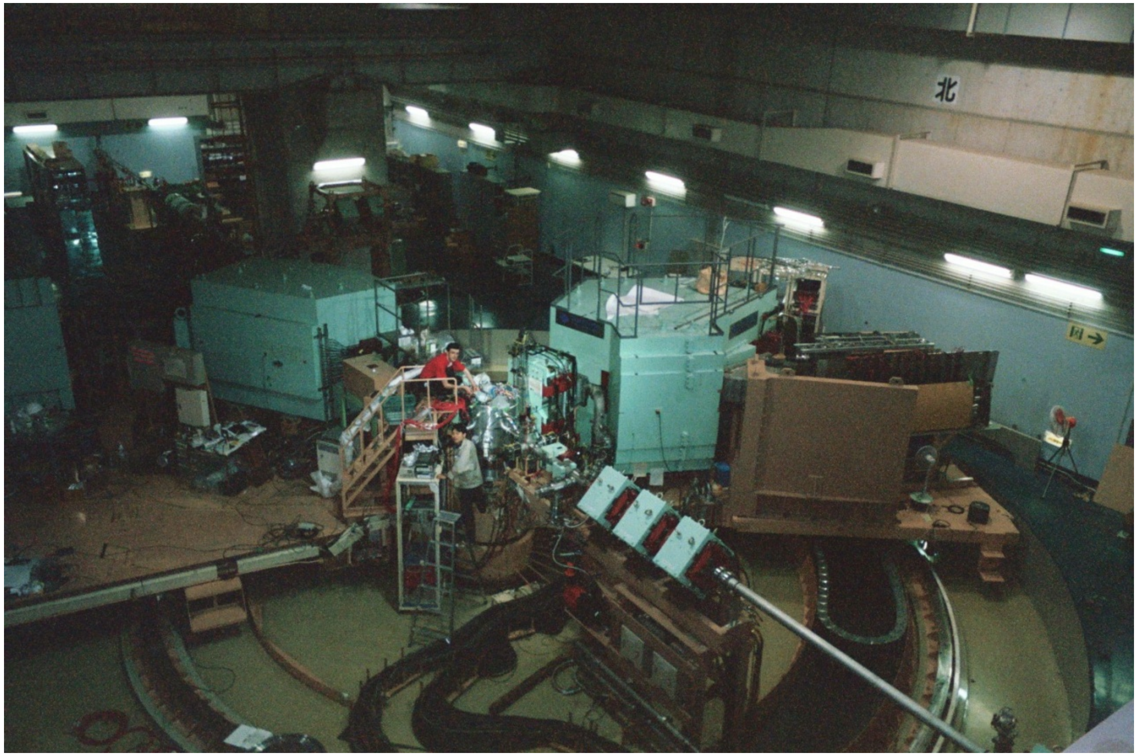
Excitation energies:
$E_2/E_1 = 0.911\eta + 0.089$

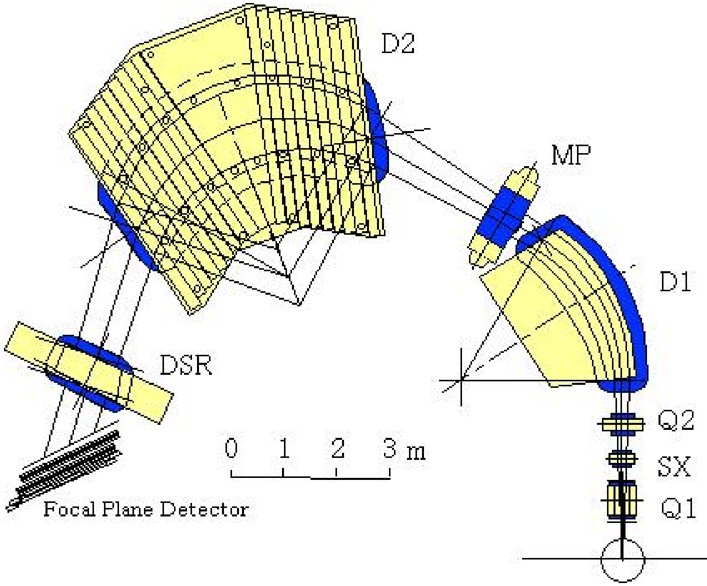
Where $\eta = b/a$

$s_1/s_2 = 1/2$

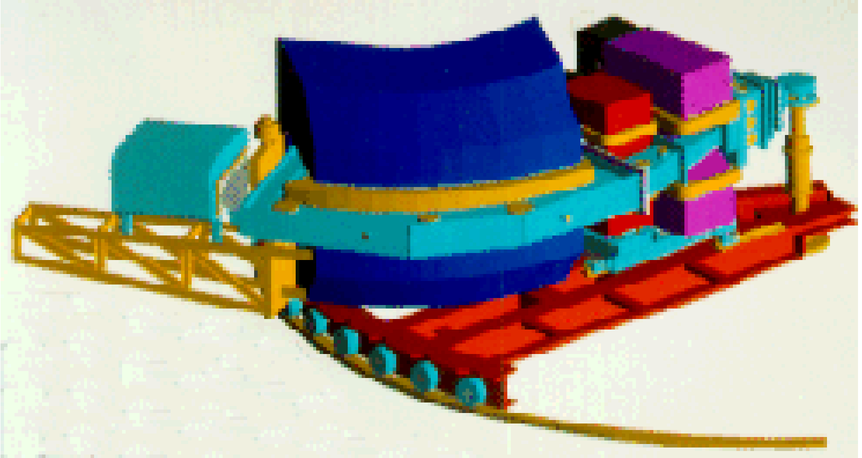








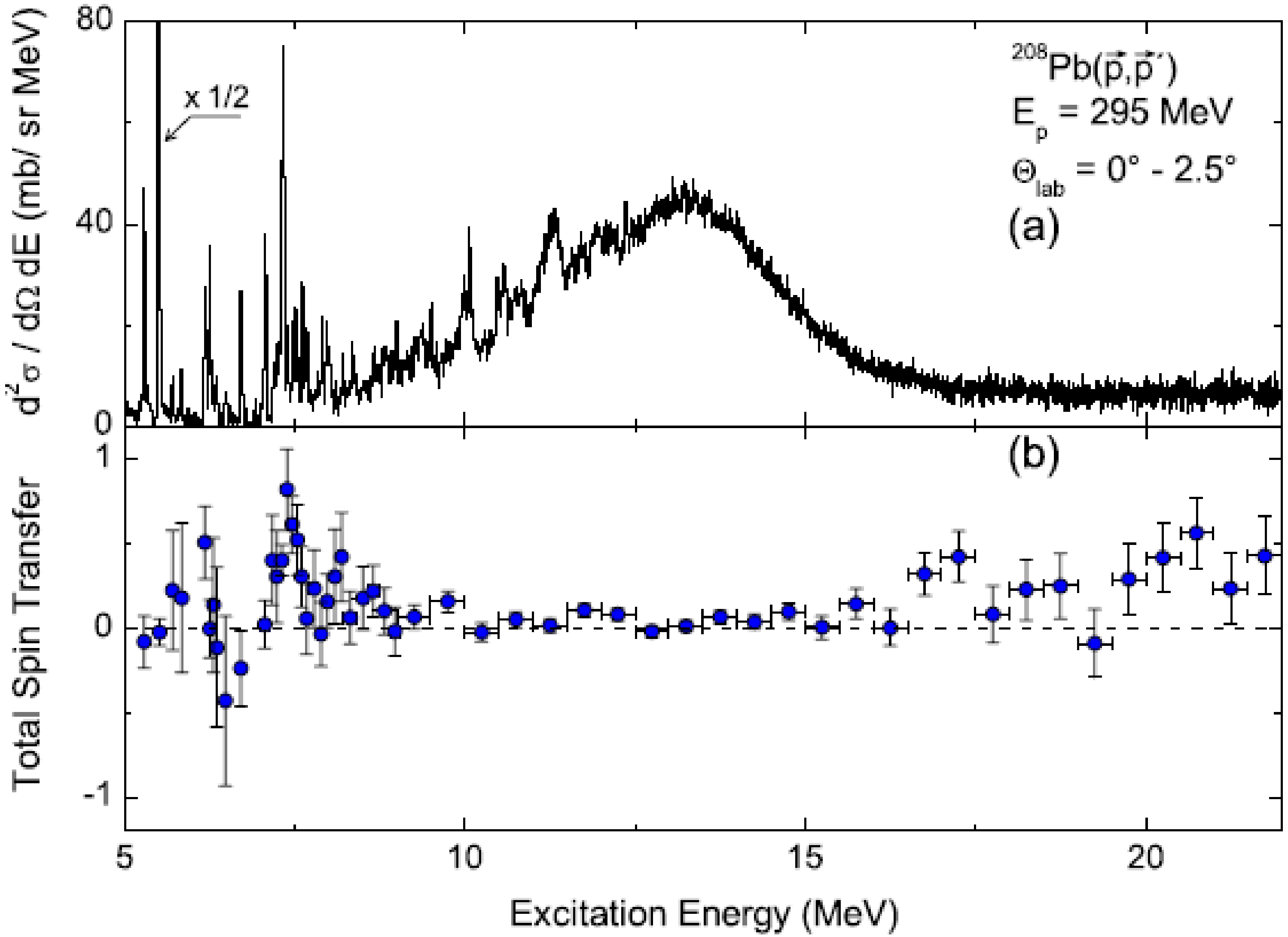
Grand Raiden@ RCNP



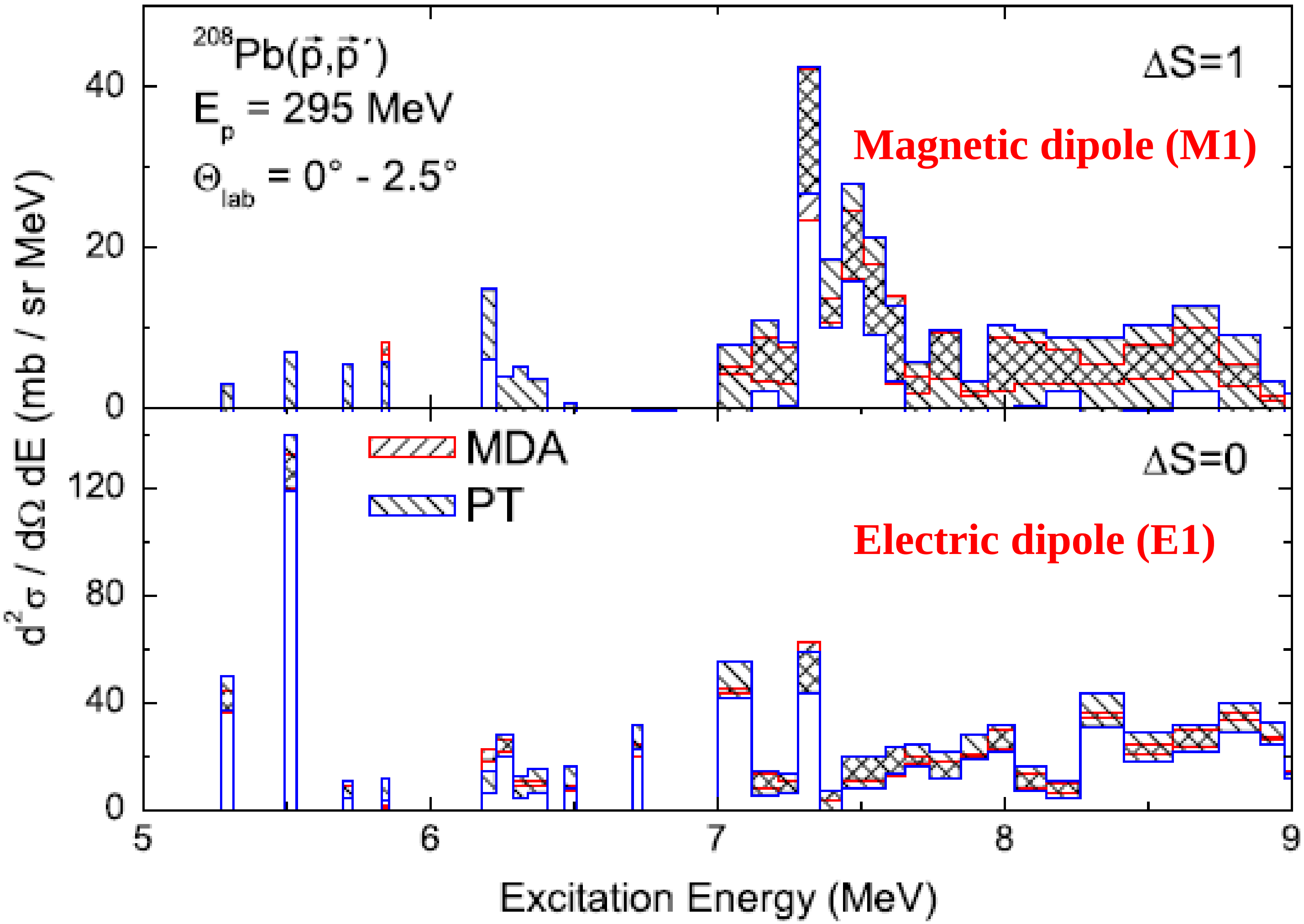
BBS@KVI

(p,p') at E_p~ 300

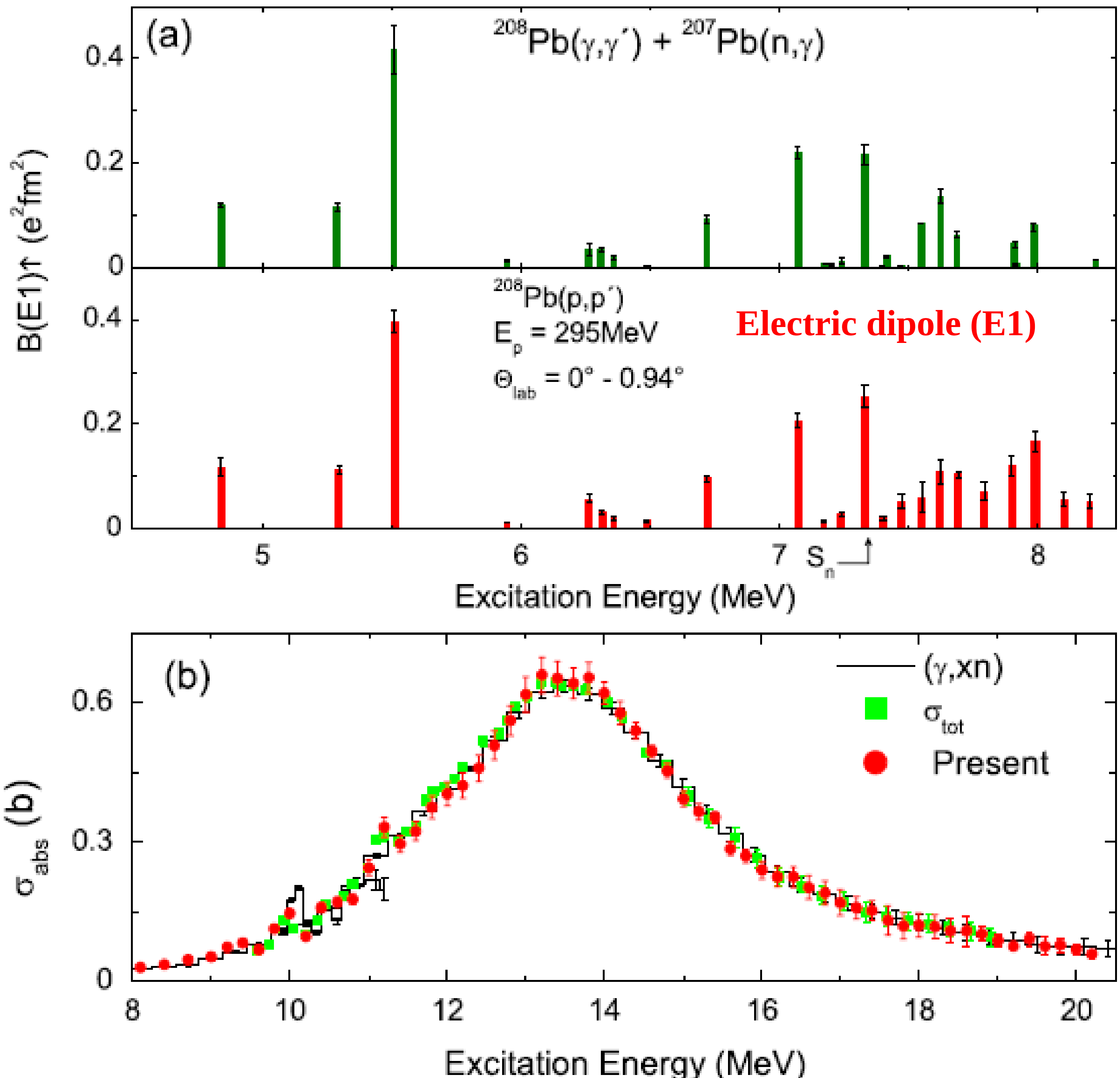
(α,α') at E_α~ 400 & 200 MeV at RCNP & KVI, respectively

