Studies on giant resonances and other collective modes

Adam Maj, Mateusz Krzysiek

Department of Atomic Nucleus Structure,
Institute of Nuclear Physics PAN in Krakow

ELI Seminar, 07.11. 2016r., Warsaw

Our team (IFJ PAN Kraków)

THE HENRYK NIEWODNICZAŃSKI
INSTITUTE OF NUCLEAR PHYSICS
POLISH ACADEMY OF SCIENCES

prof. dr hab. Adam Maj

dr hab. Maria Kmiecik, prof. IFJ

dr inż. Michał Ciemała

dr inż. Mateusz Krzysiek

(from 2017 – post-doc at ELI-NP)

mgr inż. Barbara Wasilewska *(PhD student*)

Areas of expertise regarding ELI-NP

Scientific

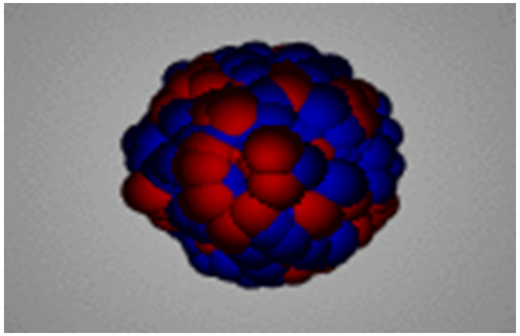
- collective modes of excitation
- reactions mechanisms

Technical

- Advanced simulations of detectors response ***(GEANT4, FLUKA)*** and reaction mechanisms ***(GEMINI++, CASCADE, FRESCO)***
- Scintillation detectors ***(BaF$_2$, LaBr$_3$, NaI, phoswich type)***
- Analog and digital electronics
- DAQ ***(also with GUI)*** and analysis software

Collective excitation of atomic nucleus

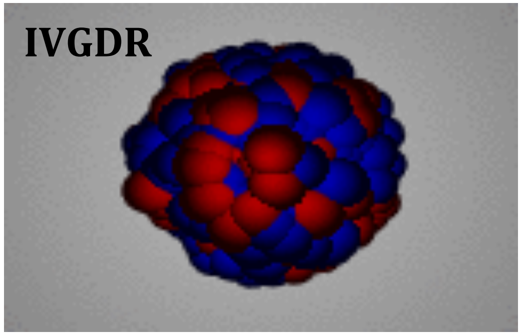
Protons and neutrons may oscillate



Collective excitation of atomic nucleus

Oscillations of almost all n and p

Giant Resonances



	ΔT = 0	Δ T = 1
Δ L = 0	**ISGMR**	**IVGMR**
Δ L = 1	**ISGDR**	**IVGDR**
Δ L = 2	**ISGQR**	**IVGQR**

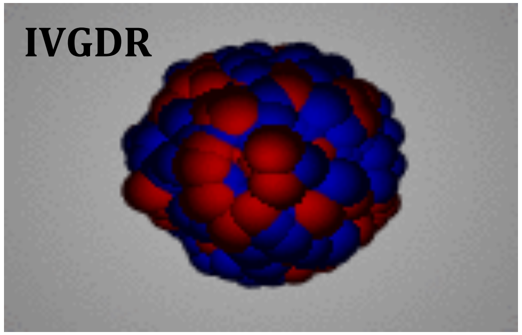
Different GRs according to multipolarity,

and isospin quantum numbers

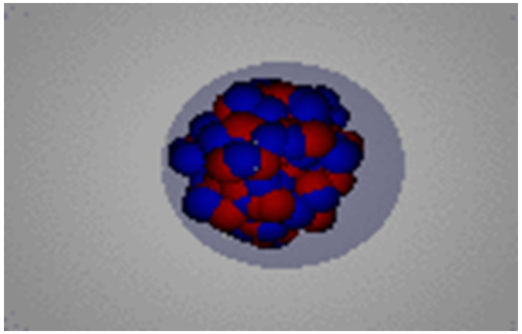
Collective excitation of atomic nucleus

Oscillations of almost all n and p

Giant Resonances



Can **„neutron skin"** oscillate as well ?



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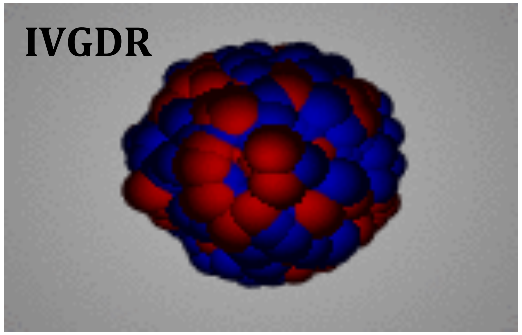

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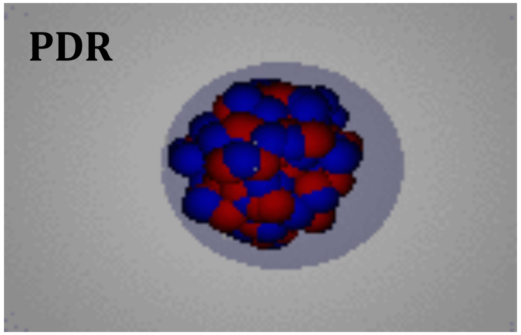

Pygmy Dipole Resonance

Collective excitation of atomic nucleus

Oscillations of almost all n and p

Giant Resonances

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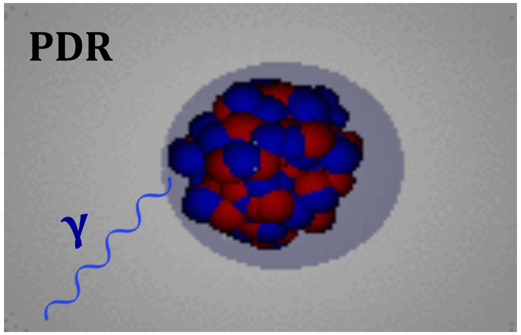
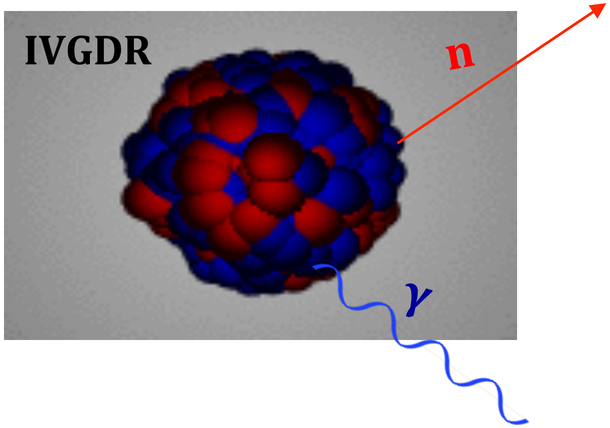
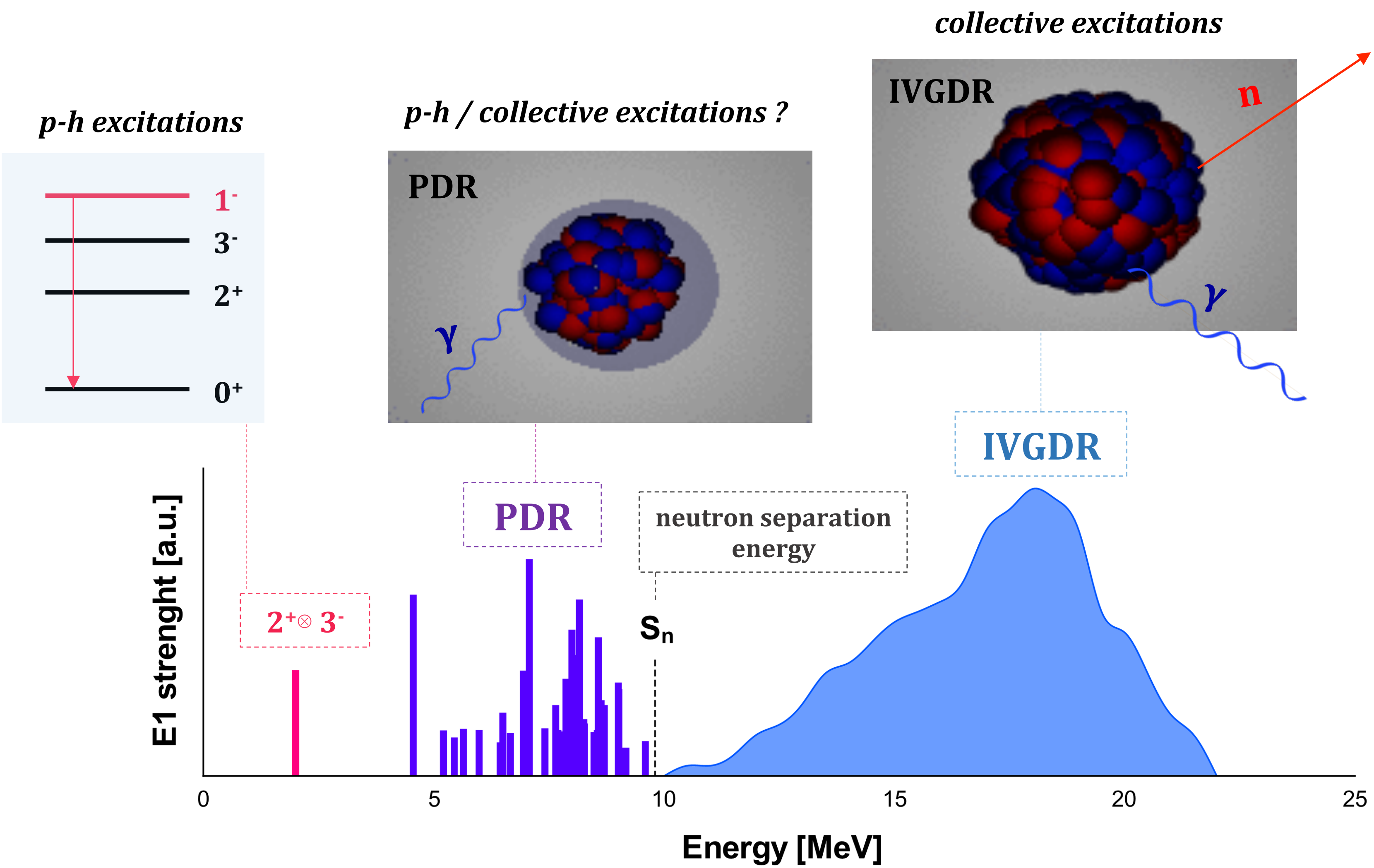




Can be studied by measuring emitted

γ rays and/or neutrons

Spectrum of electric dipole (E1) strength



Why PDR is important?

1) Contribution of PDR in r-process nucleosynthesis

- Cross section of radiative neutron capture rate related to PDR

  Goriely S., Phys. Lett. B 436 (1998) 10.