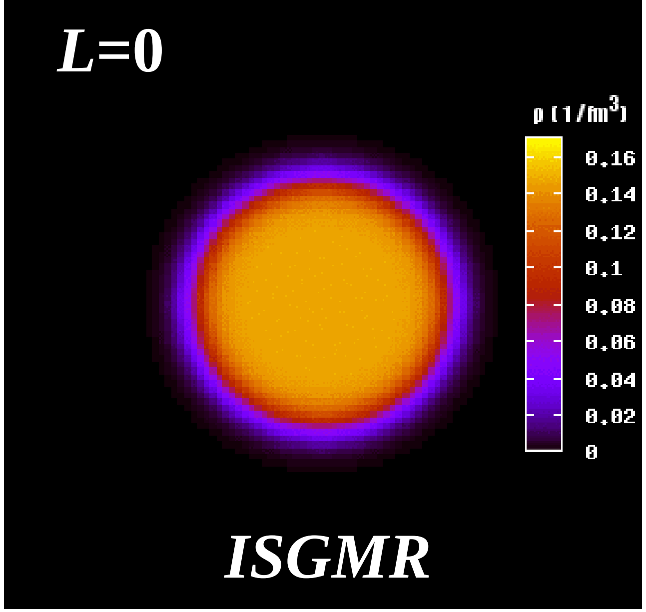


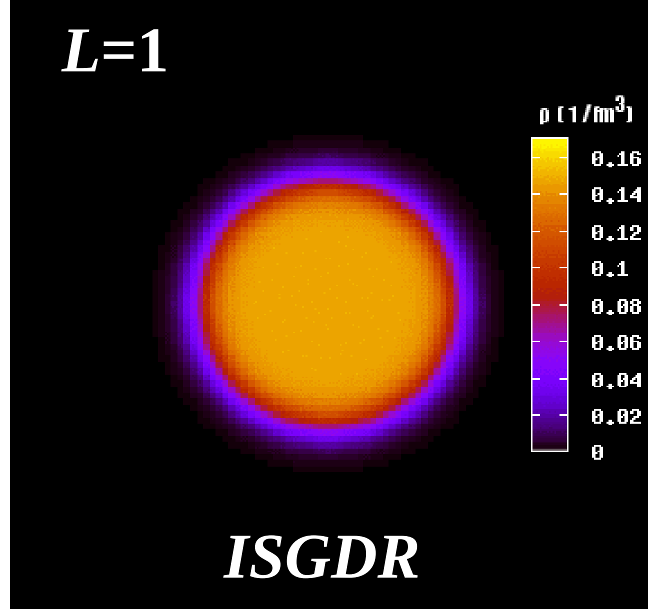
A. Tamii *et al.*, PRL 107 (2011) 062502

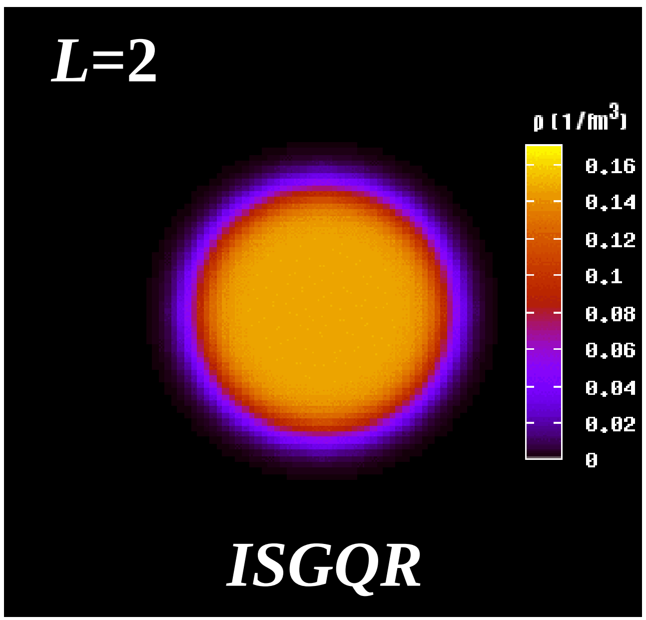


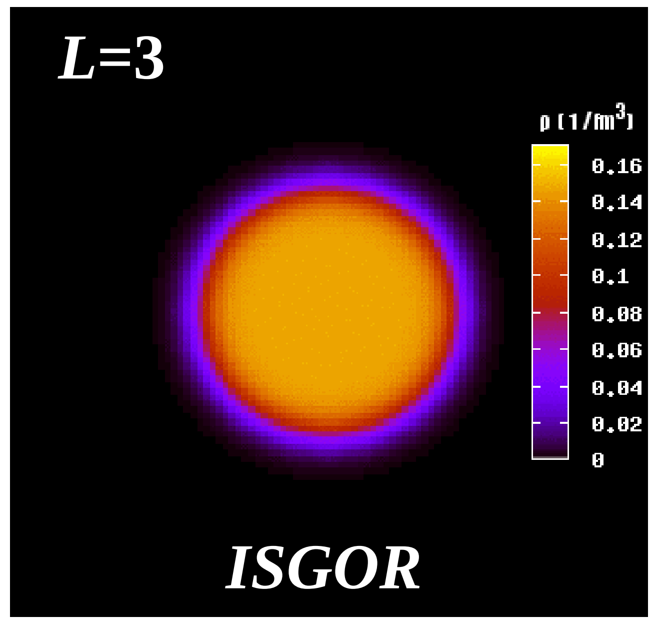
A. Tamii *et al.*, PRL 107 (2011) 062502


(a)
$^{208}Pb(\gamma,\gamma')$ + $^{207}Pb(n,\gamma)$
$B(E1)\uparrow$ (e^2fm^2)
0.4
0.2
0
$^{208}Pb(p,p')$
E_p = 295MeV
Θ_{lab} = 0° - 0.94°
Electric dipole (E1)
0.4
0.2
0
5
6
7
S_n
8
Excitation Energy (MeV)
(b)
(γ,xn)
σ_{tot}
Present
σ_{abs} (b)
0.6
0.3
0
8
10
12
14
16
18
20
Excitation Energy (MeV)


L=0
ρ (1/fm^3)
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
ISGMR


L=1
ρ (1/fm^3)
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
ISGDR


L=2
ρ (1/fm^3)
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
ISGQR


L=3
ρ (1/fm^3)
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
ISGOR

M. Itoh

In fluid mechanics, **compressibility** is a measure of the relative volume change of a fluid as a response to a pressure change.

$$\beta = -\frac{1}{V}\frac{\partial V}{\partial P}$$

where P is pressure, V is volume.

Incompressibility or **bulk modulus** (K) is a measure of a substance's resistance to uniform compression and can be formally defined:

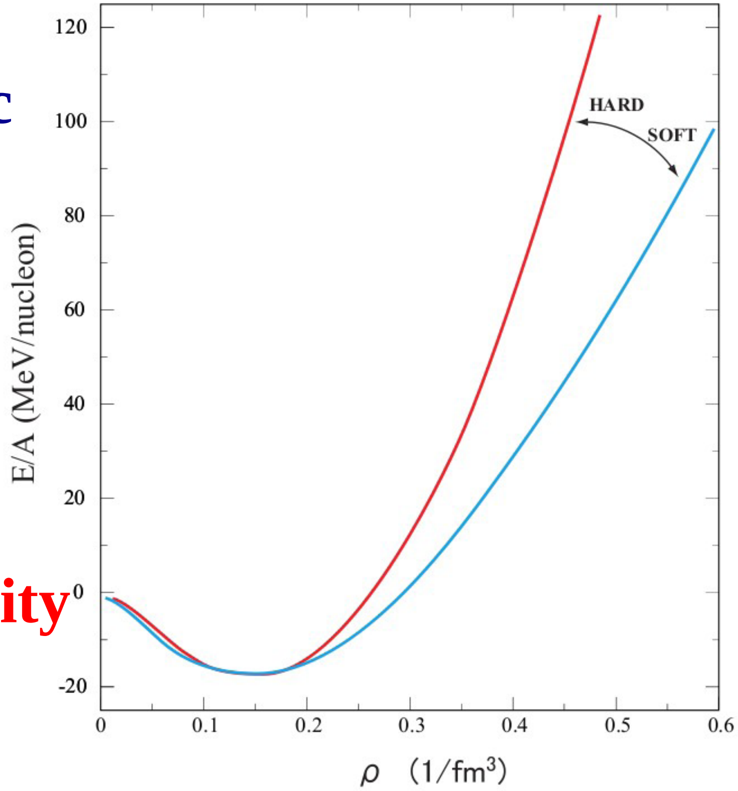
$$K = -V\frac{\partial P}{\partial V}$$

For the equation of state of symmetric nuclear matter at saturation nuclear density:

$$\left[\frac{d(E/A)}{d\rho}\right]_{\rho=\rho_0} = 0$$

and one can derive the incompressibility of nuclear matter:

$$K_{nm} = \left[9\rho^2 \frac{d^2(E/A)}{d\rho^2}\right]_{\rho=\rho_0}$$



E/A**: binding energy per nucleon**

ρ **: nuclear density**

ρ₀ **: nuclear density at saturation**

J.P. Blaizot, Phys. Rep. 64 (1980) 171

Equation of state (EOS) of nuclear matter:

More complex than for infinite neutral liquids:
Neutrons and protons with different interactions
Coulomb interaction of protons

1. **Governs the collapse and explosion of giant stars (supernovae)**
2. **Governs formation of neutron stars (mass, radius, crust)**
3. **Governs collisions of heavy ions.**
4. **Important ingredient in the study of nuclear properties.**

Isoscalar Excitation Modes of Nuclei

Hydrodynamic models/Giant Resonances

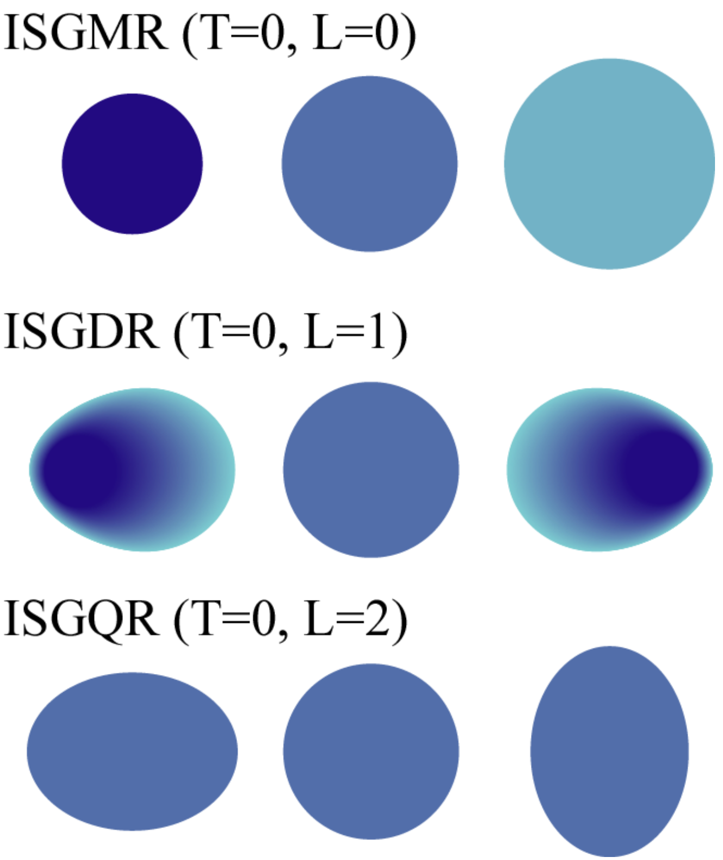
Coherent vibrations of nucleonic fluids in a nucleus.

Compression modes : ISGMR, ISGDR

In Constrained and Scaling Models:

$$E_{ISGMR} = \hbar \sqrt{\frac{K_A}{m\langle r^2 \rangle}}$$

$$E_{ISGDR} = \hbar \sqrt{\frac{7}{3} \frac{K_A + \frac{27}{25}\varepsilon_F}{m\langle r^2 \rangle}}$$



ε_F is the Fermi energy and the nucleus incompressibility:

$$\rightarrow K_A = \left[r^2 (d^2(E/A)/dr^2) \right]_{r=R_0}$$

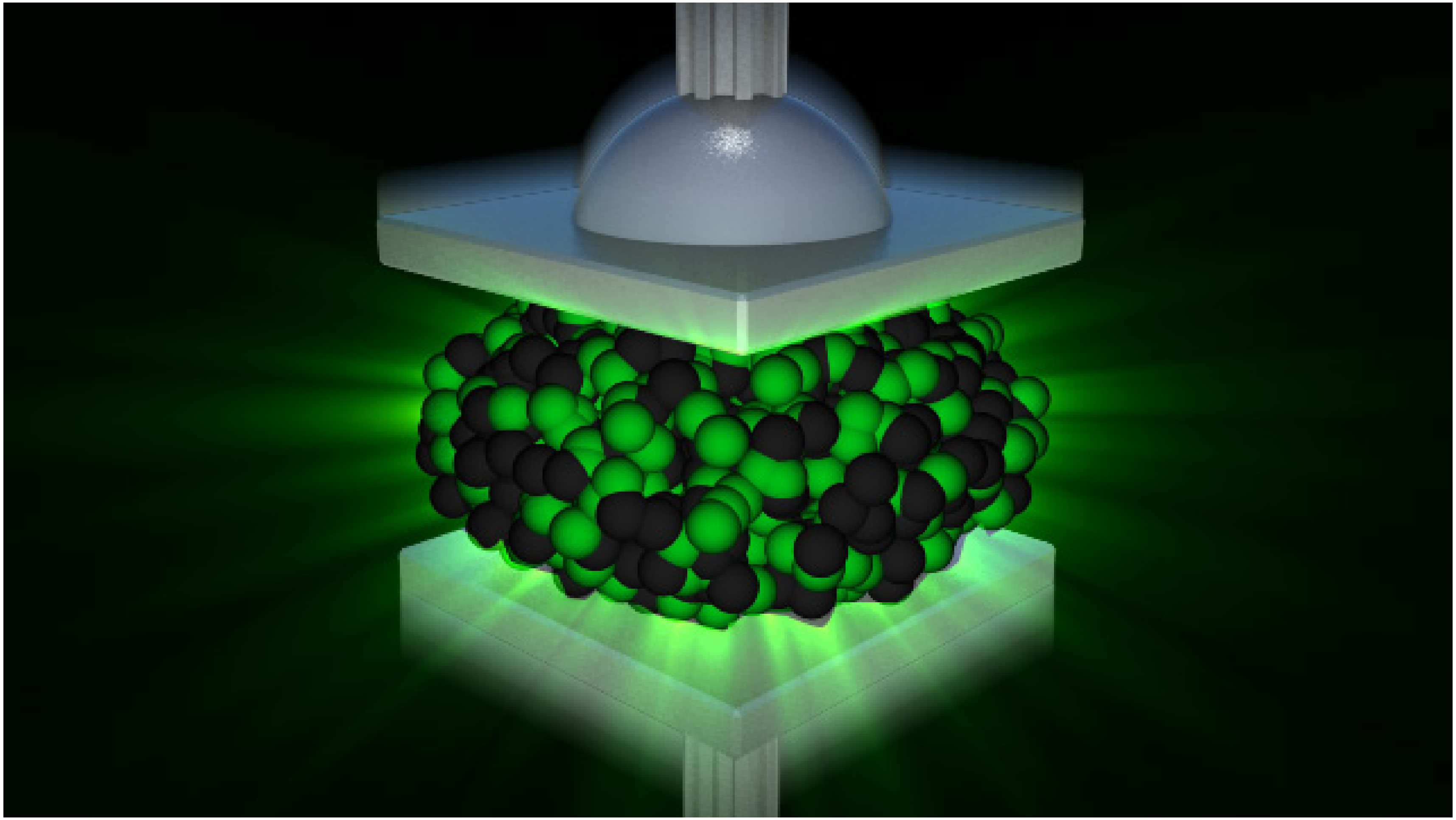
J.P. Blaizot, Phys. Rep. 64 (1980) 171

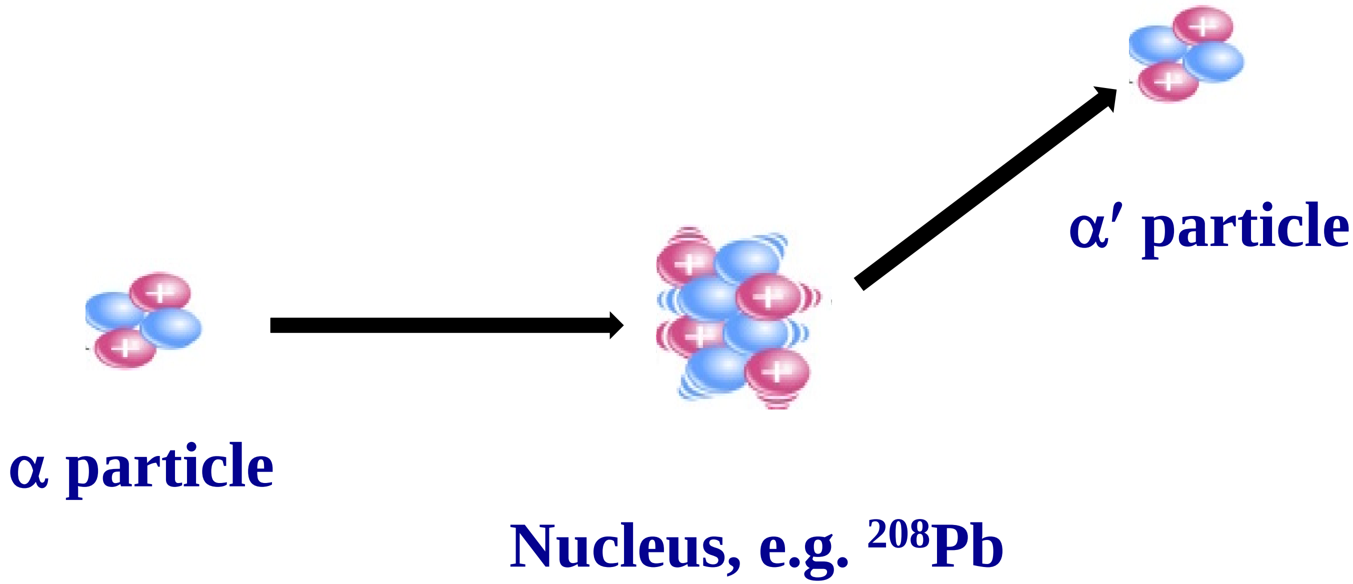
Giant resonances

- **Macroscopic properties: E_x, Γ, %EWSR**
- **Isoscalar giant resonances; compression modes**

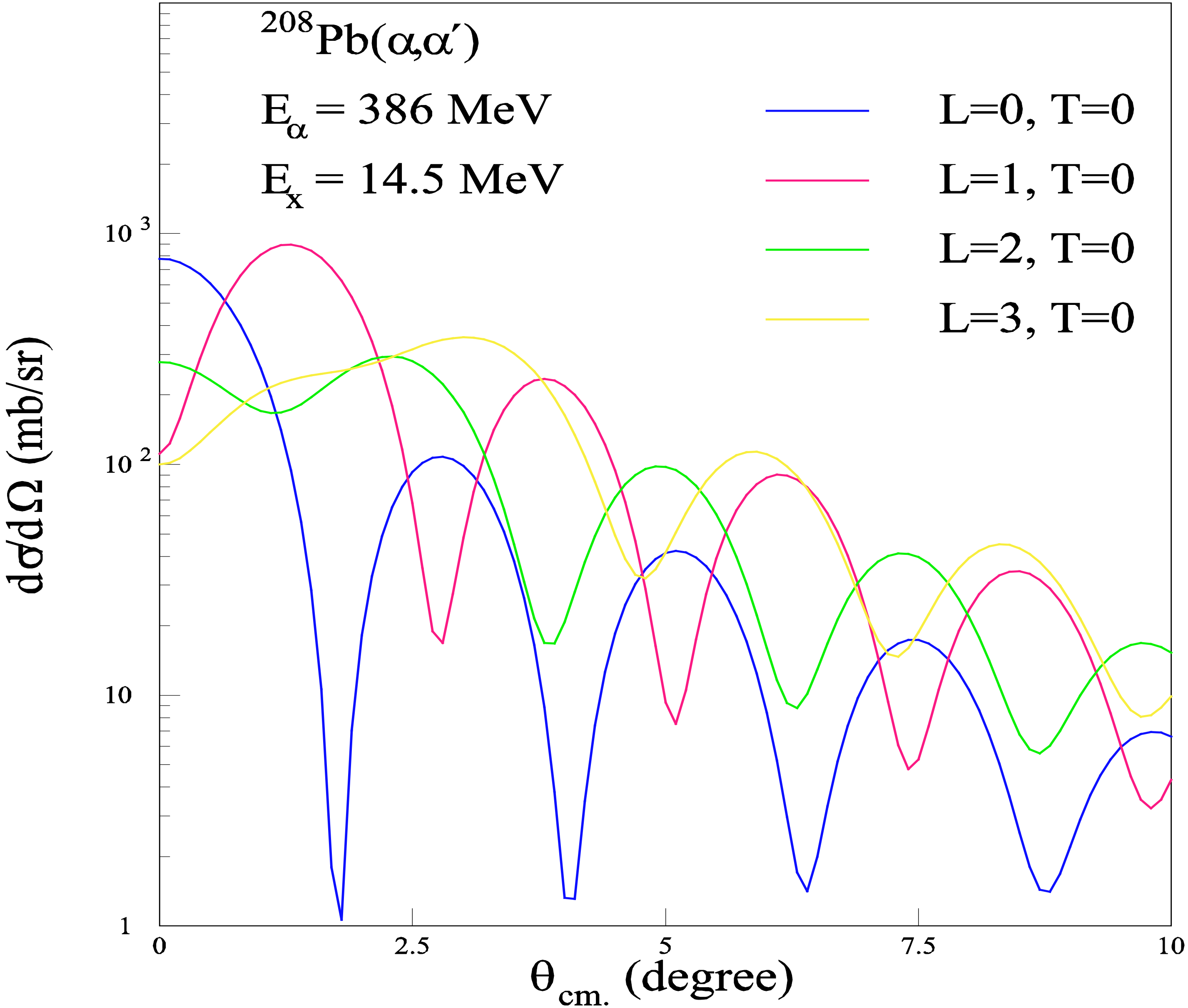
  ISGMR, ISGDR $\Rightarrow$ Incompressibility, symmetry energy

$$K_A = K_{vol} + K_{surf} A^{-1/3} + K_{sym}((N-Z)/A)^2 + K_{Coul} Z^2 A^{-4/3}$$





Inelastic α scattering

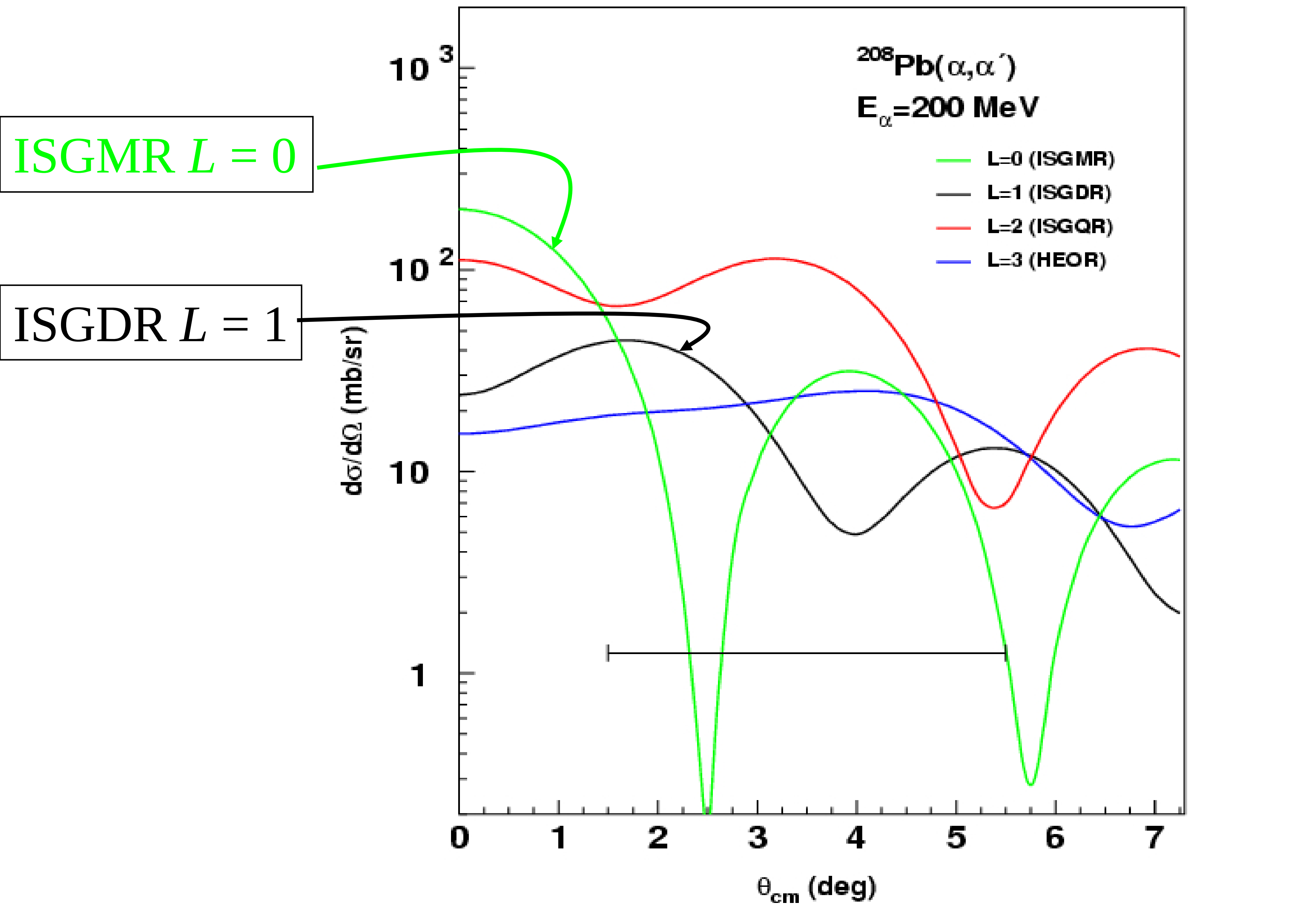


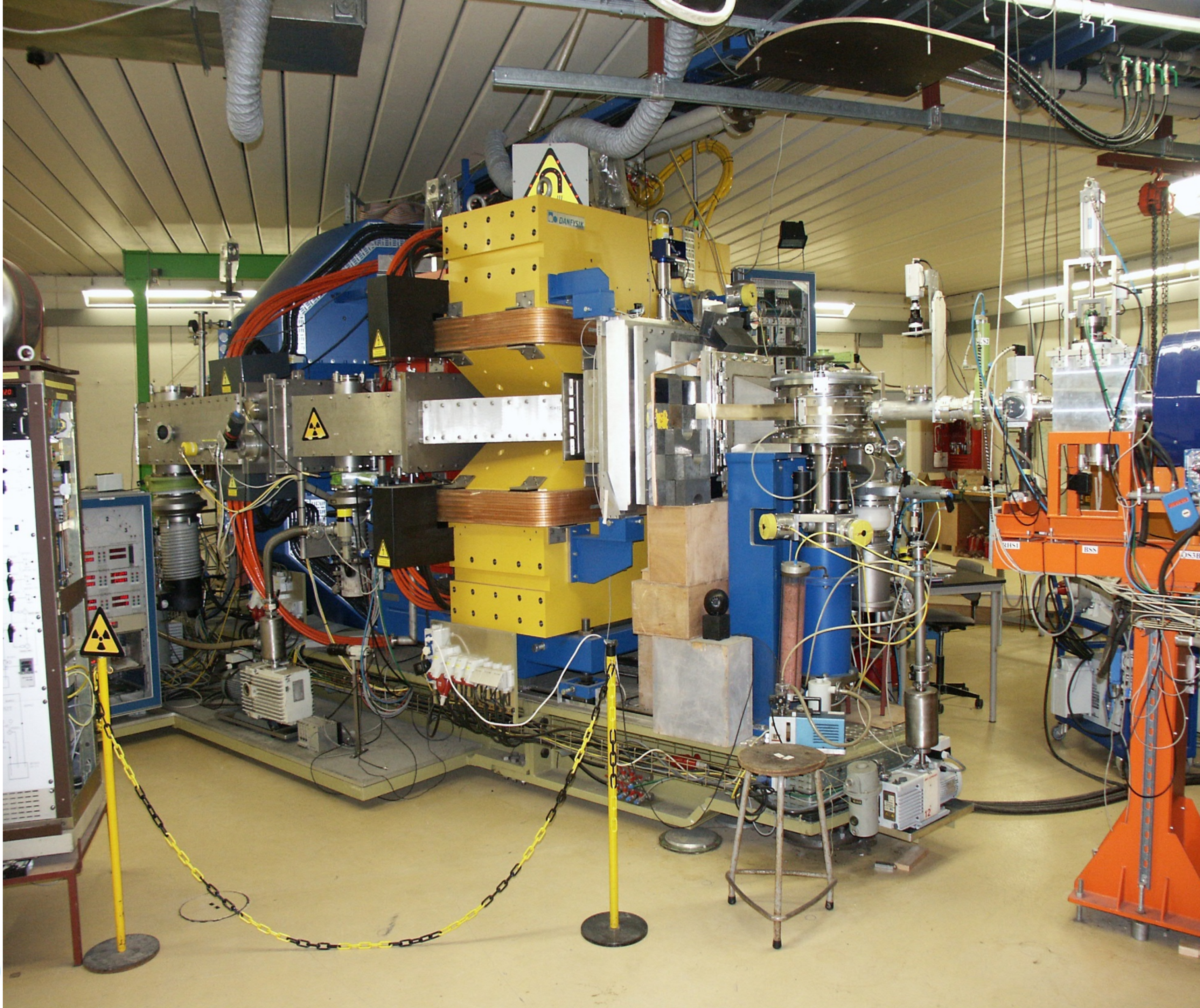
ISGMR, ISGDR

ISGQR, HEOR

100 % EWSR

At E_x= 14.5 MeV


ISGMR L = 0
ISGDR L = 1
^{208}Pb(α,α´)
E_α=200 MeV
L=0 (ISGMR)
L=1 (ISGDR)
L=2 (ISGQR)
L=3 (HEOR)
dσ/dΩ (mb/sr)
θ_{cm} (deg)
10^3
10^2
10
1
0
1
2
3
4
5
6
7



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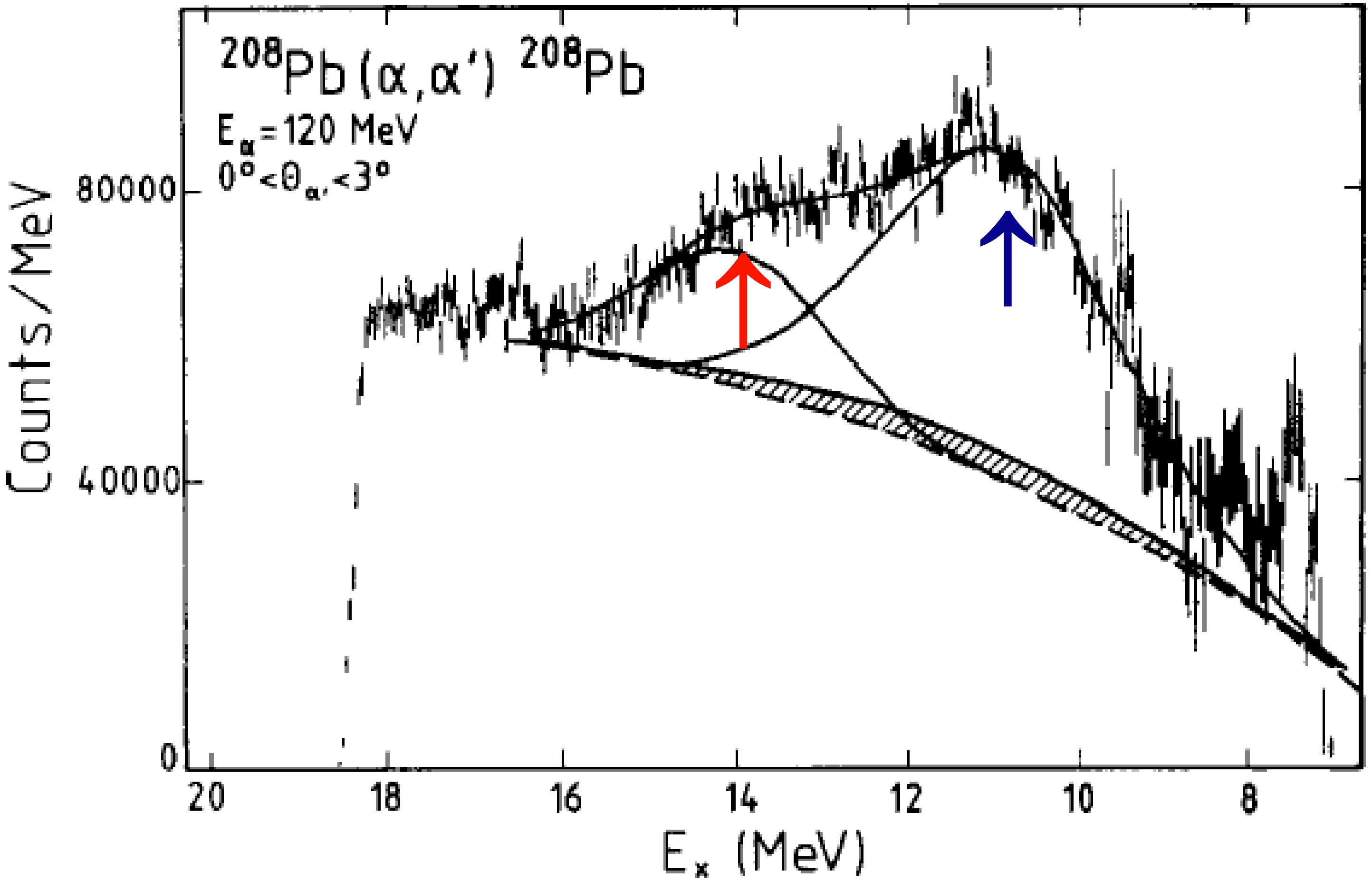
M. N. Harakeh *et al.*, Phys. Rev. Lett. 38, 676 (1977)