Synthesis of nuclei heavier than iron

2) Analogy between neutron skin in atomic nucleus and neutron star

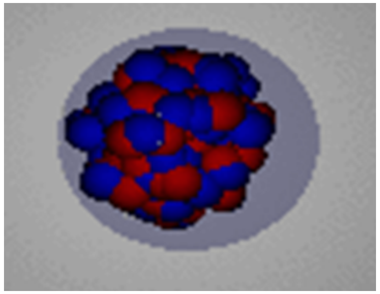
- *Neutron skin thickness correlated with PDR strength*

  Carbone et al. Phys. Rev. C 81, 041301(R) (2010)

- *Neutron skin thickness correlated with symmetry energy of EoS*

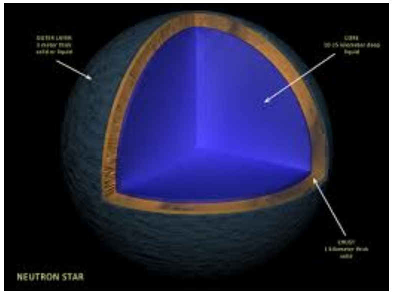
  Brown B. Alex, Phys. Rev. Lett. 85, 5296 (2000)

Properties of neutron stars



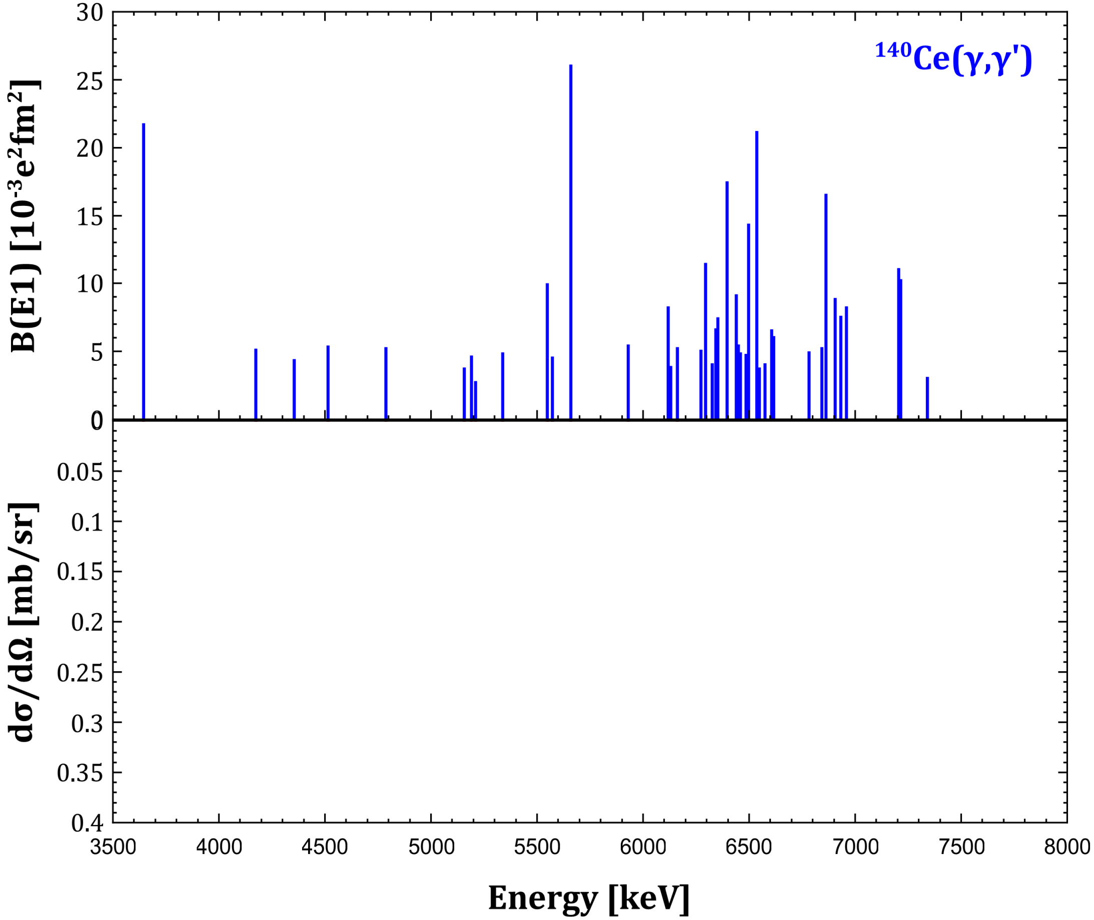
Equation of state

of nuclear matter



Pygmy states(PDR) *isospin character*

D. Savran *et al.*, PRL **97** (2006) 172502



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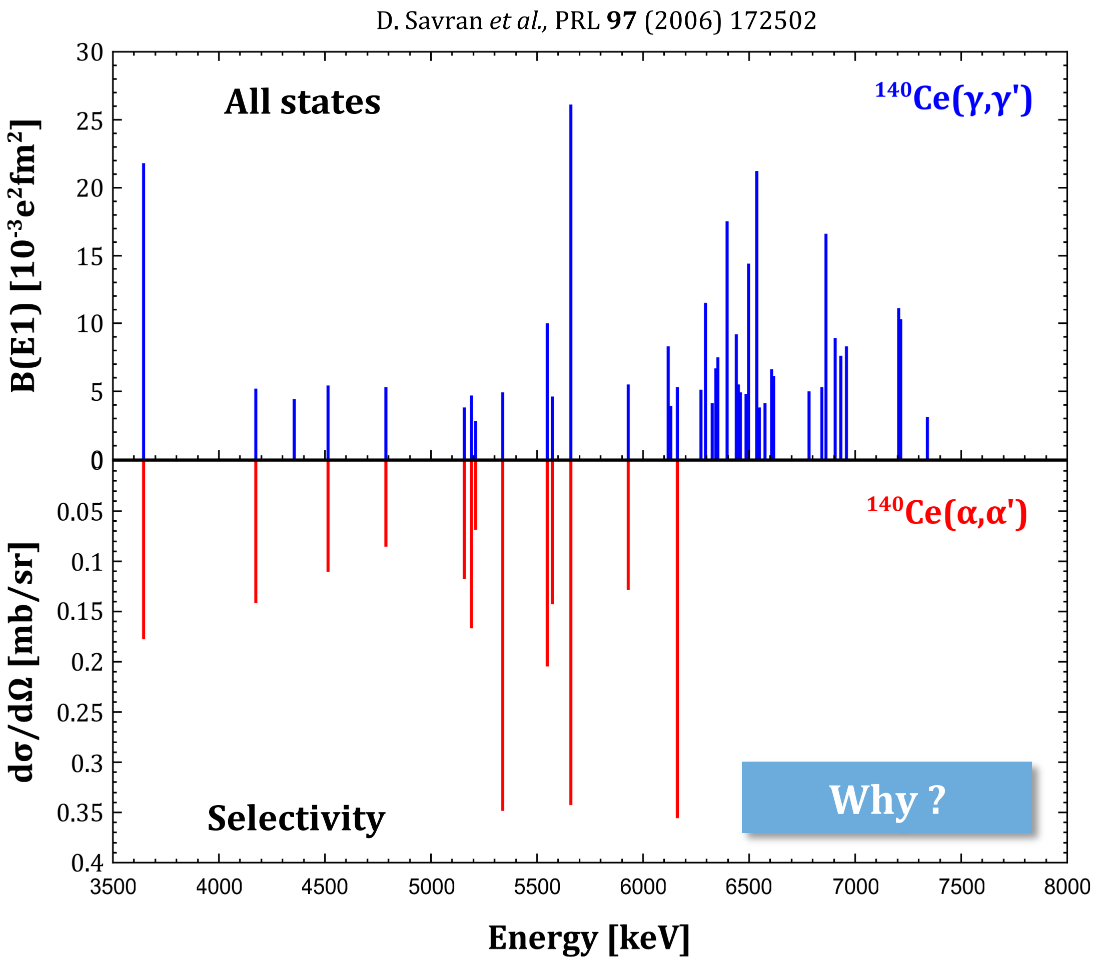

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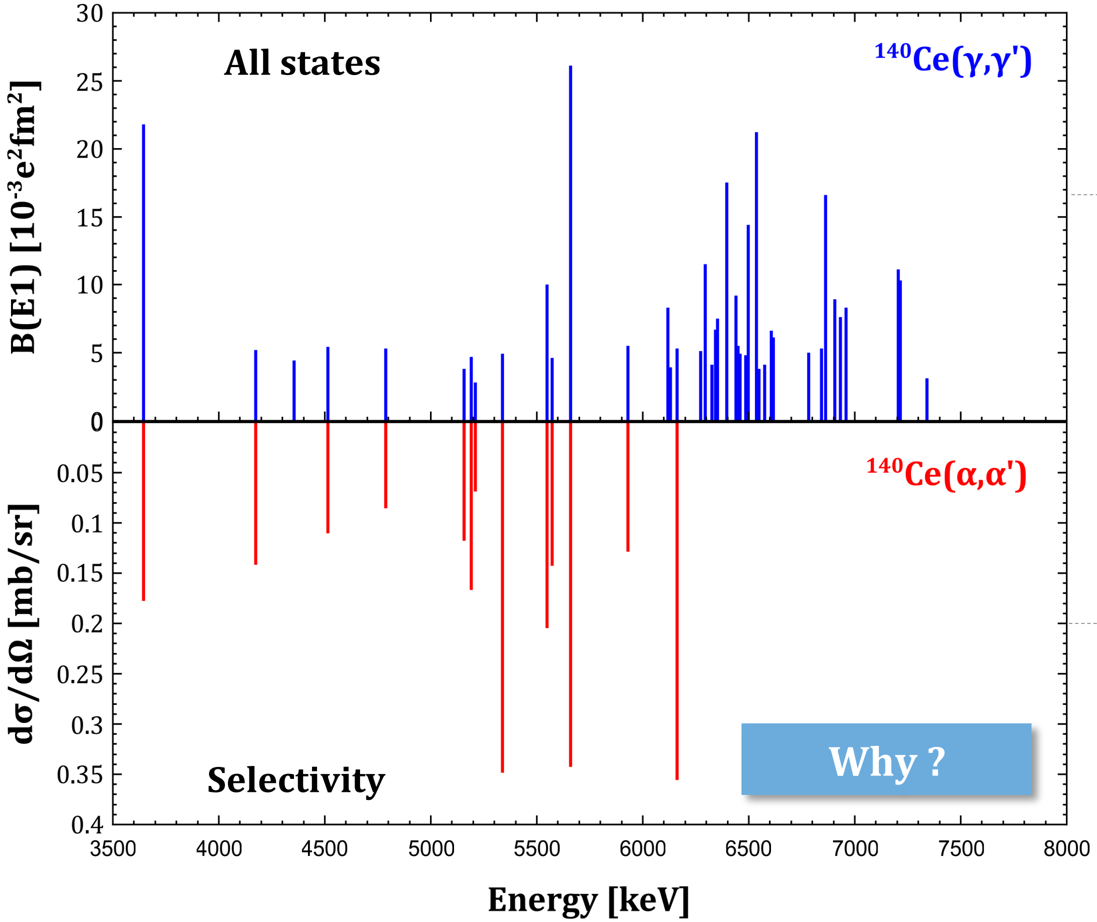
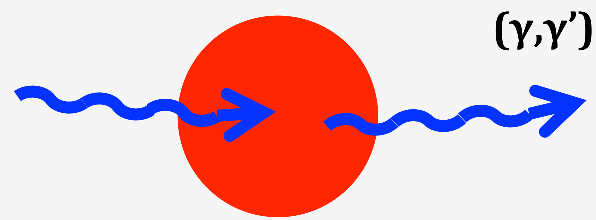
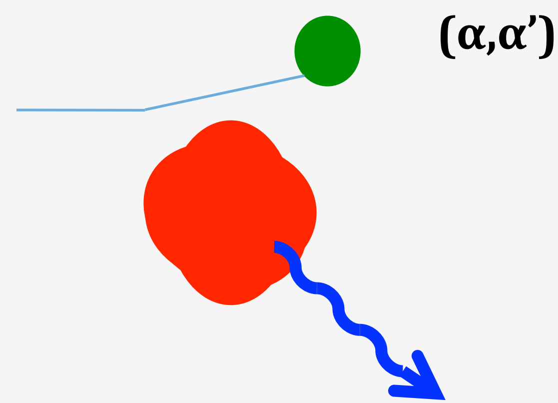