ISGQR at 10.9 MeV
ISGMR at 13.9 MeV



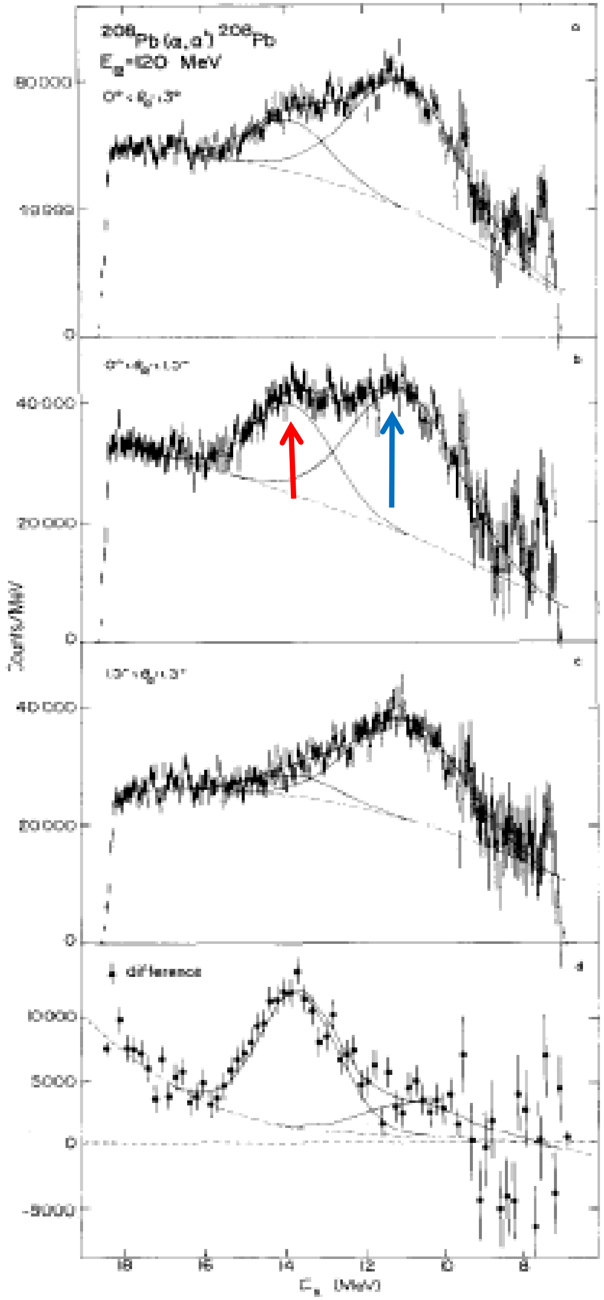
Difference of spectra

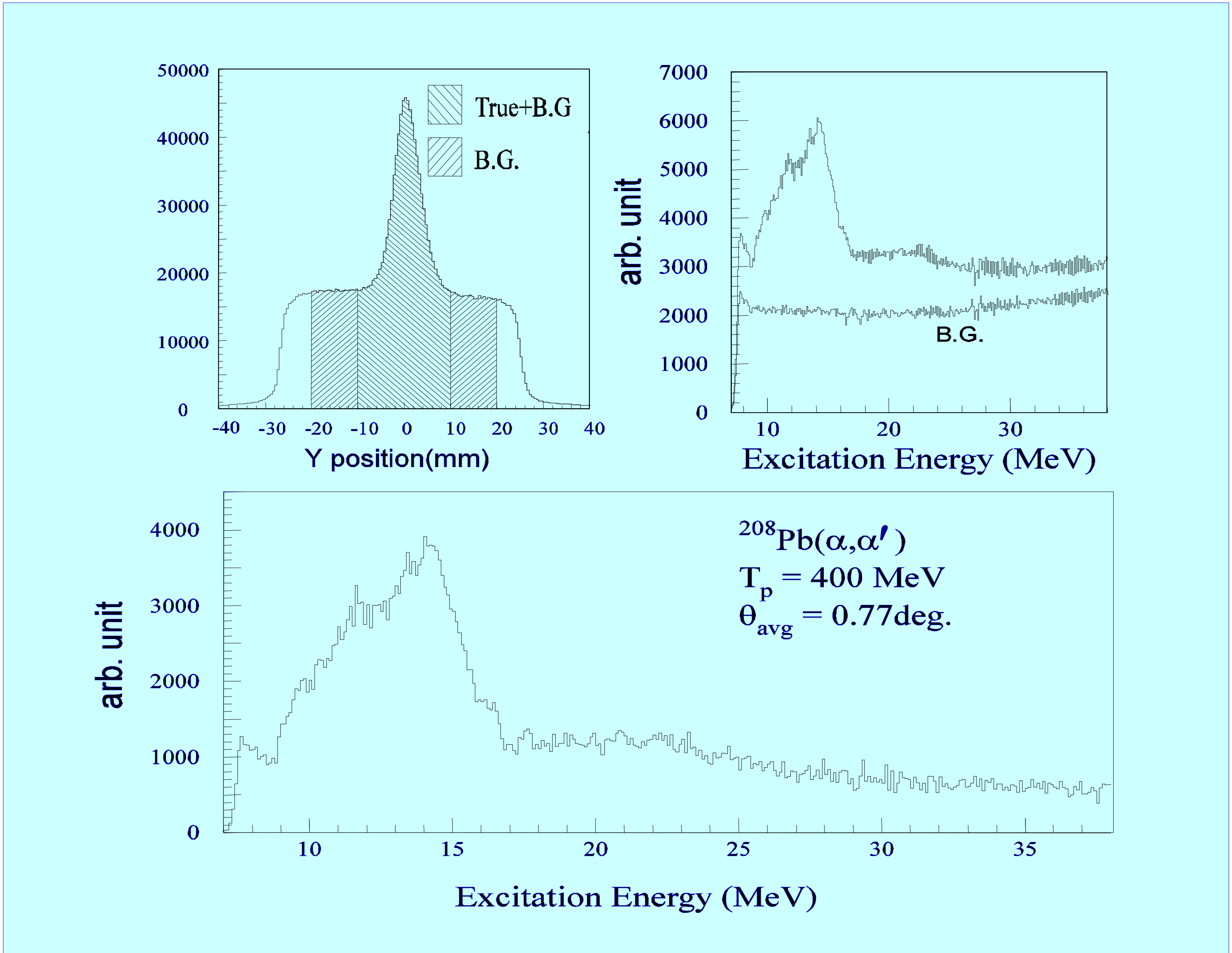
$0° < \theta_{\alpha'} < 3°$

$0° < \theta_{\alpha'} < 1.5°$

$1.5° < \theta_{\alpha'} < 3°$

Difference




True+B.G
B.G.
Y position(mm)
arb. unit
Excitation Energy (MeV)
B.G.
arb. unit
Excitation Energy (MeV)
^{208}Pb(α,α′)
T_p = 400 MeV
θ_{avg} = 0.77deg.

Multipole decomposition analysis (MDA)

$$\left(\frac{d^2\sigma}{d\Omega dE}(\vartheta_{c.m.},E)\right)^{\exp.} = \sum_L a_L(E)\left(\frac{d^2\sigma}{d\Omega dE}(\vartheta_{c.m.},E)\right)_L^{calc.}$$

$$\left(\frac{d^2\sigma}{d\Omega dE}(\vartheta_{c.m.},E)\right)^{\exp.} : \text{Experimental cross section}$$

$$\left(\frac{d^2\sigma}{d\Omega dE}(\vartheta_{c.m.},E)\right)_L^{calc.} : \text{DWBA cross section (unit cross section)}$$

$a_L(E)$: EWSR fraction

a. **ISGR (L<15)+ IVGDR (through Coulomb excitation)**

b. **DWBA formalism; single folding ⇒ transition potential**

$$\delta U(r,E) = \int d\vec{r}'\,\delta\rho_L(\vec{r}',E)[V(|\vec{r}-\vec{r}'|,\rho_0(r')) + \rho_0(r')\frac{\partial V(|\vec{r}-\vec{r}'|,\rho(r'))}{\partial\rho_0(r')}]$$

$$U(r) = \int d\vec{r}'V(|\vec{r}-\vec{r}'|,\rho_0(r'))\rho_0(r')$$

Transition density

- **ISGMR Satchler, Nucl. Phys. A472 (1987) 215**

$$\delta\rho_0(r,E) = -\alpha_0[3 + r\frac{d}{dr}]\rho_0(r)$$

$$\alpha_0^2 = \frac{2\pi\hbar^2}{mA < r^2 > E}$$

- **ISGDR Harakeh & Dieperink, Phys. Rev. C23 (1981) 2329**

$$\delta\rho_1(r,E) = -\frac{\beta_1}{R\sqrt{3}}[3r^2\frac{d}{dr} + 10r - \frac{5}{3} < r^2 > \frac{d}{dr} + \varepsilon(r\frac{d^2}{dr^2} + 4\frac{d}{dr})]\rho_0(r)$$

$$\beta_1^2 = \frac{6\pi\hbar^2}{mAE}\frac{R^2}{(11 < r^4 > -(25/3) < r^2 >^2 - 10\varepsilon < r^2 >)}$$

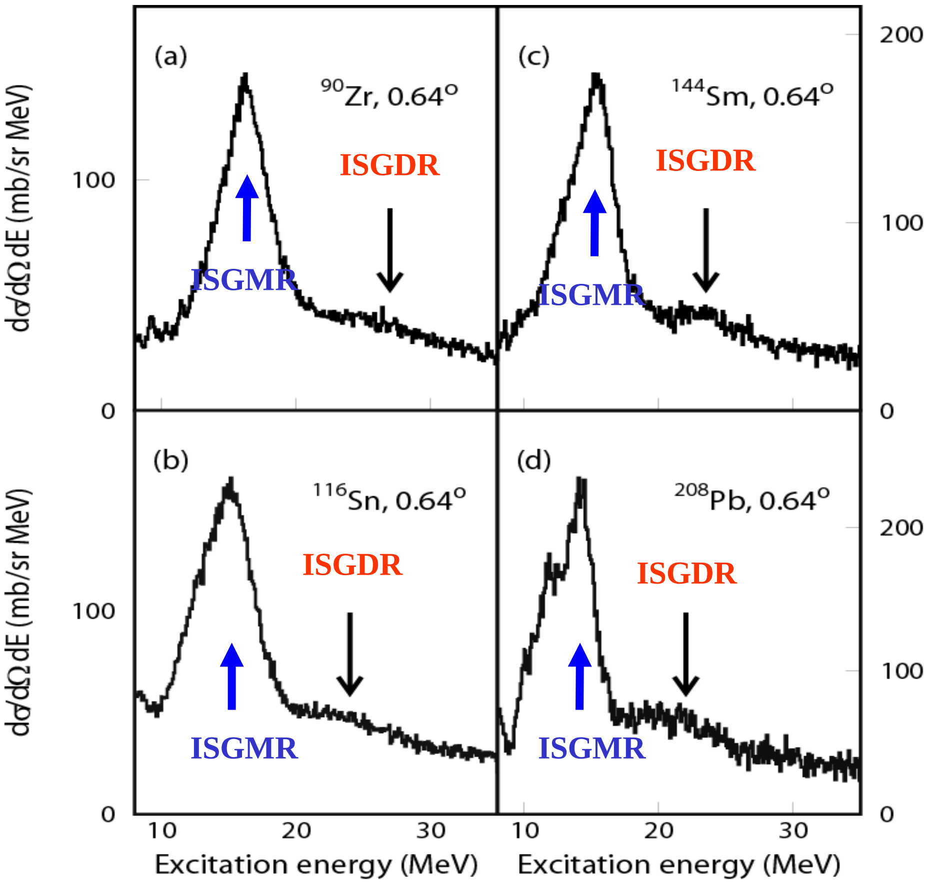
- **Other modes Bohr-Mottelson (BM) model**

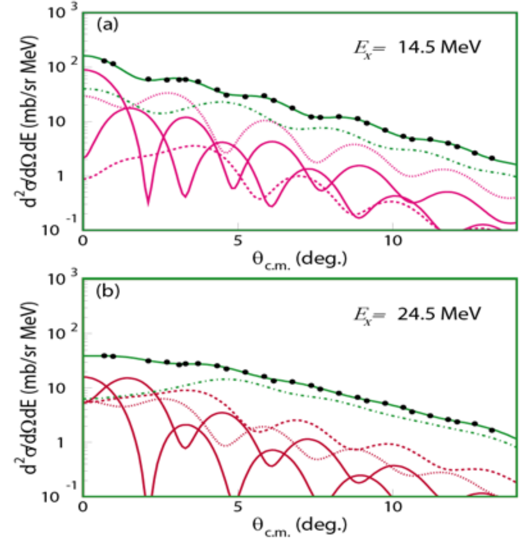
$$\delta\rho_L(r,E) = -\delta_L\frac{d}{dr}\rho_0(r)$$

$$\delta_L^2 = (\beta_L c)^2 = \frac{L(2L+1)^2}{(L+2)^2}\frac{2\pi\hbar^2}{mAE}\frac{< r^{2L-2} >}{< r^{L-1} >^2}$$

Uchida *et al.*,
Phys. Lett. B557 (2003) 12
Phys. Rev. C69 (2004) 051301

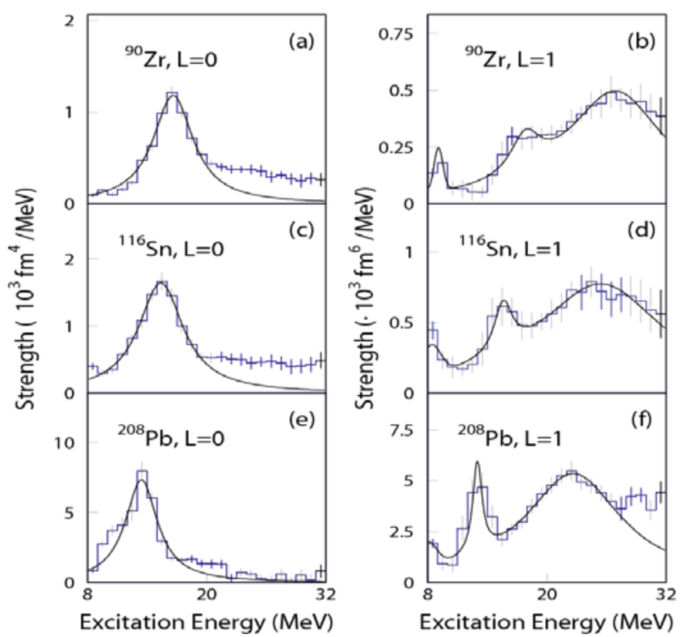
(α,α') spectra at 386 MeV





^{116}Sn

MDA results for L=0 and L=1



In HF+RPA calculations,

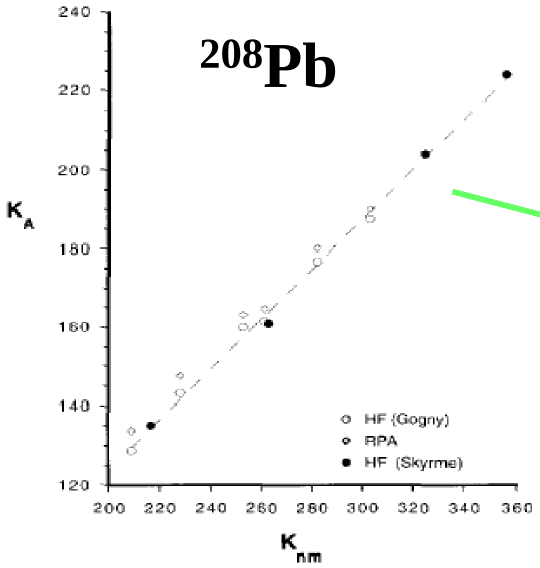
$$K_{nm} = \left[9\rho^2 \frac{d^2(E/A)}{d\rho^2} \right]_{\rho=\rho_0}$$

Nuclear matter

***E/A*: binding energy per nucleon** ***K_A*: incompressibility**

***ρ* : nuclear density**

***ρ_0* : nuclear density at saturation**



K_A is obtained from excitation energy of ISGMR & ISGDR

$K_A = 0.64 K_{nm} - 3.5$

J.P. Blaizot, NPA591 (1995) 435

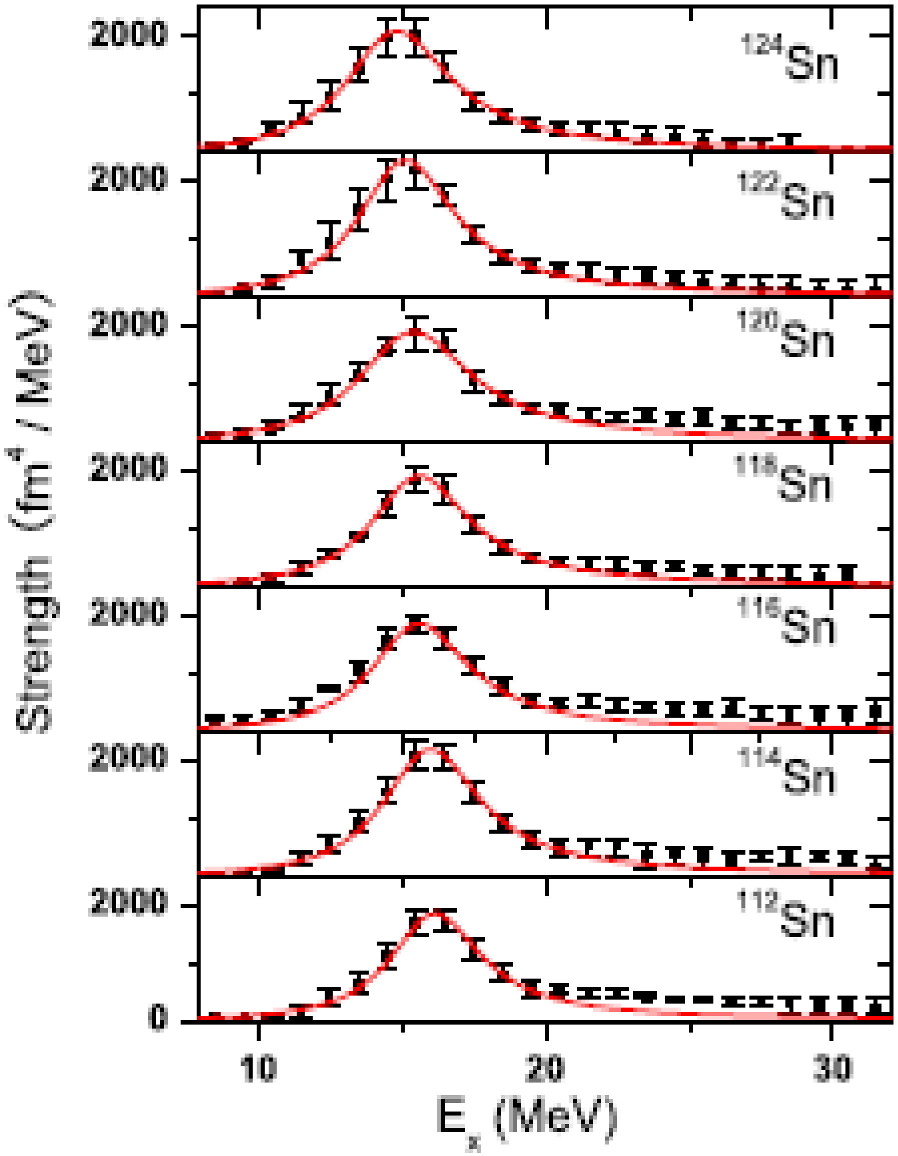
From GMR data on ^{208}Pb and ^{90}Zr,

$K_\infty = 240 \pm 10$ **MeV** **[± 20 MeV]**

[See, *e.g.*, G. Colò *et al.*, Phys. Rev. C 70 (2004) 024307]

This number is consistent
with both ISGMR and ISGDR Data
and
with non-relativistic and relativistic calculations

Isoscalar GMR strength distribution in Sn-isotopes obtained by Multipole Decomposition Analysis of singles spectra obtained in ^{A}Sn(α,α′) measurements at incident energy 400 MeV and angles from 0º to 9º



$$K_A = K_{vol} + K_{surf}A^{-1/3} + K_{sym}((N-Z)/A)^2 + K_{coul}Z^2A^{-4/3}$$

$$K_A \sim K_{vol}(1 + cA^{-1/3}) + K_\tau((N - Z)/A)^2 + K_{Coul}Z^2A^{-4/3}$$

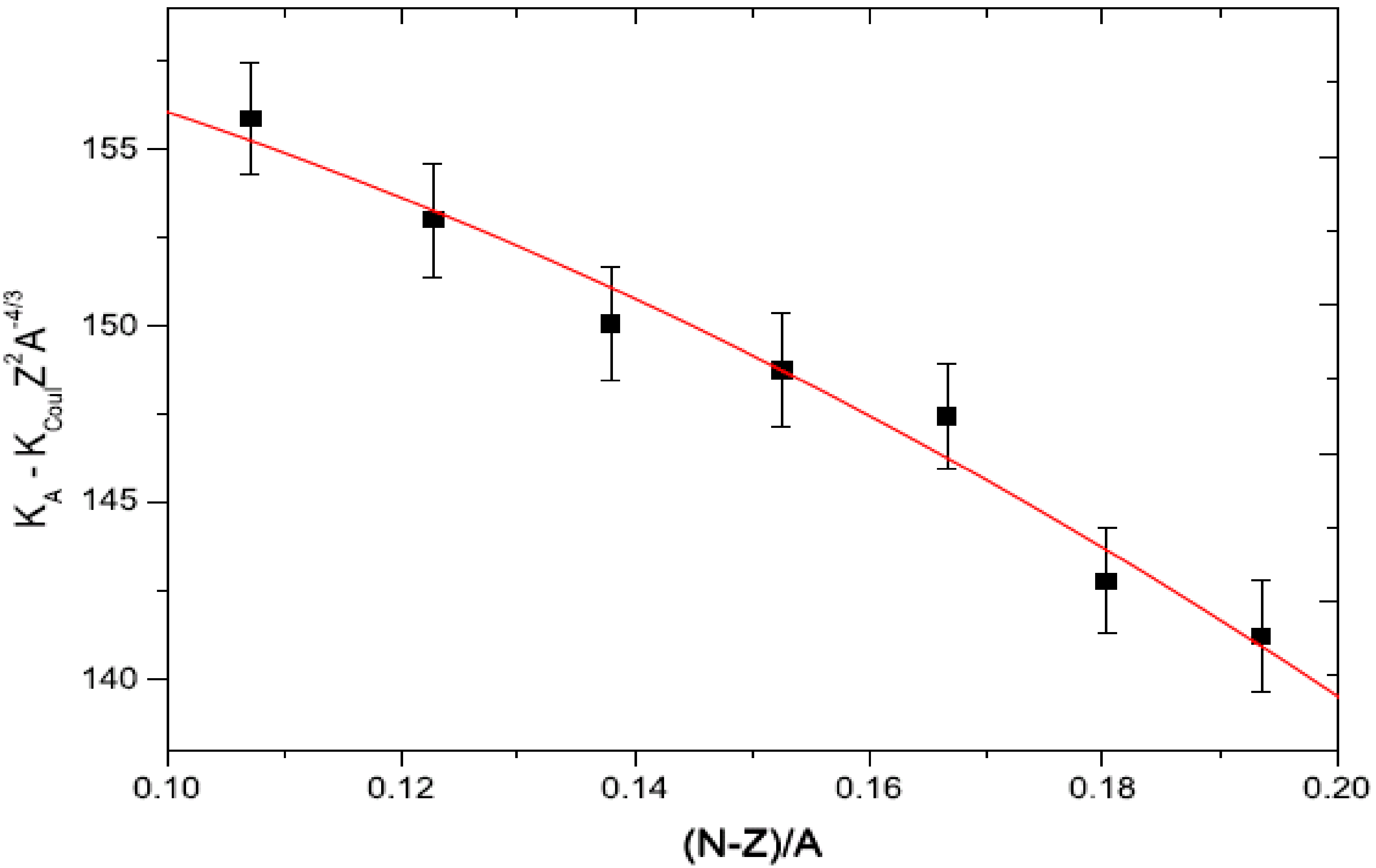
$$K_A - K_{Coul}Z^2A^{-4/3} \sim K_{vol}(1 + cA^{-1/3}) + K_\tau((N - Z)/A)^2$$

$$\sim \text{Constant} + K_\tau((N - Z)/A)^2$$

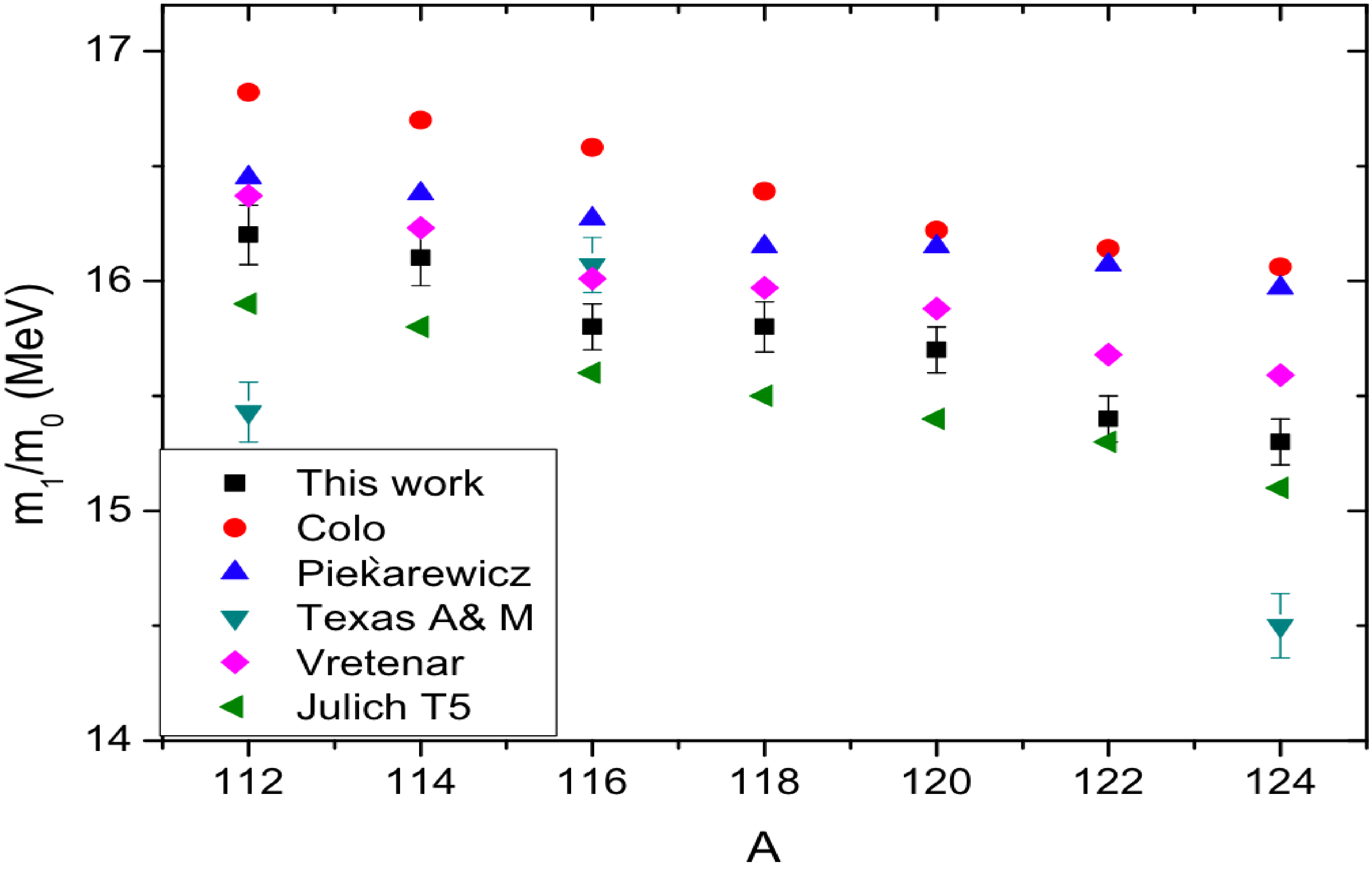
K_{Coul} = - 5.2 MeV (from Sagawa)

$(N - Z)/A$

^{112}Sn – ^{124}Sn: 0.107 – 0.194



$$K_\tau = -550 \pm 100 \text{ MeV}$$



17
16
15
14
m_1/m_0 (MeV)
112
114
116
118
120
122
124
A
This work
Colo
Piekarewicz
Texas A& M
Vretenar
Julich T5

Colò *et al*.: Non-relativistic RPA (without pairing) reproduces ISGMR in ^{208}Pb and ^{90}Zr [K_∞ = 240 MeV]

Piekarewicz: Relativistic RPA (FSUGold model) reproduces g.s. observables and ISGMR in ^{208}Pb, ^{144}Sm and ^{90}Zr [K_∞ = 230 MeV]

Vretenar: Relativistic mean field (DD-ME2: density-dependent mean-field effective interaction).

[K_∞ = 240 MeV].

Tselyaev *et al*.: Quasi-particle time-blocking approximation (QTBA) (T5 Skyrme interaction)

[K_∞ = 202 MeV?!]

Softness of Sn and Cd nuclei (compared to ^{208}Pb and ^{90}Zr) is still unresolved.

Spin-isospin excitations

Neutral (ν,ν') and charged (ν_e,e^-), (ν_e,e^+) currents

NC ⇒ Inelastic electron and proton scattering

⇒ M0, M1, M2

CC ⇒ Charge-exchange reactions

Isovector charge-exchange modes

⇒ GTR, IVSGMR, IVSGDR, etc.

Importance for nuclear astrophysics,

ν-physics, 2β-decay, n-skin thickness, etc.