isovector (ΔT =1) excitations

Interaction with the whole nucleus

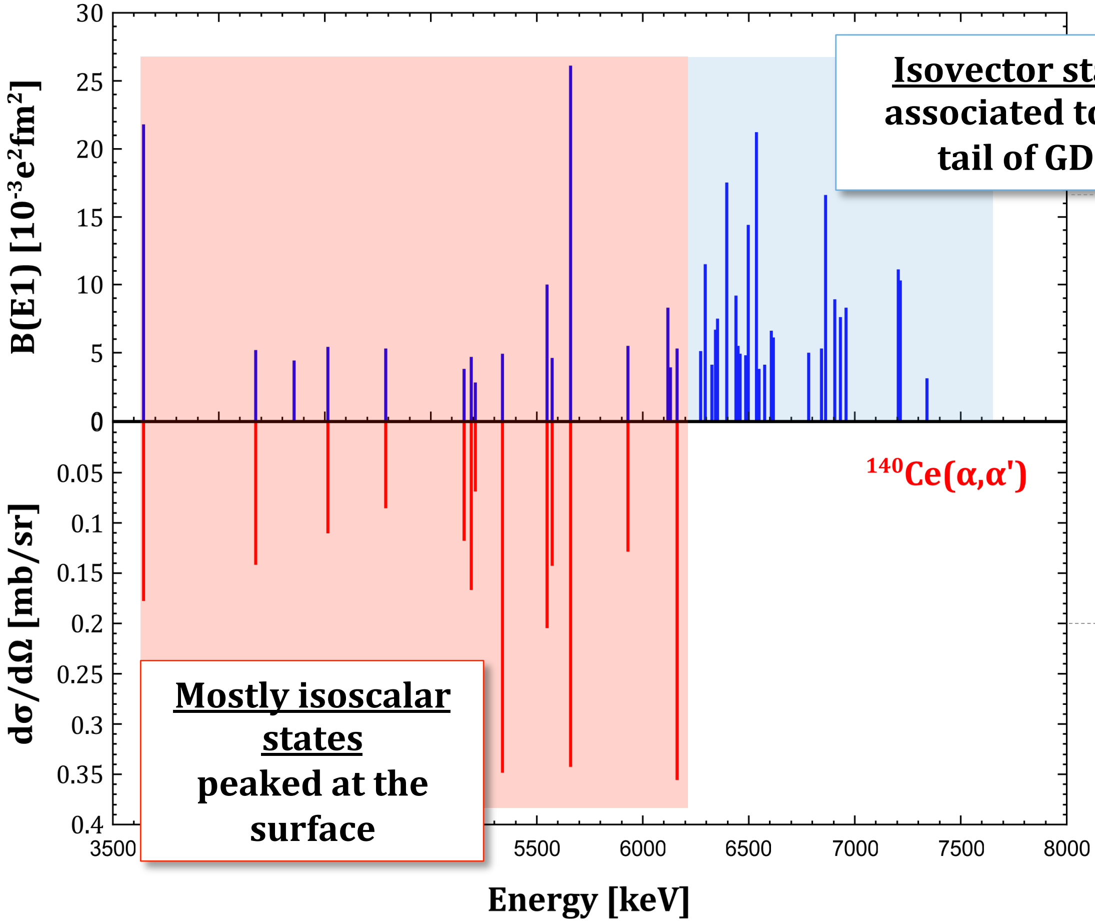


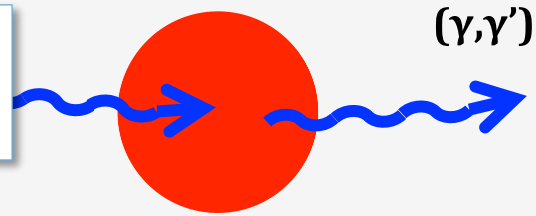
isoscalar (ΔT =0) excitations

Interaction mainly with the surface

Pygmy states(PDR) *isospin character*

D. Savran *et al.*, PRL **97** (2006) 172502





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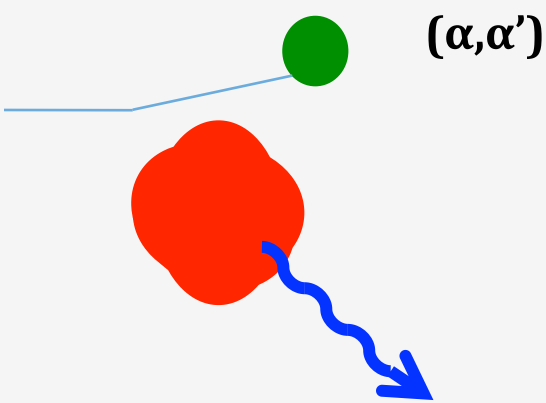
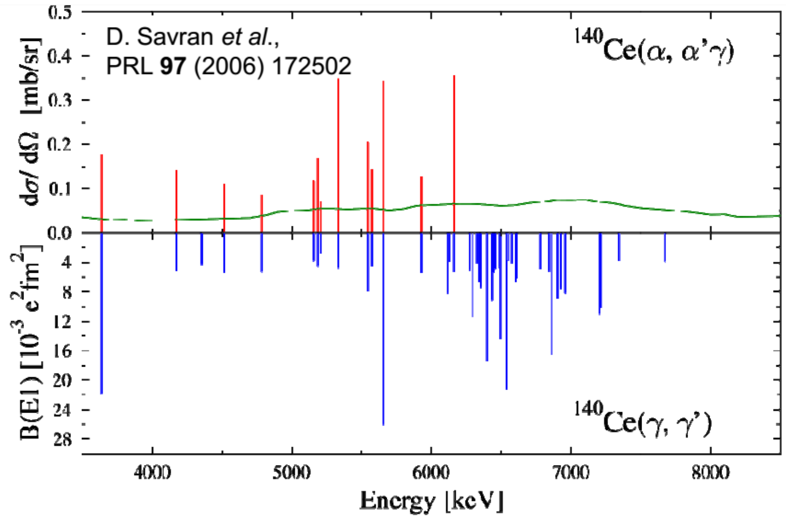


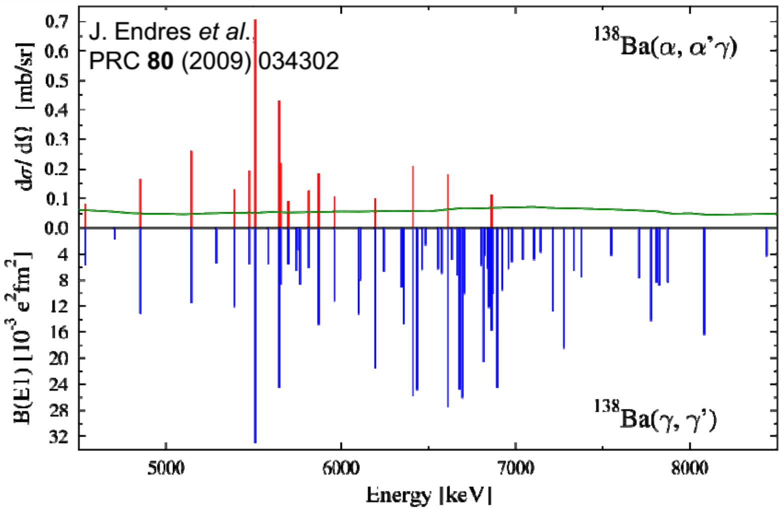
isoscalar (ΔT =0) excitations

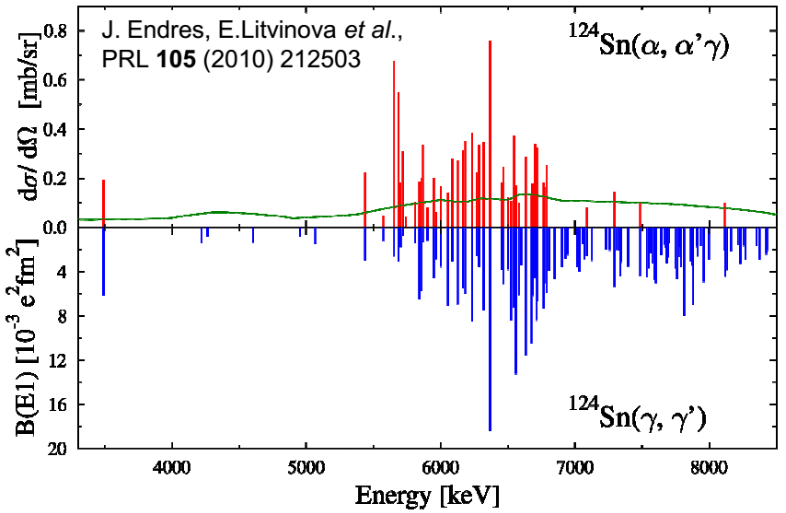
Interaction mainly with the surface

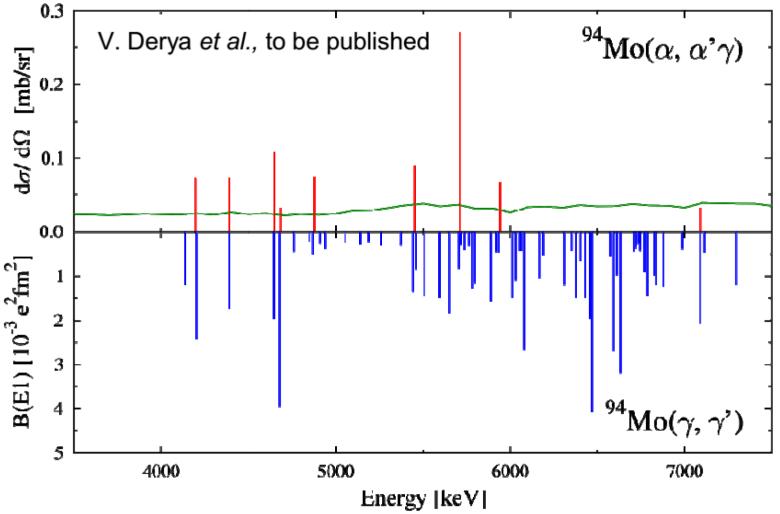
<u>Pygmy states(PDR)</u> *isospin character*

The same effect in different nuclei









Question: how would heavy ions excite?