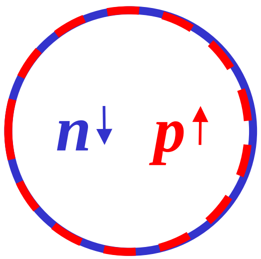
(p,n), $({}^3\mathrm{He},t)$ $\{\mathrm{GT}^-\}$; (n,p), $(d,{}^2\mathrm{He})$ & $(t,{}^3\mathrm{He})$ $\{\mathrm{GT}^+\}$

Nucleus → **Many-body system with a finite size**

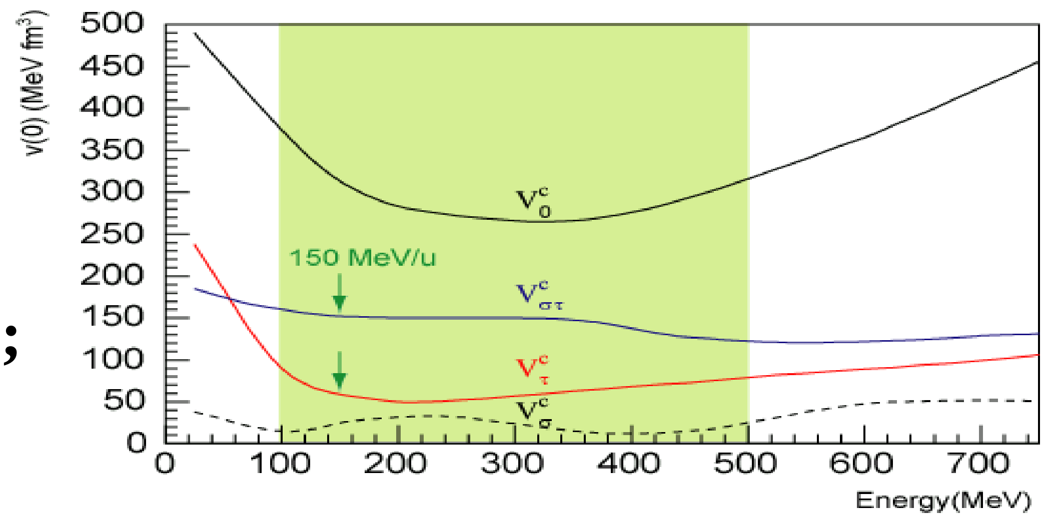
Vibrations → **Multipole expansion with r, Y_{lm}, τ, σ**

	$\Delta S=0, \Delta T=0$	$\Delta S=0, \Delta T=1$	$\Delta S=0, \Delta T=1$	$\Delta S=1, \Delta T=1$	$\Delta S=1, \Delta T=1$
L=0: Monopole	**ISGMR** $r^2 Y_0$	**IAS** τY_0	**IVGMR** $\tau r^2 Y_0$	**GTR** $\tau \sigma Y_0$	**IVSGMR** $\tau \sigma r^2 Y_0$
L=1: Dipole	**ISGDR** $(r^3 - 5/3\langle r^2\rangle r) Y_1$		**IVGDR** $\tau r Y_1$		**IVSGDR** $\tau\sigma r Y_1$
L=2: Quadrupole	**ISGQR** $r^2 Y_2$		**IVGQR** $\tau r^2 Y_2$		**IVSGQR** $\tau\sigma r^2 Y_2$
L=3: Octupole	**LEOR, HEOR** $r^3 Y_3$				

Spin-isospin excitations



ΔL=0 ΔS=1 ΔT=1
GTR



- **Gamow-Teller transitions;**
  Isospin (ΔT=1)
  Spin (ΔS=1)

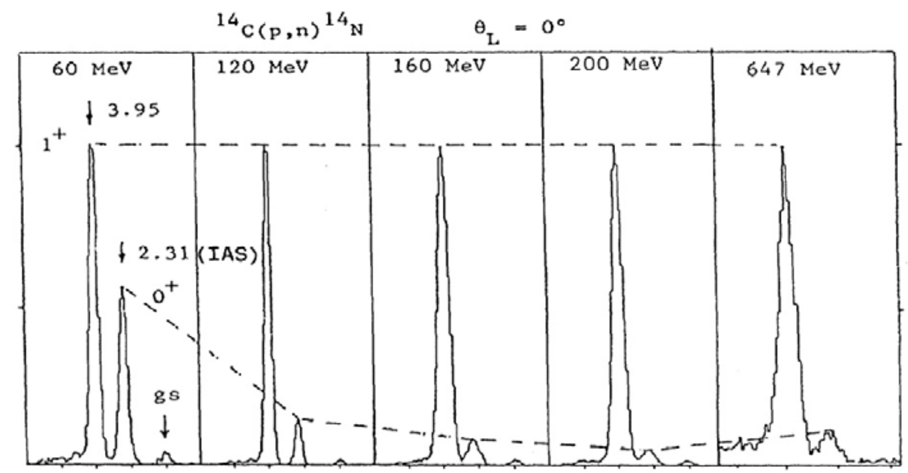
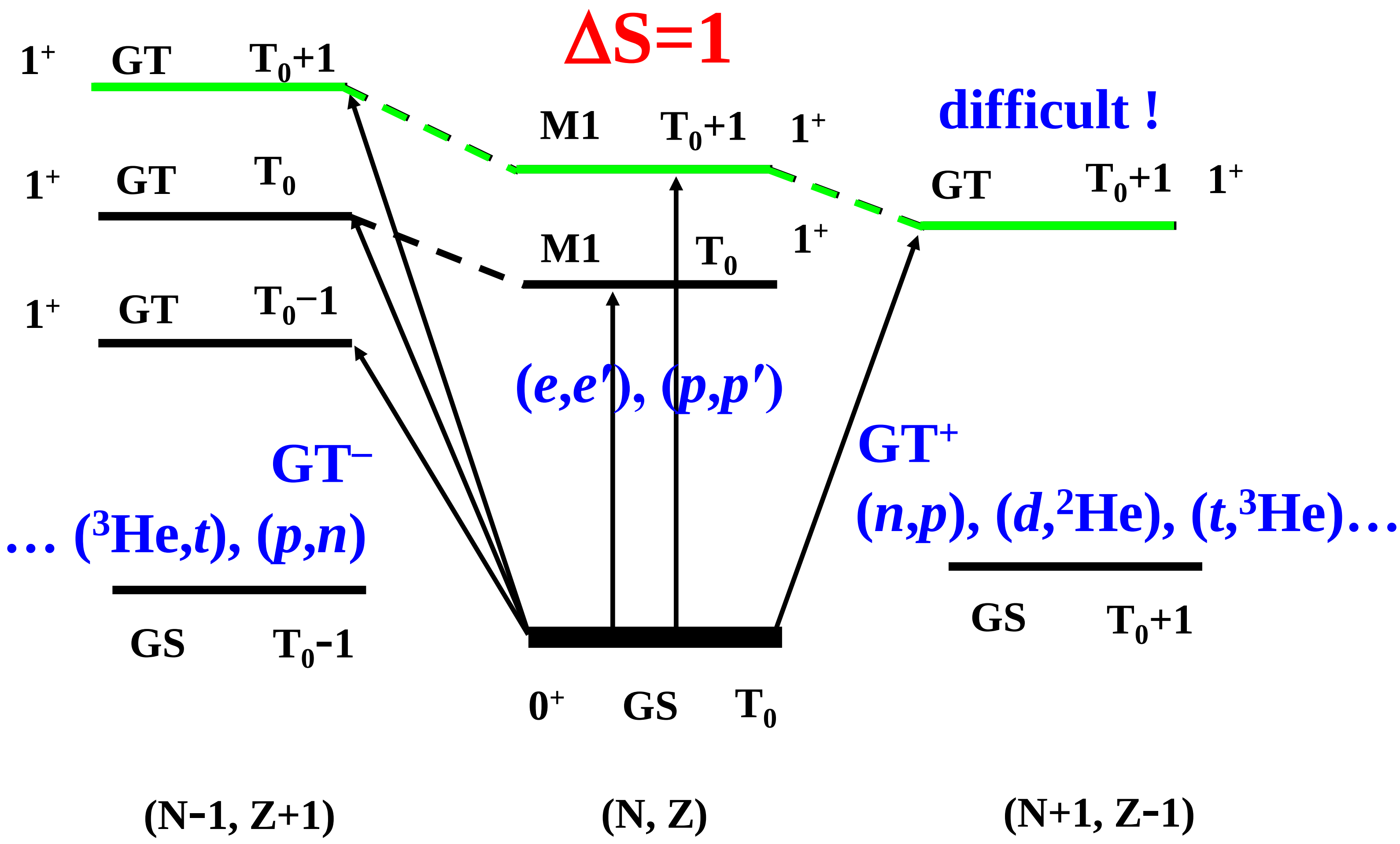


FIG. 4. Zero-degree cross-section spectra for the $^{14}C(p,n)^{14}N$ reactions at the indicated bombarding energies. The spectra have been arbitrarily normalized. From Gaarde (1985) and Rapaport (1989).

Advantages

- **Cross section peaks at θ° (ΔL=0)**
- **Strong excitation of GT states at E/A=100-500 MeV/u**

Spin-flip & GT transitions



The (^{3}He,*t*) reaction at 0 degree

- **Cross sections at E(^{3}He)=450 MeV, *q*=0 for (^{3}He,*t*) reactions**

$$\frac{d\sigma}{d\Omega} = \frac{\mu_i \mu_f}{(\pi\hbar^2)^2}\left(\frac{k_f}{k_i}\right)\left(N_\tau^D\, |J_\tau|^2\, B(F) + N_{\sigma\tau}^D\, |J_{\sigma\tau}|^2\, B(GT)\right)$$

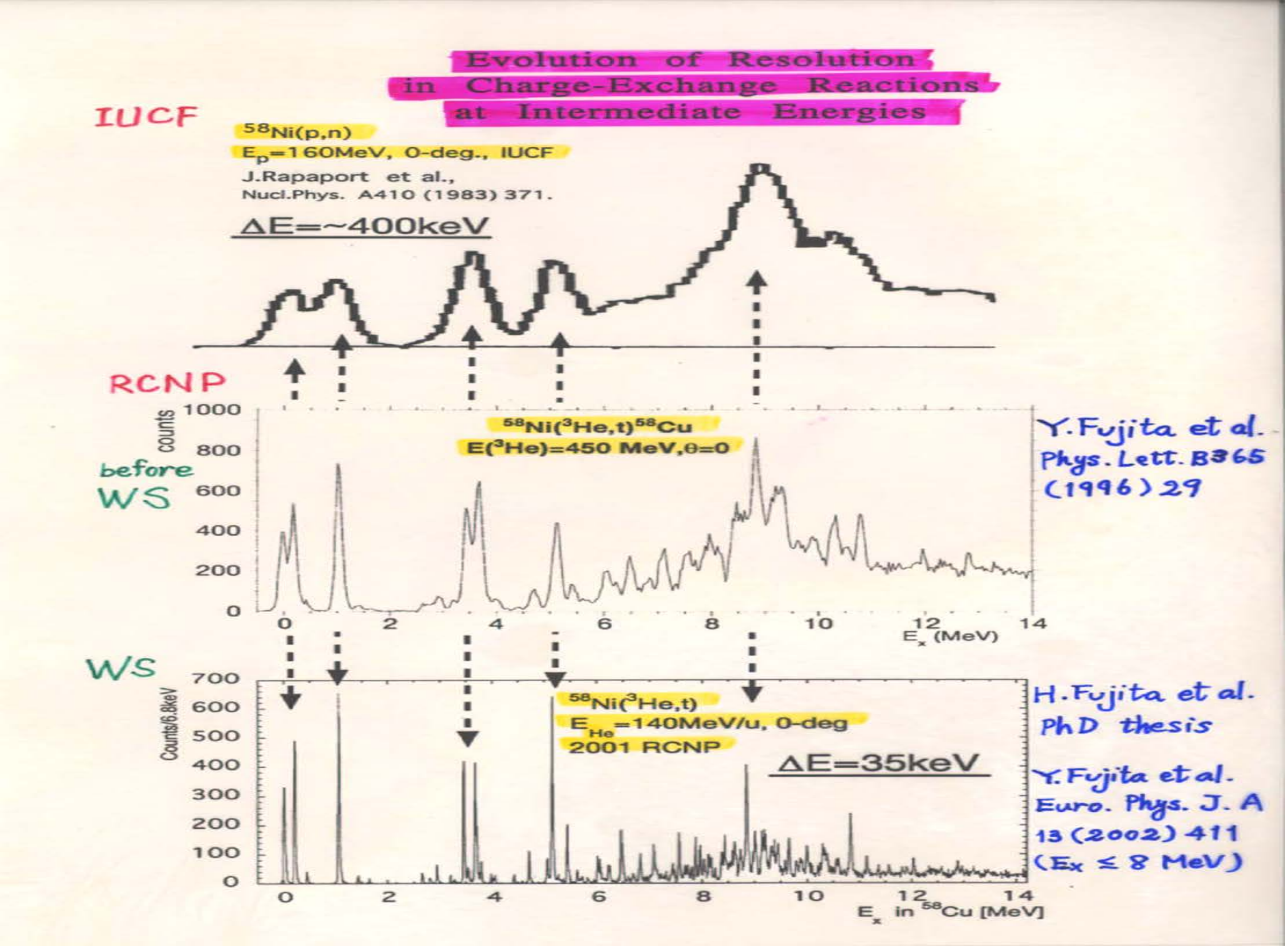
T. N. Taddeucci *et al*., Nucl. Phys. A469, 125 (1987)
I. Bergqvist *et al*., Nucl. Phys. A469, 648 (1987)

- **Neutrino absorption cross sections**

$$\sigma = \frac{1}{\pi\hbar^4 c^3}\left[G_V^2 B(F) + G_A^2 B(GT)\right] \times F(Z, E_e)\, p_e E_e$$

***F*(*Z*, E_e) is the relativistic Coulomb barrier factor**

Importance of charge-exchange reactions at intermediate energies


Evolution of Resolution
in Charge-Exchange Reactions
at Intermediate Energies
IUCF
58Ni(p,n)
Ep=160MeV, 0-deg., IUCF
J.Rapaport et al.,
Nucl.Phys. A410 (1983) 371.
ΔE=~400keV
RCNP
58Ni(3He,t)58Cu
E(3He)=450 MeV,θ=0
before WS
counts
Y.Fujita et al.
Phys.Lett.B365 (1996) 29
Ex (MeV)
WS
58Ni(3He,t)
EHe=140MeV/u, 0-deg
2001 RCNP
ΔE=35keV
Counts/6.8keV
H.Fujita et al.
PhD thesis
Y.Fujita et al.
Euro. Phys. J. A 13 (2002) 411
(Ex ≤ 8 MeV)
Ex in 58Cu [MeV]

Determination of GT$^+$ Strength and its Astrophysical Implications

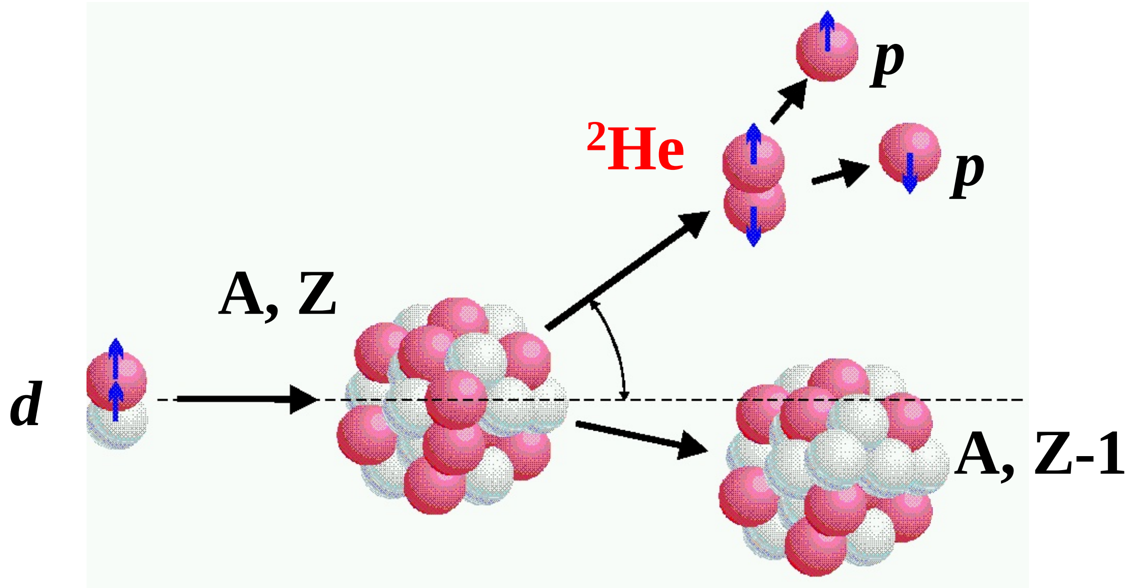
In supernova explosions, electron capture (EC) on *fp*-shell nuclei plays a dominant role during the last few days of a heavy star with M > 10 $M_\odot$

Presupernova stage; deleptonization ⇒ core collapse ⇒ subsequent type IIa Supernova (SN) explosion

H.A. Bethe *et al*., Nucl. Phys. A324 (1979) 487

Supernova Simulatie

Exclusive excitations ΔS=ΔT=1: (*d*,^{2}He)

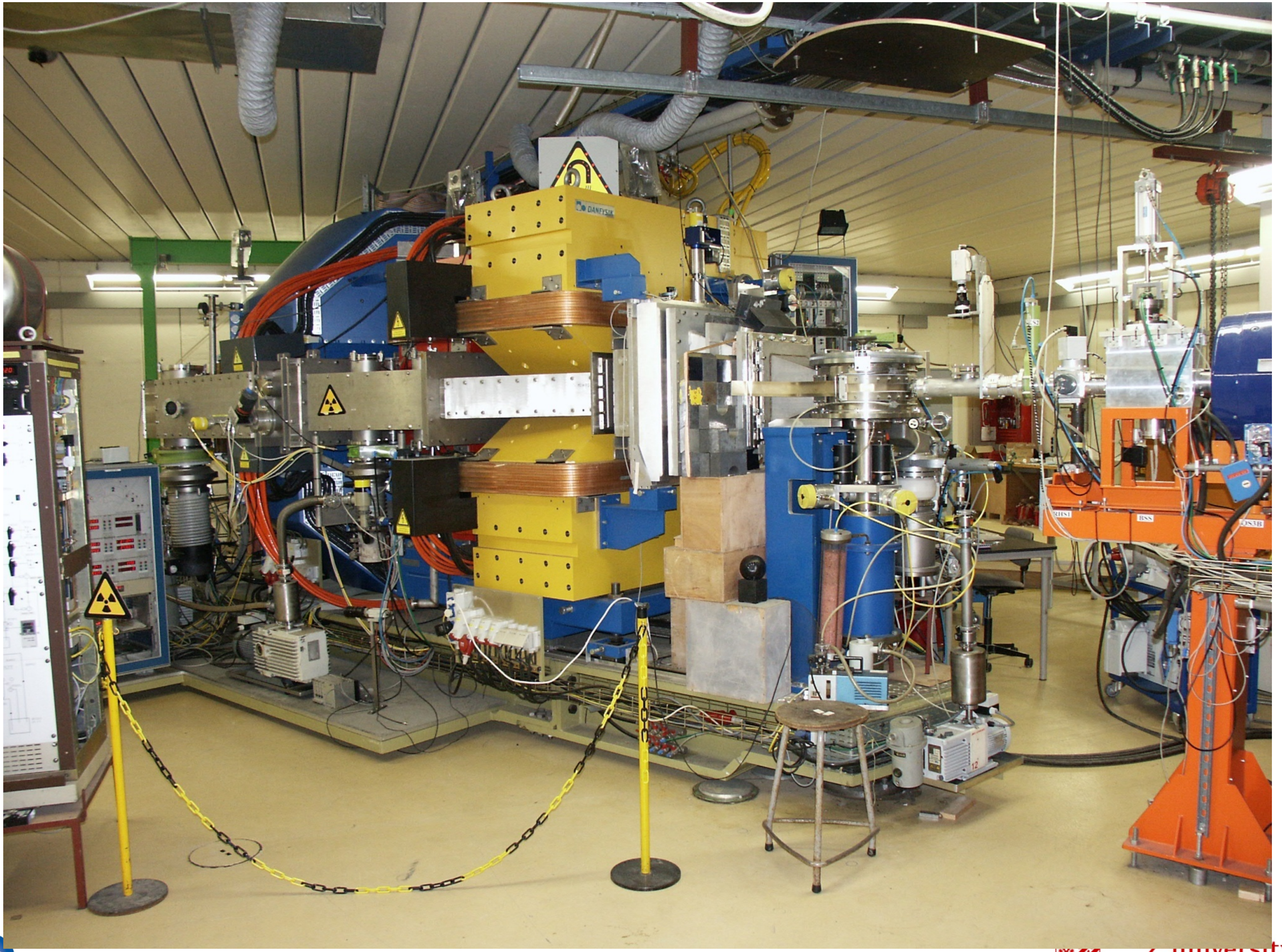


$^3S_1$ deuteron ⇒ $^1S_0$ di-proton (^{2}He)

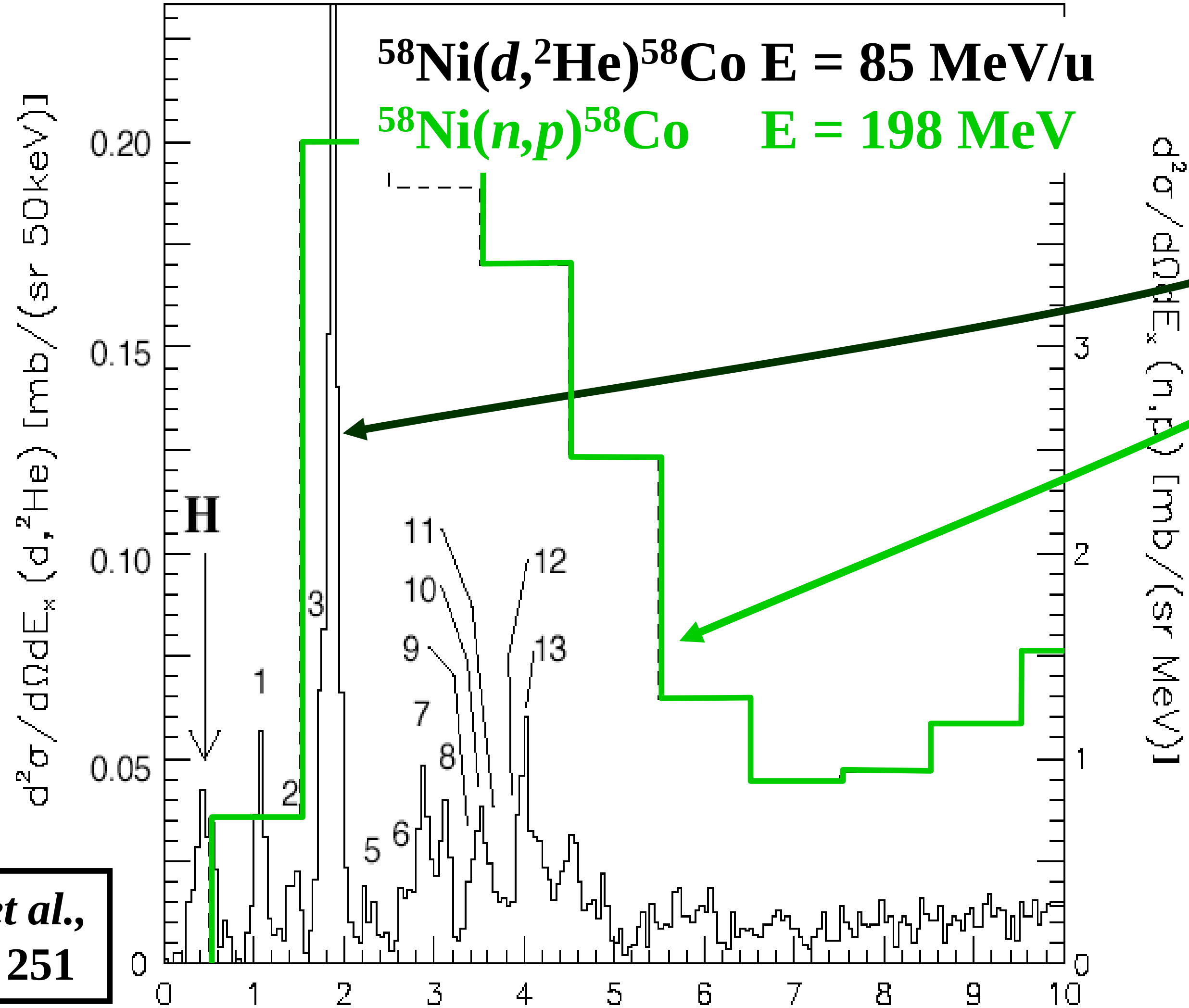
$^1S_0$ dominates if (relative) 2-proton kinetic energy ε < 1 MeV

(*n*,*p*)-type probe with exclusive ΔS=1 character (GT$^+$ transitions)

But near 0°, tremendous background from *d*-breakup

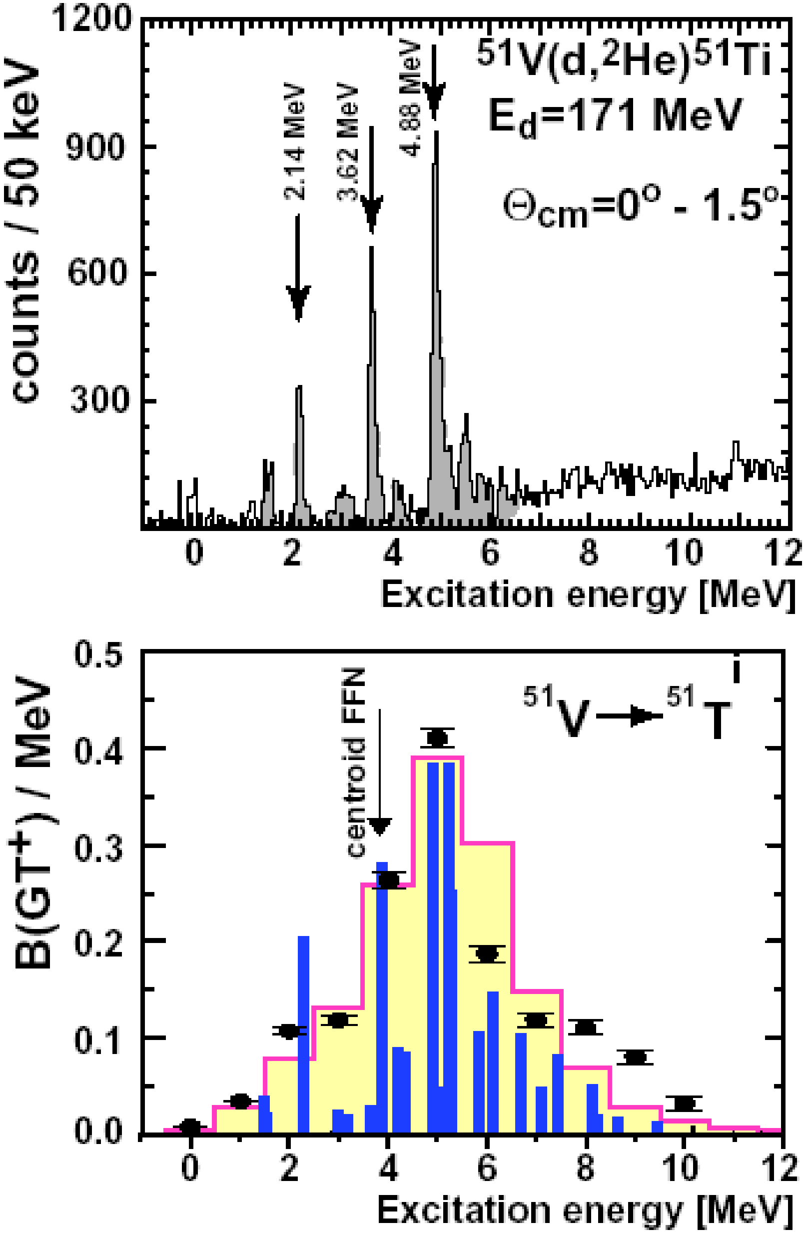

DANFYSIK

(d,^{2}He) as GT$^+$ probe in *fp*-shell nuclei



M. Hagemann *et al.*,
PLB 579 (2004) 251

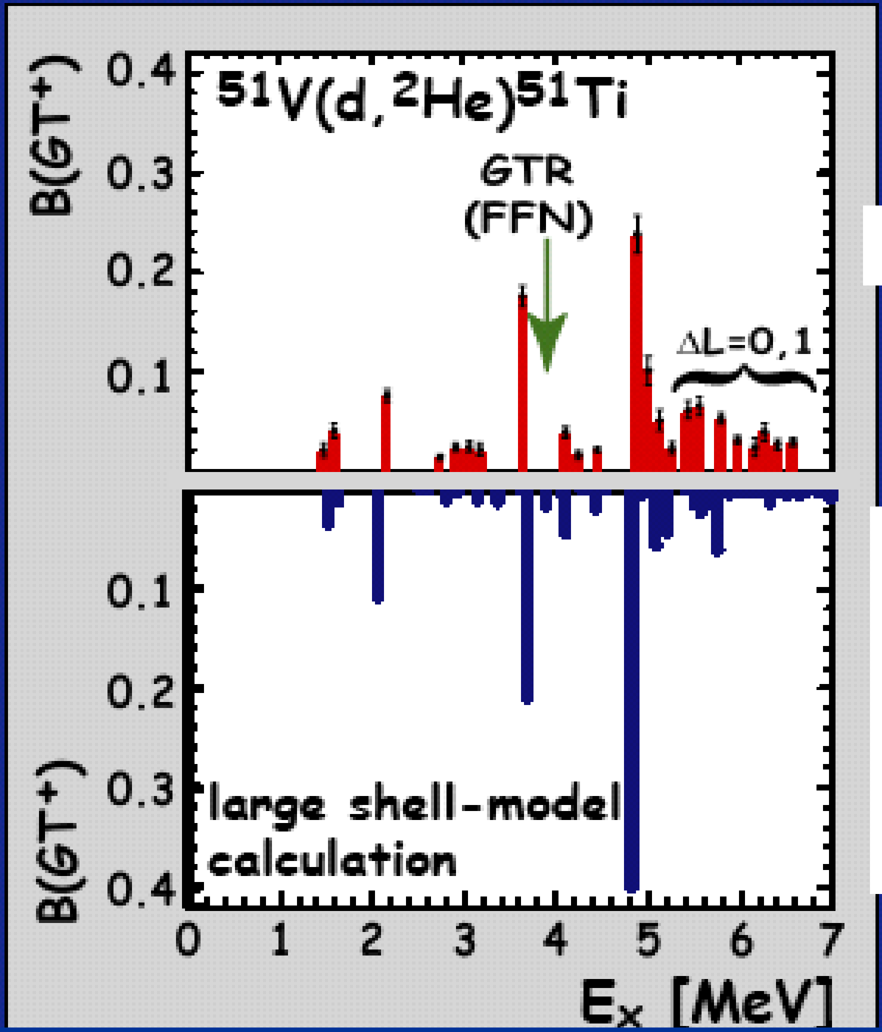
C. Bäumer *et al.*, PRC **68**, 031303(R) (2003)



KVI

university of groningen

^{51}V(d,^{2}He): Comparison with shell-model calculations



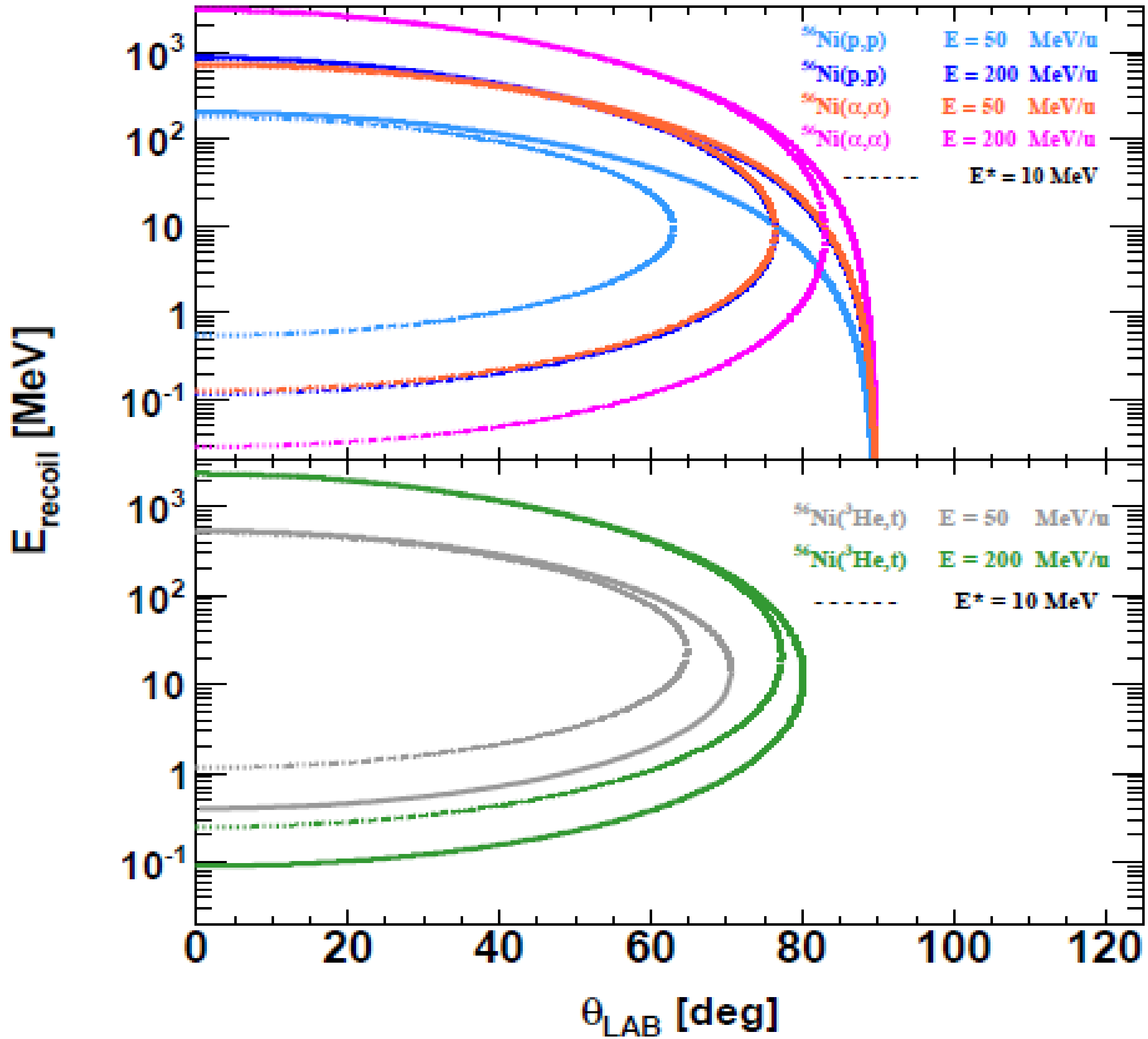
← Experimental result

← Full *fp*-shell model calculations
quenching factor $(0.74)^2$
G. Martínez-Pinedo, K. Langanke

Outlook

Radioactive ion beams will be available at energies where it will be possible to study ISGMR, ISGDR and GT transitions (RIKEN, NSCL, FAIR, SPIRAL2)

- **Determine GT strength in unstable *sd* & *fp* shell nuclei**
- **Measure ISGMR and ISGDR in extended isotope chain**
- **Unravel the nature of the pygmy dipole resonance**
- **Use IV(S)GDR as tool to determine n-skin [IV(S)GDR]**
- **Exotic excitations such as double GT (SHARAQ)**



^{56}Ni(p,p) E = 50 MeV/u
^{56}Ni(p,p) E = 200 MeV/u
^{56}Ni(α,α) E = 50 MeV/u
^{56}Ni(α,α) E = 200 MeV/u
E* = 10 MeV
^{56}Ni(^{3}He,t) E = 50 MeV/u
^{56}Ni(^{3}He,t) E = 200 MeV/u
E* = 10 MeV
E_{recoil} [MeV]
θ_{LAB} [deg]

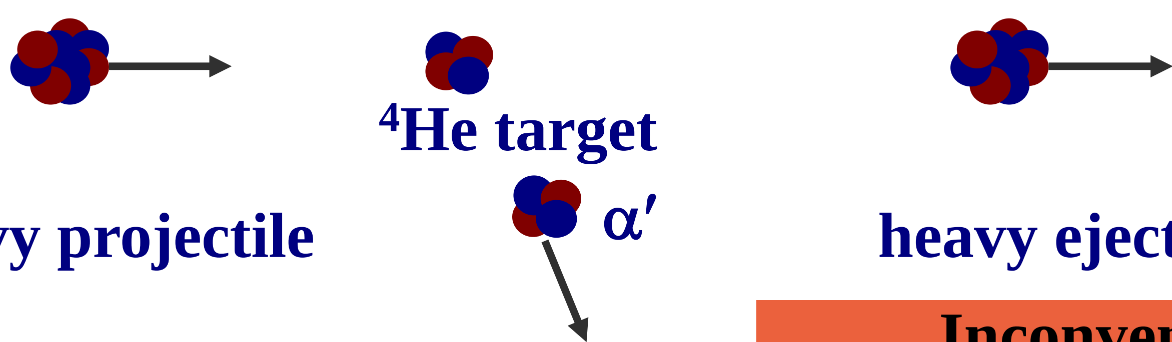
Nuclear structure studies with reactions in inverse kinematics

- Possible at FAIR, RIKEN and NSCL

(beam energies of 50-100 MeV/u are needed!)