Inelastic scattering of ^{17}O @ 20 MeV/u on ^{90}Zr, ^{124}Sn, ^{140}Ce, ^{208}Pb

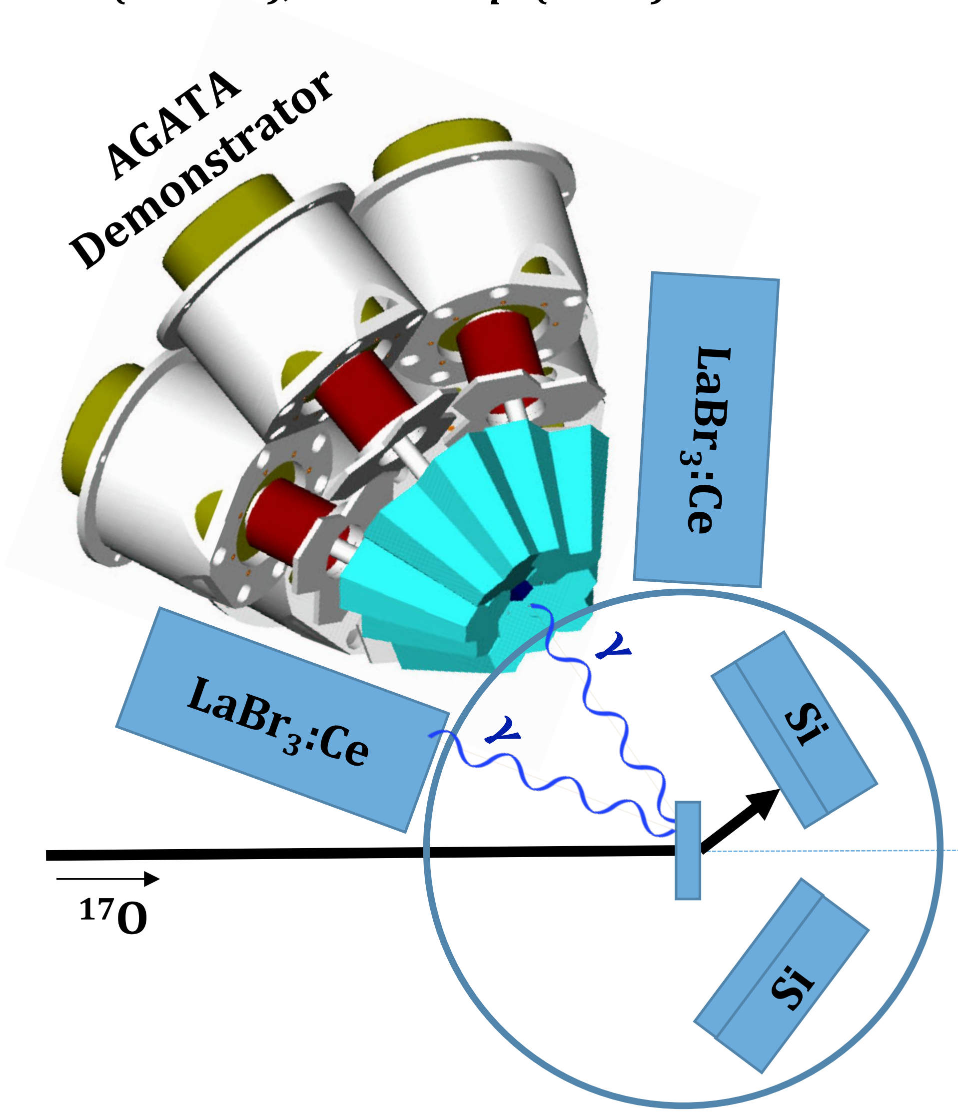
LNL-Legnaro, spokepersons: Maria Kmiecik (Krakow), Fabio Crespi (Milan)

Idea of experiment:

- Inelastic scattering of heavy ions for the first time to study PDR – ***TRACE array***
- Coincidence measurement of γ rays with high resolution and efficiency – ***AGATA*** and ***HECTOR+***

Why ^{17}O ?

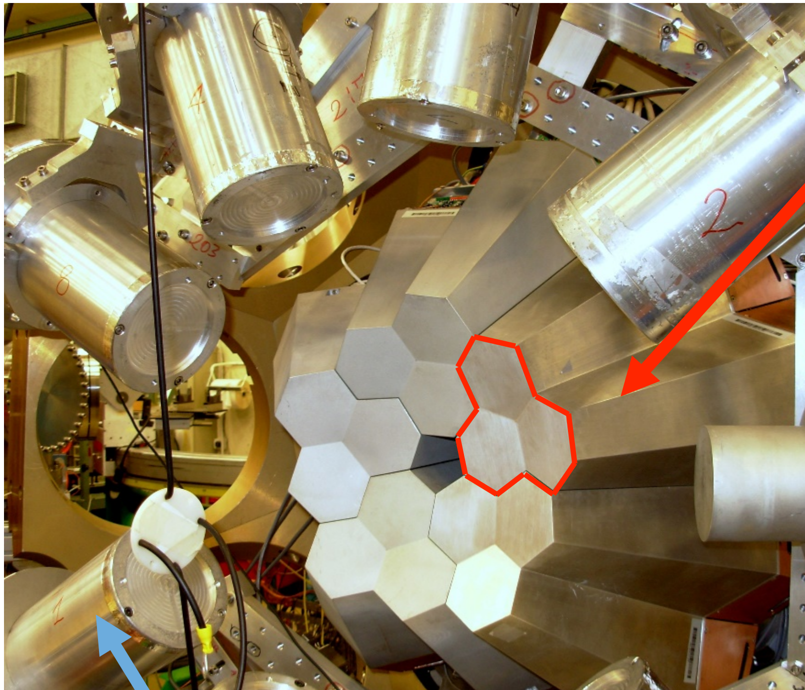
- Low neutron separation Energy (4.1 MeV) – no background from projectile excitation



M. Krzysiek, Ph.D. Thesis, 2016

Experimental setup – gamma detectiob

Gamma detection:



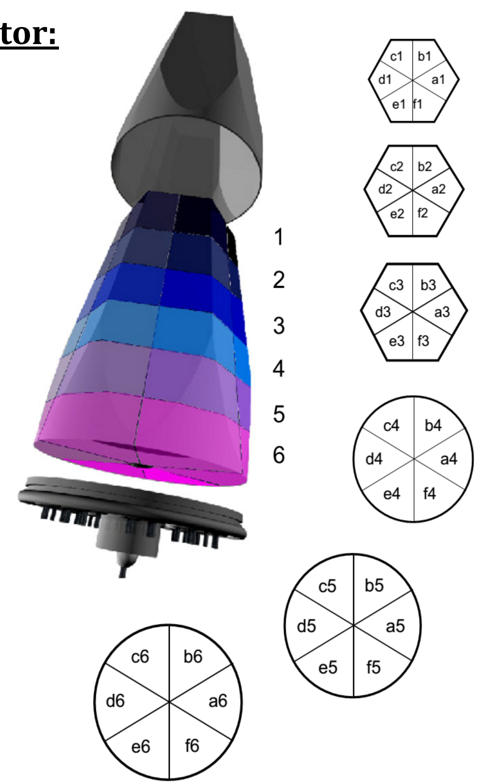
AGATA Demonstrator: **5 triple clusters**

Germanium detectors (HPGe)

Algorithms:

- ❑ Pulse Shape Analysis (PSA)
- ❑ Tracking

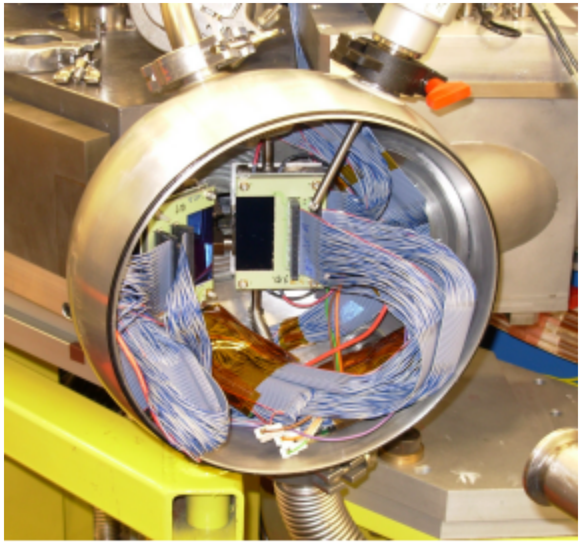
Single detector:

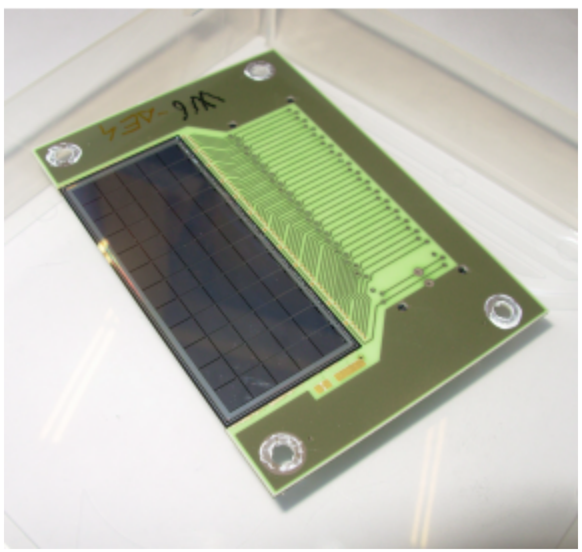


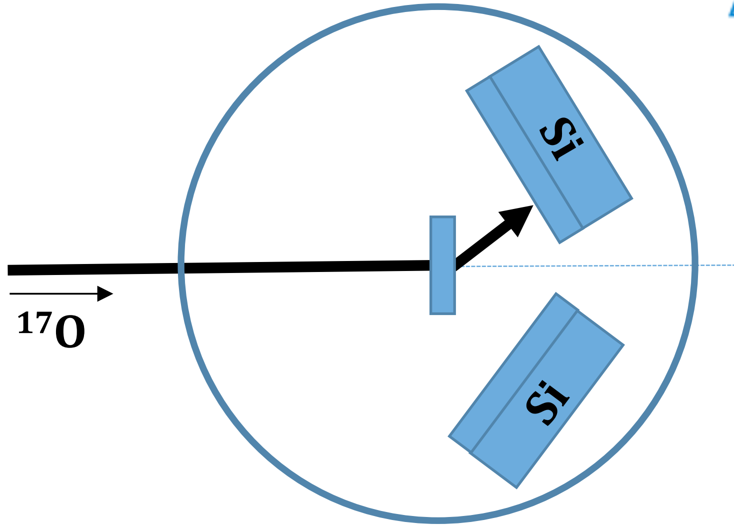
HECTOR+: 9 large volume $LaBr_3$: Ce

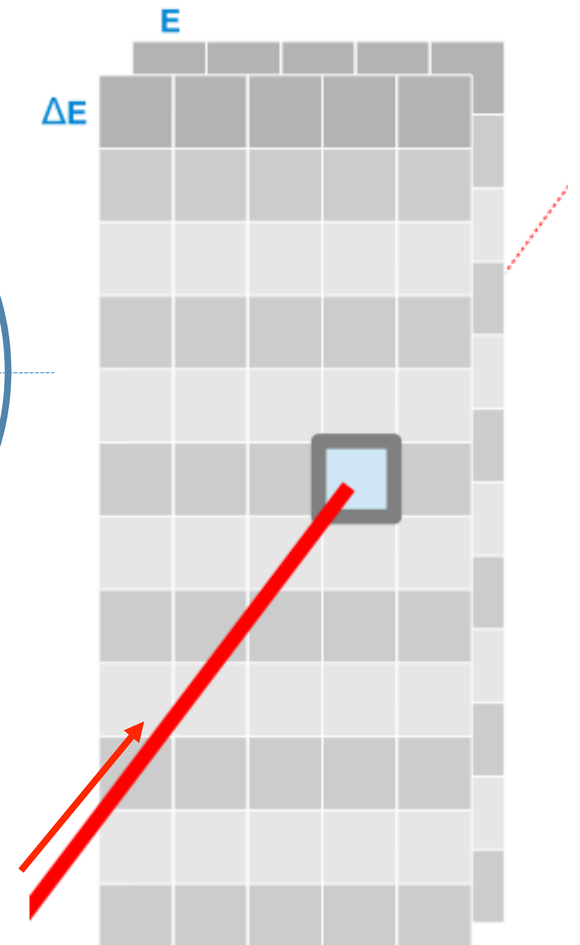
- ❑ Scintillation detectors
- ❑ High efficiency for high energy
- ❑ Good Energy resolution

Inelastic scattering ^{17}O @ 20 MeV/u









Position sensitivity

ion identification

Particle detection:

TRACE: 2 ΔE-E Si detectors

60 pixels each (5 x 12)

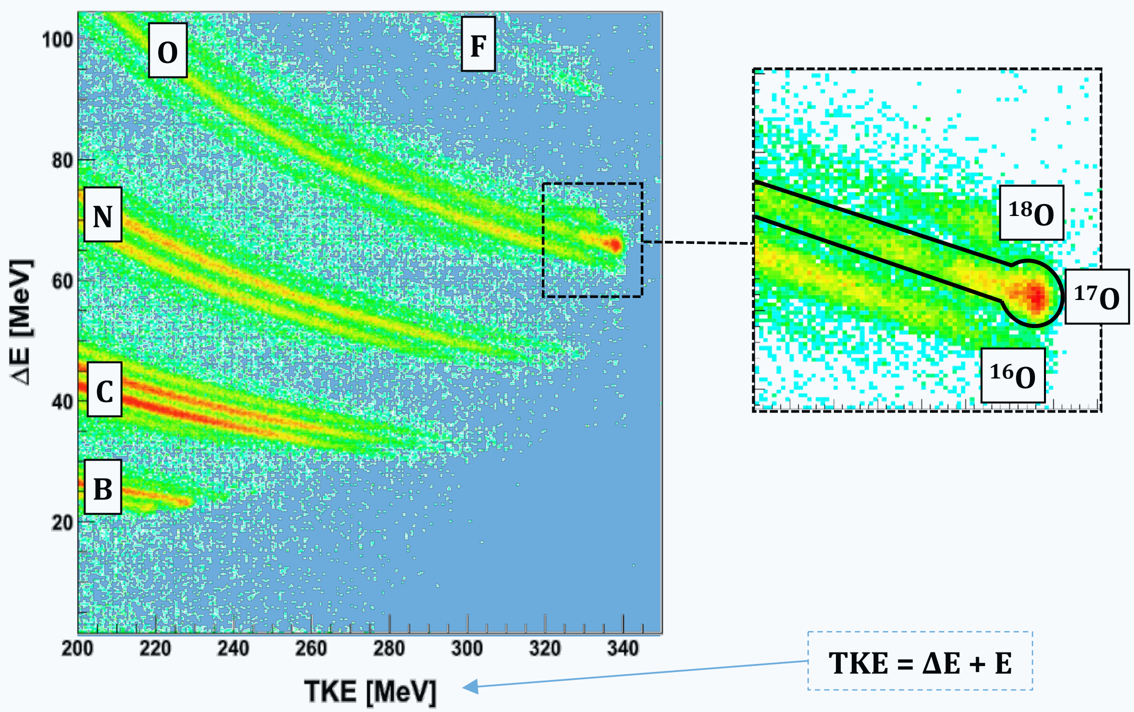
Pixel area: 4 x 4 mm^2

Active area: 20 x 50 mm^2

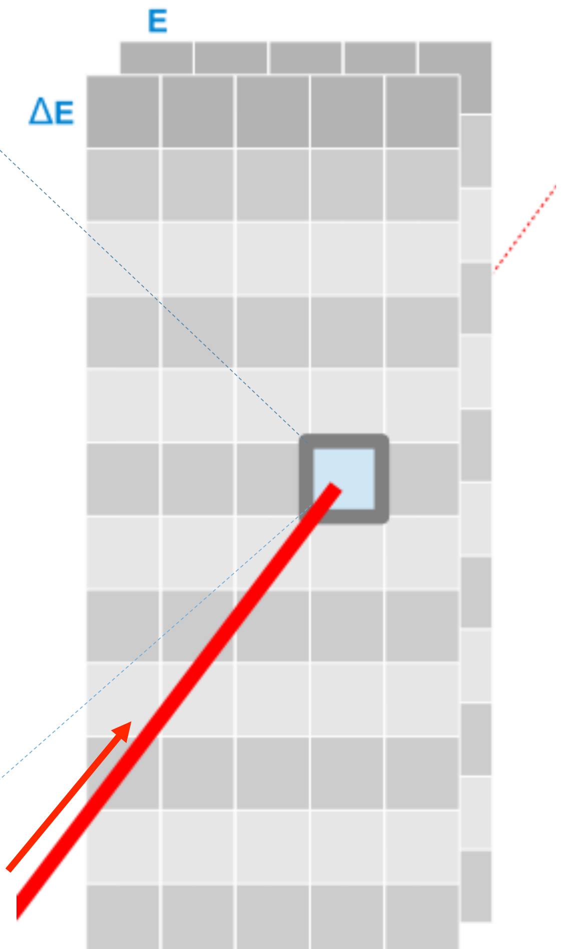
Thickness: ΔE – 200 um

E – 1 mm

Identification matrix of reaction products (for each pixel)



TKE = ΔE + E



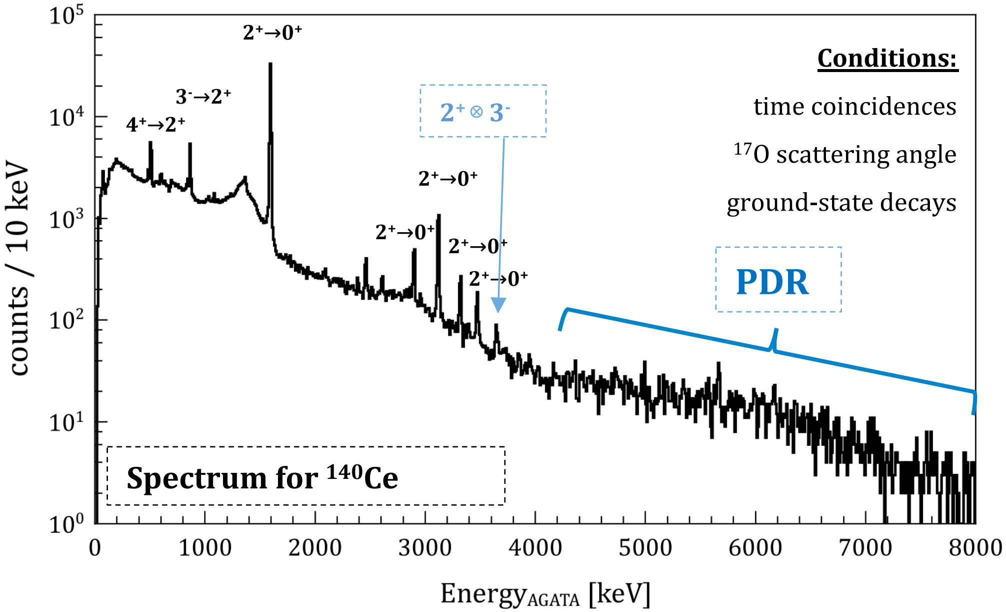
Position sensitivity

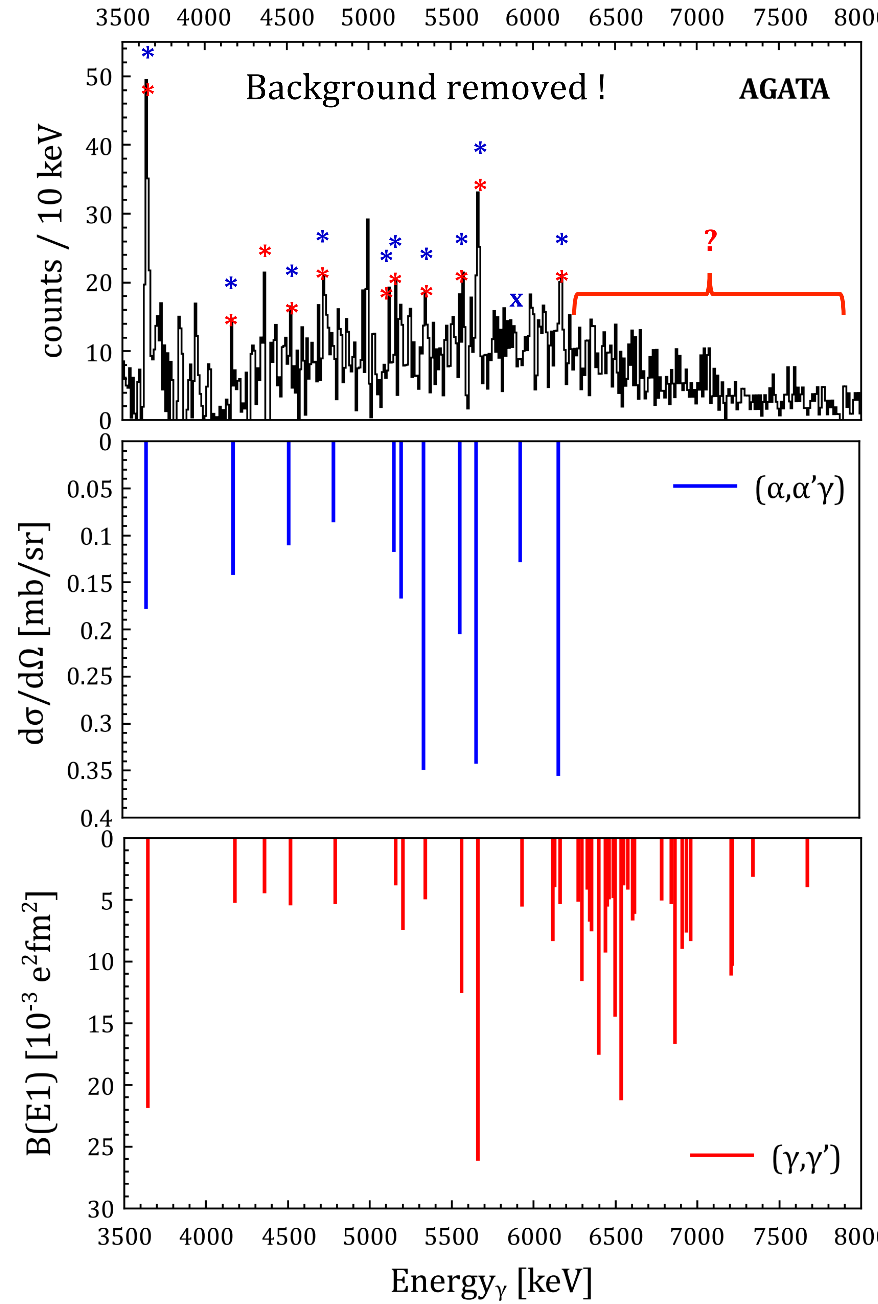
ion identification

Ground-state decays selection condition : $E_x = E_\gamma$

E_x = TKE – 337.94 MeV

Spectrum measured with AGATA



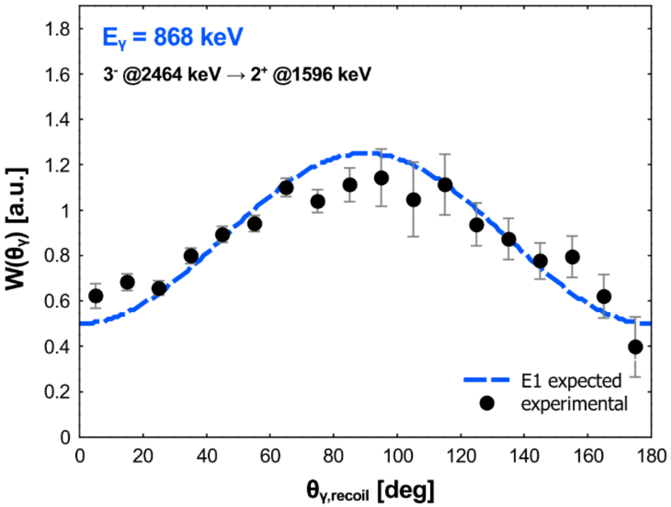


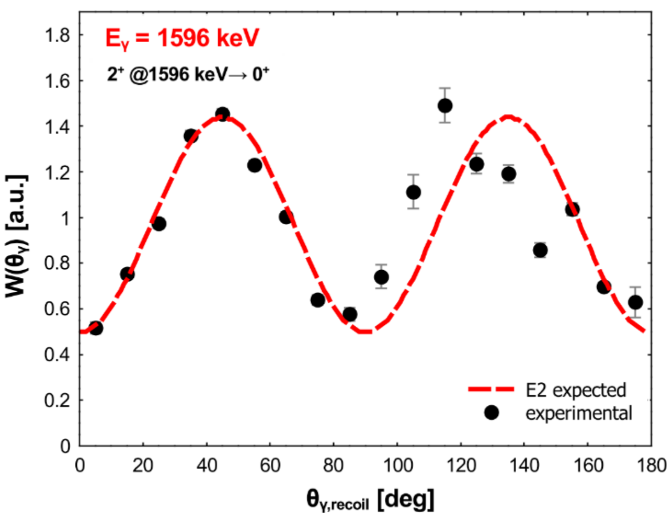
General excitation mechanism similar to (α,α')

- ❑ **Detailed analysis revealed some differences in excitation mechanism between (^{17}O,^{17}O') and (α,α')**
- ❑ **Some excitations present in high-energy part**

Angular distributions of γ rays

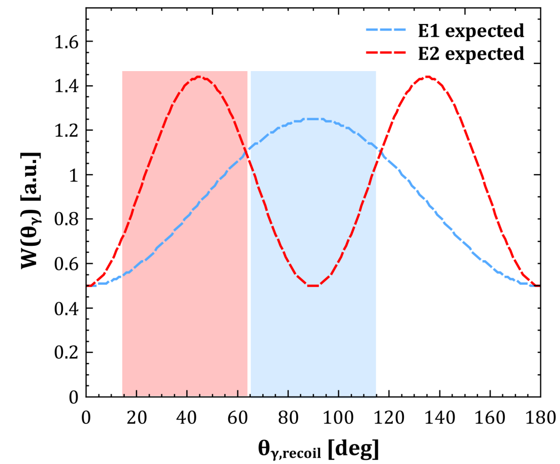
Thanks to position sensitivity of AGATA and TRACE

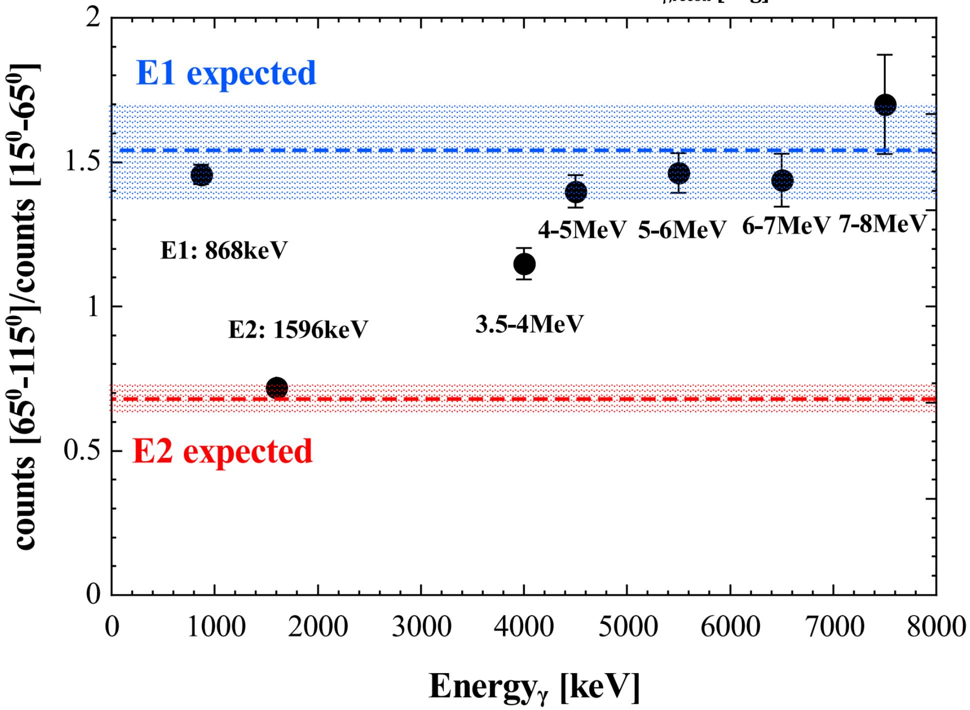




What is the multipolarity of pygmy tranistions?