Approach:
measure the recoiling alphas

(α,α')



heavy projectile

heavy ejectile

recoiling alphas

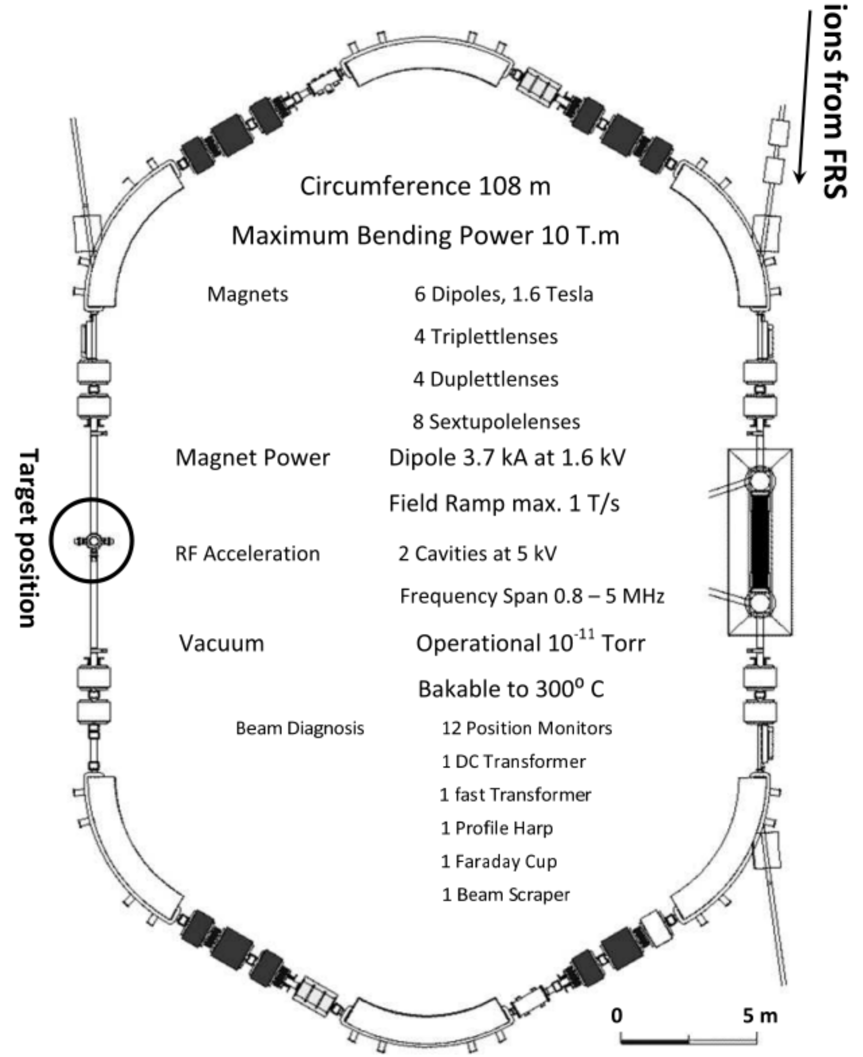
Inconvenience:
difficulty to detect the low-energy alphas

Storage Ring

Experimental storage ring at GSI

Luminosity: $10^{26} - 10^{27}$ cm^{-2}s^{-1}

EPJ Web of Conferences 66, 03093 (2014)



Detection system @ FAIR

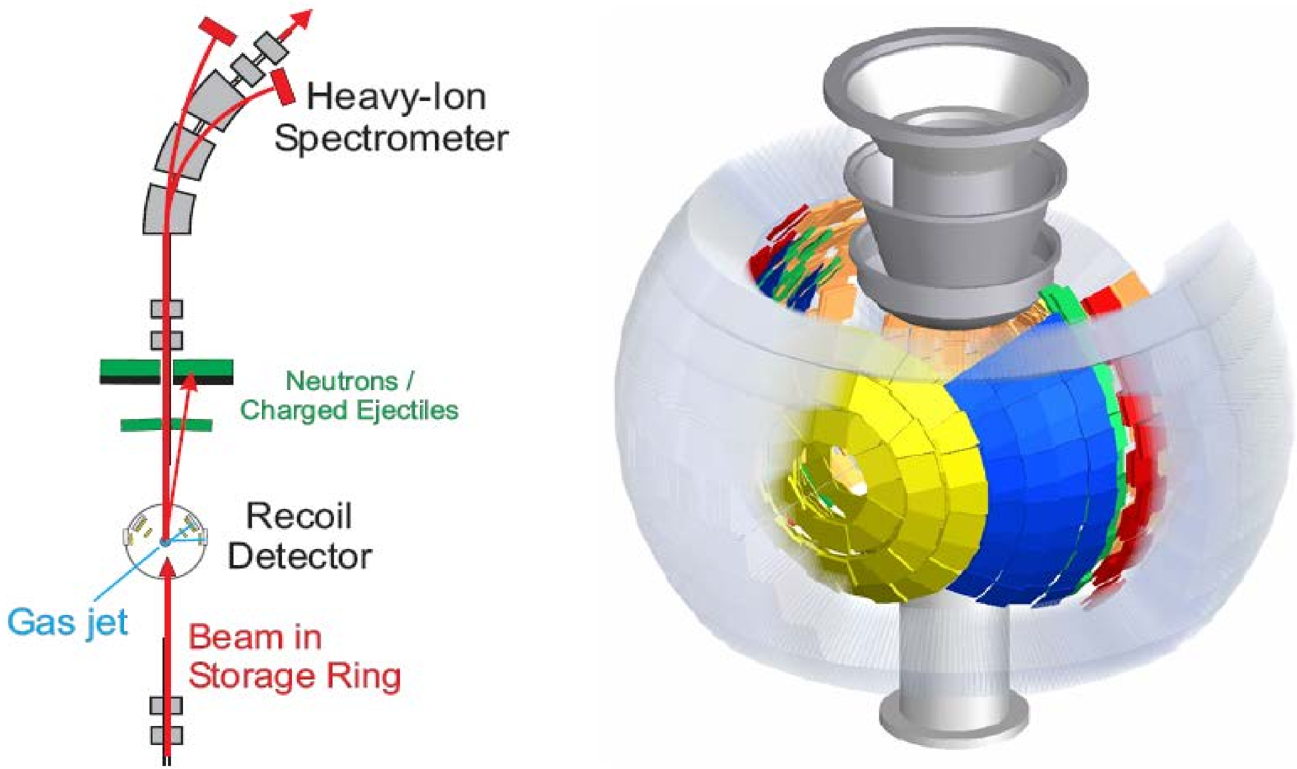
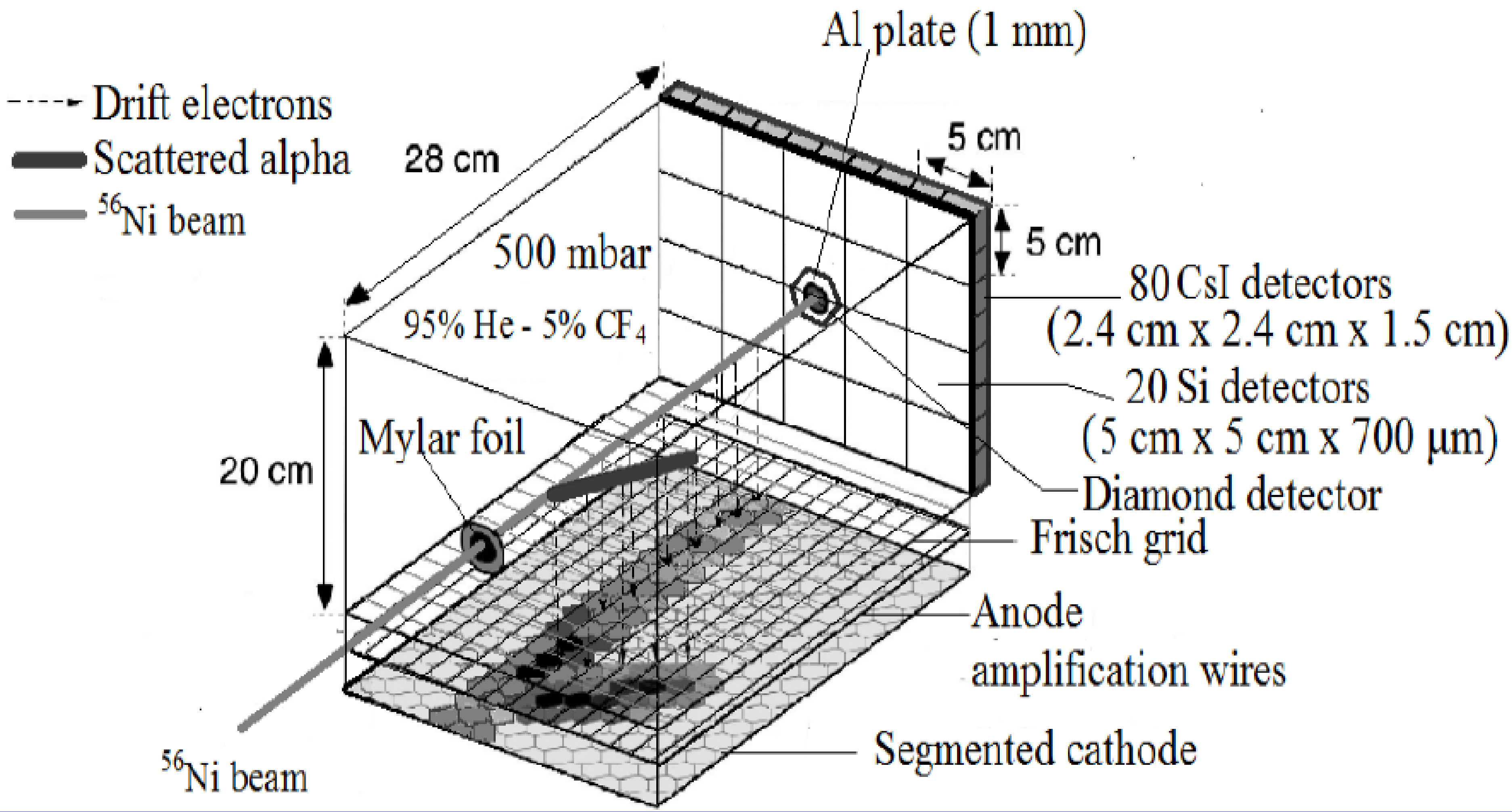


Figure 1: *Schematic view of the EXL detection systems. Left: Set-up built into the NESR storage ring. Right: Target-recoil detector surrounding the gas-jet target.*

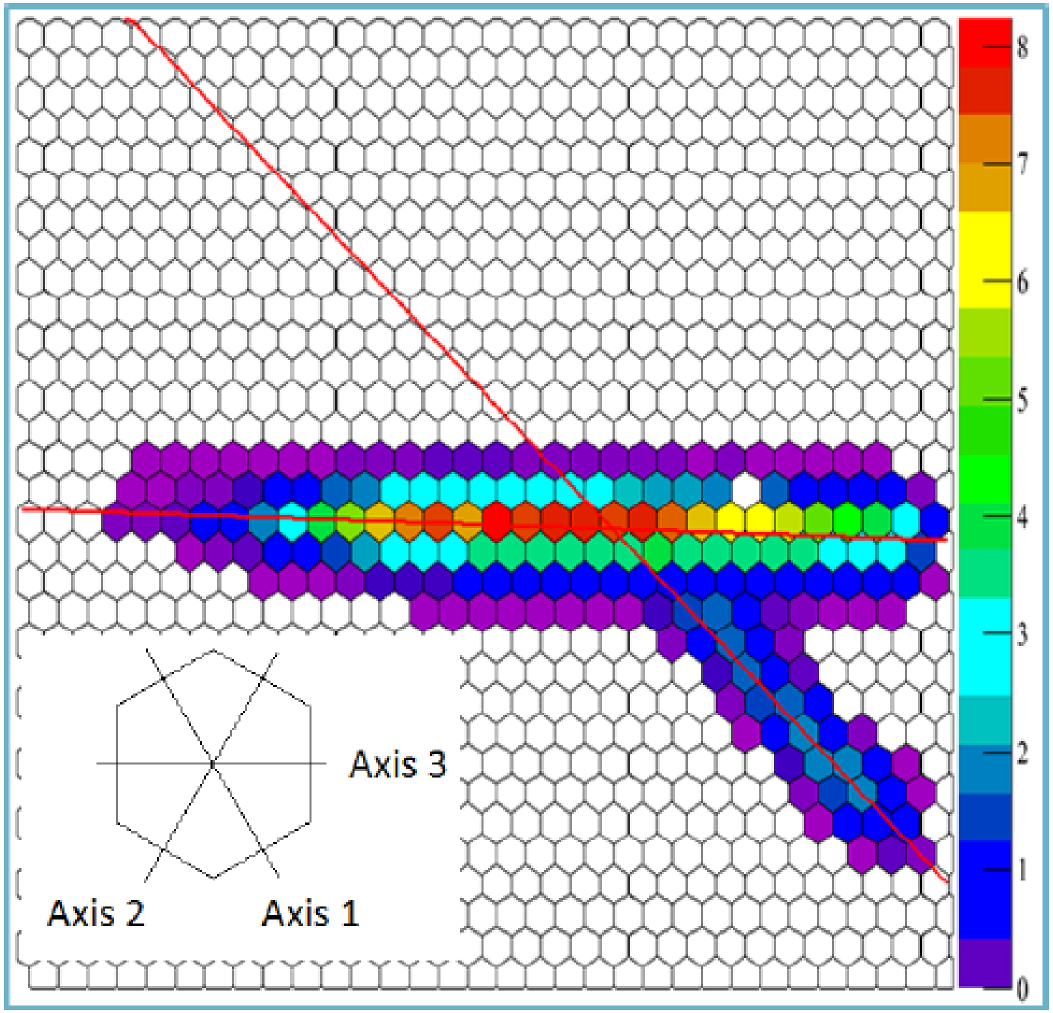
Use of EXL recoil detector prototype has been successfully tested [Nasser Kalantar talk on Tuesday afternoon]

Schematic view of MAYA active target detector



Marine Vandebrouck talk on Tuesday afternoon

Recoil Track



- Recoil alpha particle track due to inelastic scattering with ^{56}Ni.
- Background events can be separated from the range of the recoil particles and also from the magnitude of charges induced on the pads.

- **Pygmy Dipole Resonance (PDR): Tuesday morning**
- **IVGMR: Tuesday afternoon (Remco Zegers)**
- **Anti-analogue GDR and n-skin:**

  Tuesday afternoon (Attila Krasznahorkay)
- **Hot IVGDR: Wednesday morning**

Etc.

Thank you for your attention