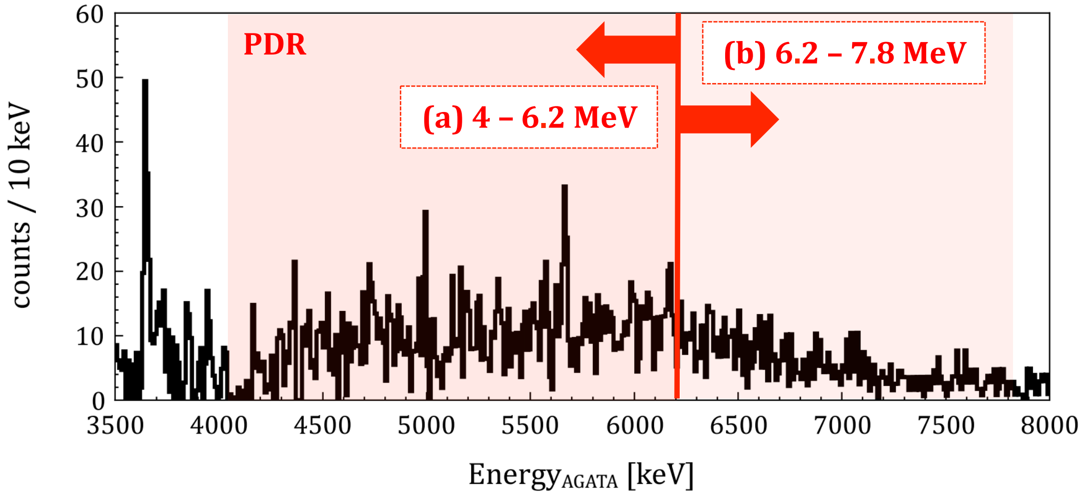
Expected trends

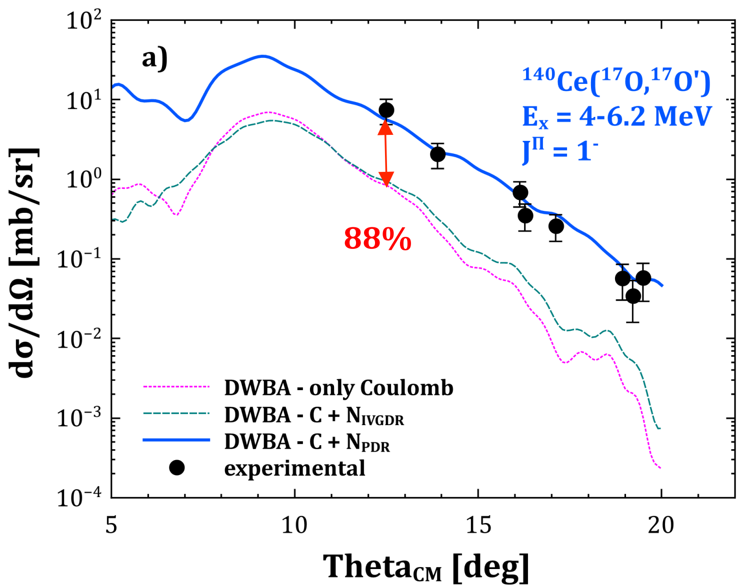


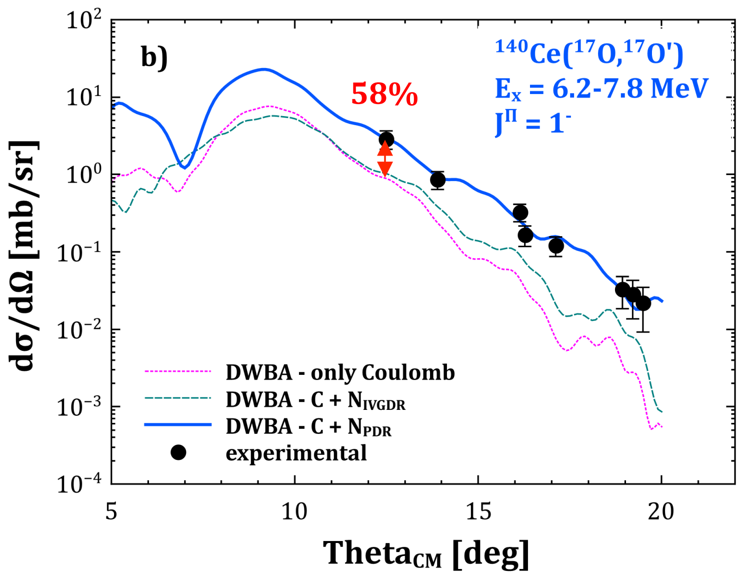


Dipole character of transitions in PDR energy region cofirmed

DWBA *(Distorted Wave Born Approximation)* calculations







***DWBA calculations* using interactions:**

- only Coulomb
- Coulomb + nuclear (standard form factor)
- Coulomb + nuclear (microscopic form factor)

Fraction of ISEWSR exhausted by PDR:

Sum in all region: **2.03(26)%**

- low-energy part: **1.42(22)%**
- high-Energy part: **0.61(14)%**

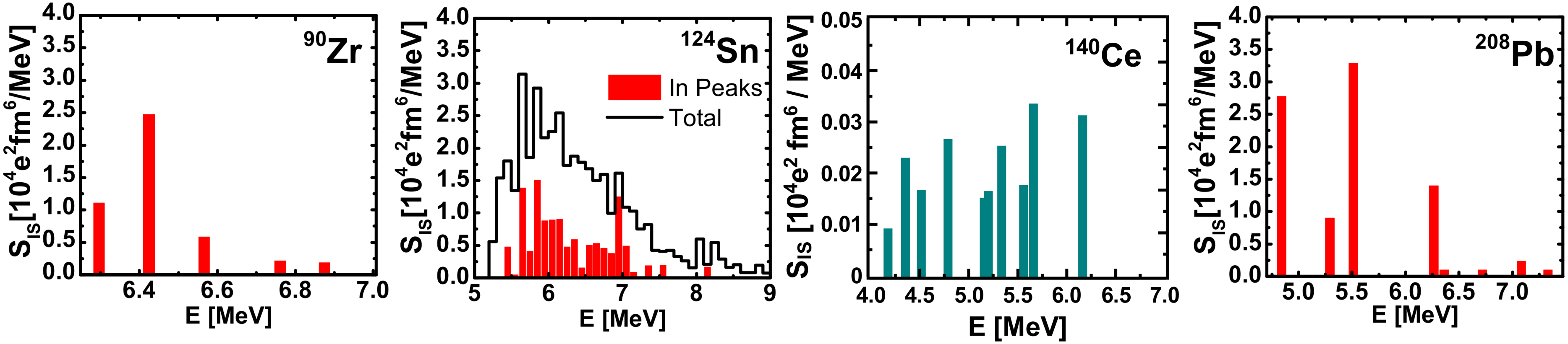
Sum of all discrete states: **0.44(12)%**

M. Krzysiek et al., Phys. Rev. C 93, 044330 (2016)

Inelastic scattering of ^{17}O @ 20 MeV/u to study PDR for different nuclei: ^{90}Zr , ^{124}Sn, ^{208}Pb and ^{140}Ce

Nucleus	Selection	Energy range [MeV]	ISEWSR [%]	B(E1)↑ [10^{-3} e^2fm^2]
^{90}Zr	in peaks	6.3 – 6.9	4.0(6)	87
^{124}Sn	in peaks	5.5 – 9.0	2.2(3)	228
^{124}Sn	total	5.5 – 9.0	7.8(7)	228
^{140}Ce	in peaks	4.1 – 7.8	0.44(12)	307
^{140}Ce	total	4.1 – 7.8	2.03(26)	307
^{208}Pb	in peaks	4.8 – 7.3	9.0(1.5)	1084

- ❑ **Increase of isovector part with mass of nucleus**
- ❑ **No such correlation for isoscalar part**
- ❑ **Influence of nucleus structure – shell closure**



([1]) F.C.L. Crespi *et al.*, Phys. Rev. C 91, 024323 (2015). ([2]) L. Pellegri *et al.*, PLB 738 (2014) 519-523 ([3]) M. Krzysiek *et al.*, Phys. Rev. C 93, 044330 (2016)
([4]) F.C.L. Crespi *et al*. Phys. Rev. Lett. 113 (2014) 012501

Inelastic scattering of fast protons - *Adjustment of energy and scattering angle – selectivity for spin and parity*

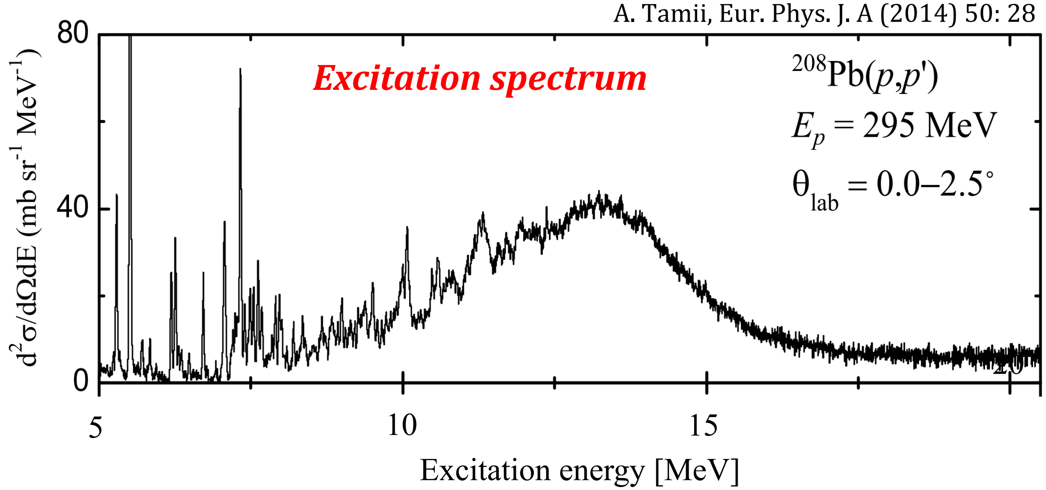
RCNP Osaka

- **GRAND Raiden -** protons detection
- **CAGRA (HPGe) -** γ-rays detection

CAGRA + GR campaign:

- „Study of the Structure of the PDR States in $^{90,94}Zr$, $^{120,124}Sn$, $^{206,208}Pb$ via the (p, p' γ) and (α,α'γ) Reactions"
- „Study of the Structure of the PDR States in ^{64}Ni via the (p,p'γ) and (α,α'γ) Reactions"

A. Tamii, Eur. Phys. J. A (2014) 50: 28



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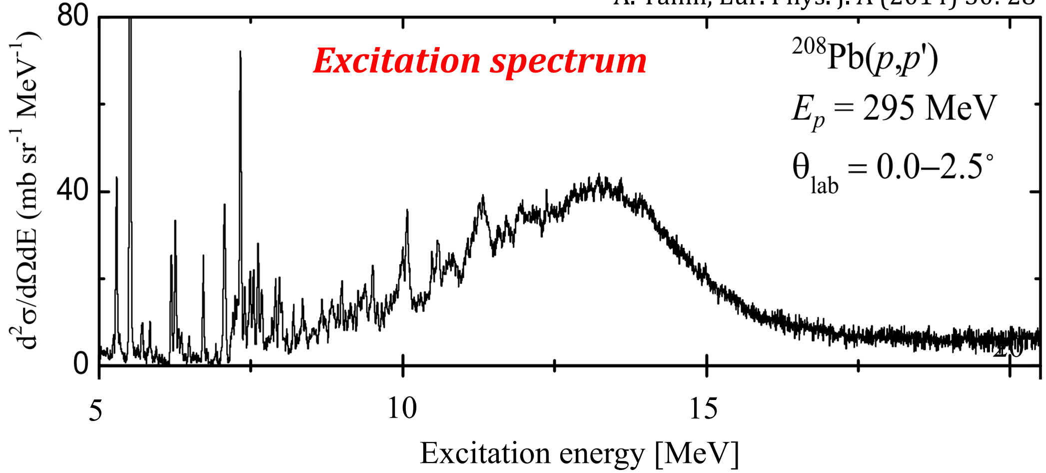


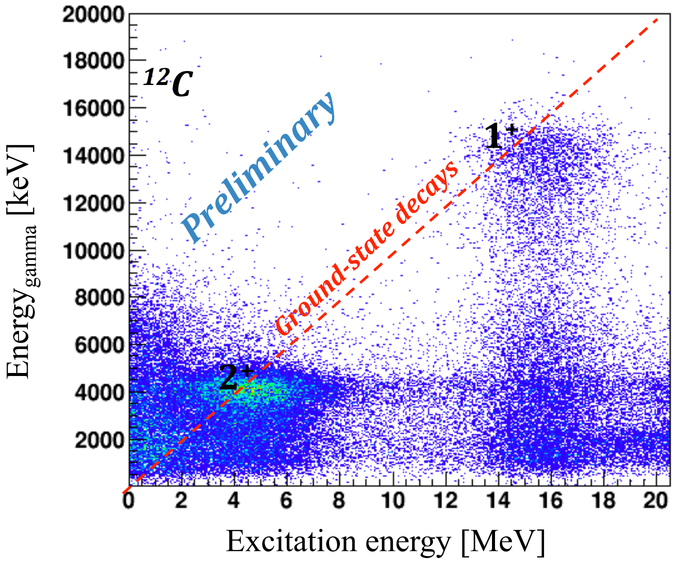
CCB Kraków

- ❑ **KRATTA Array -** protons detection
- ❑ **HECTOR+LaBr$_3$ (scintillation det.) -** γ-rays detection

CCB campaign:

„The gamma decay from high-lying states and giant resonances excited in ^{208}Pb and ^{90}Zr via (p, p'γ) reaction at 140 MeV bombarding Energy"

M. Kmiecik at al., to be published



Gamma beams at ELI-NP - *Produced in Compton backscattering of laser beam on accelerated electrons*

Beam properties:

Energy range up to E_{γ} = 19.5 MeV

Bandwidth: ~0.1 %

Intensity: 10^{13} γ/s

Nuclear Physics

Physics cases with gamma beams

ELI-NRF *(Nuclear Resonance Fluorescence)*

ELI-GANT *(Gamma Above Neutron Threshold)*

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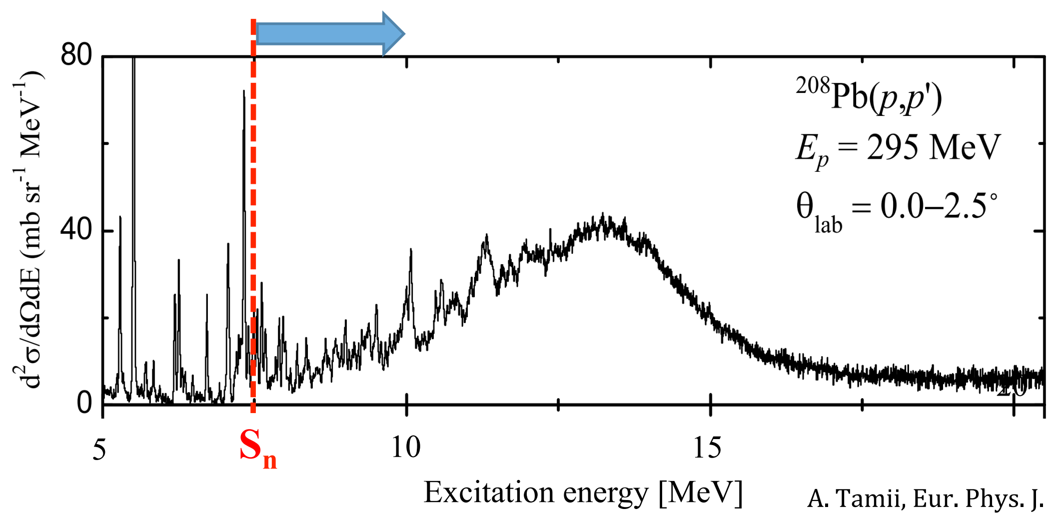


A. Tamii, Eur. Phys. J. A (2014) 50: 28

Detection systems for ELIGANT

ELIGANT-GN

16 $LaBr_3$ + 16 $CeBr_3$ – gamma detection

Liquid (BC501A) scintillators – fast neutrons (E<1MeV)

^{6}Li glass (GS20) scintillators – fast neutrons (E>1MeV)

ELIGANT-TN

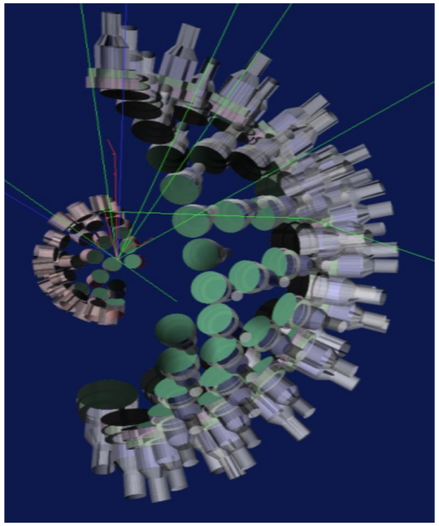
^{3}He proportional counters – thermal neutrons

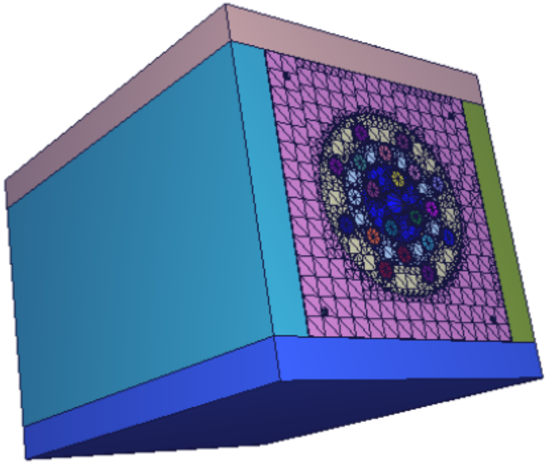
ELIGANT-TNH

high-efficiency 4π

ELIGANT-TNF

flat-efficiency 4π





Detection systems for ELIGANT

ELIGANT-GN

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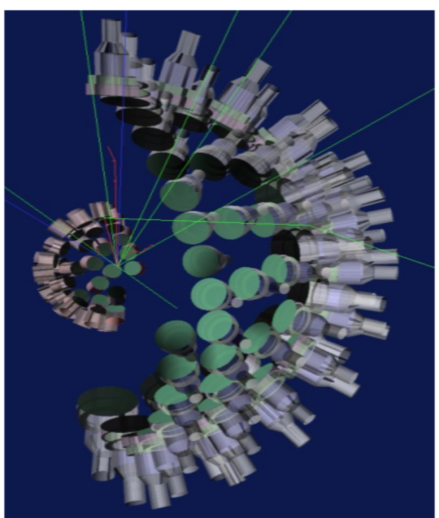
Liquid (BC501A) scintillators – fast neutrons (E<1MeV)

^{6}Li glass (GS20) scintillators – fast neutrons (E>1MeV)

„Day 1" experiments

- **Ground-state γ decay of GDR in ^{208}Pb**
- **Exclusive neutron decays of GDR, PDR, and MDR**



ELIGANT-TN

^{3}He proportional counters – thermal neutrons

ELIGANT-TNH

high-efficiency 4π

„Day 1" experiments

p-proces nucleosynthesis:

- ^{180}Ta(γ,n)^{179}Ta
- ^{138}La(γ,n)^{137}La

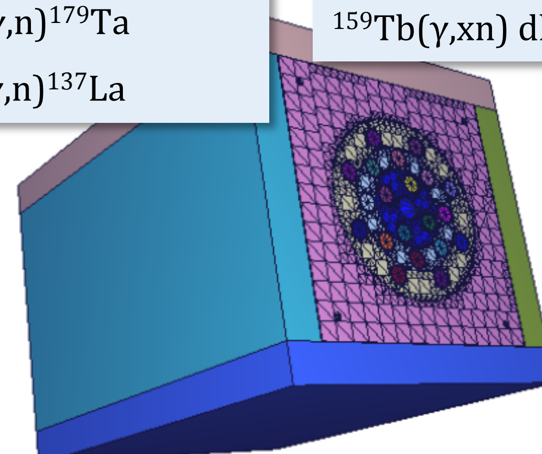
ELIGANT-TNF

flat-efficiency 4π

„Day 1" experiments

New compilation:

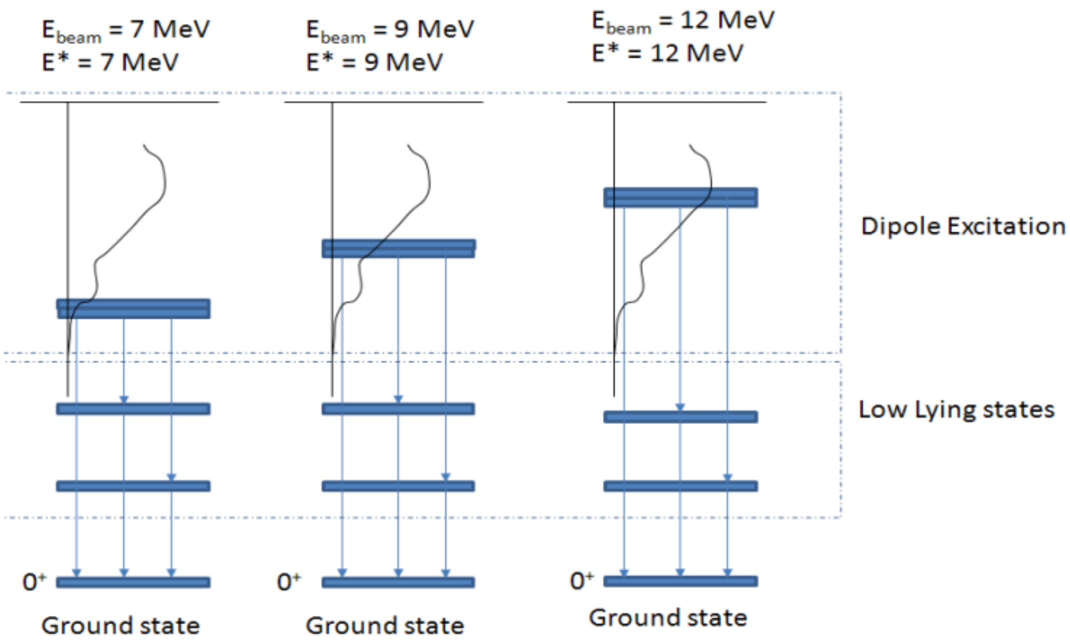
^{159}Tb(γ,xn) dla x=1-2



Nuclear Structure of GDR/PDR/MDR

„Ground-state γ decay of GDR in ^{208}Pb"

„Exclusive neutron decays of GDR, PDR, and MDR"



Excitation energy is fixed with great precision (σ=0.2%)
UNIQUE FEATURE

- ❑ **Study of the neutron and γ decay of the GDR-PDR**
- ❑ **Measurement of the absolute values of B(E1) and B(M1)**
- ❑ **Measurement of the absolute values of the neutron and γ branching ratio**

Summary:

- **Giant and pygmy resonances** are very important tools to study the bulk properties of atomic nuclei
- It is of high importance to use different probes: protons, alphas, heavy-ions and gammas
- ELI-NP in Bucharest will be a very important facility in this type of studies
- The group from IFJ PAN Krakow is already involved in preparation of the gamma experiments in ELI-NP