3rd International Symposium on Nuclear Symmetry Energy

NSCL/FRIB, East Lansing, Michigan
July 22 - 26, 2013

On the nature of the Pygmy dipole resonance via inelastic scattering of ^{17}O

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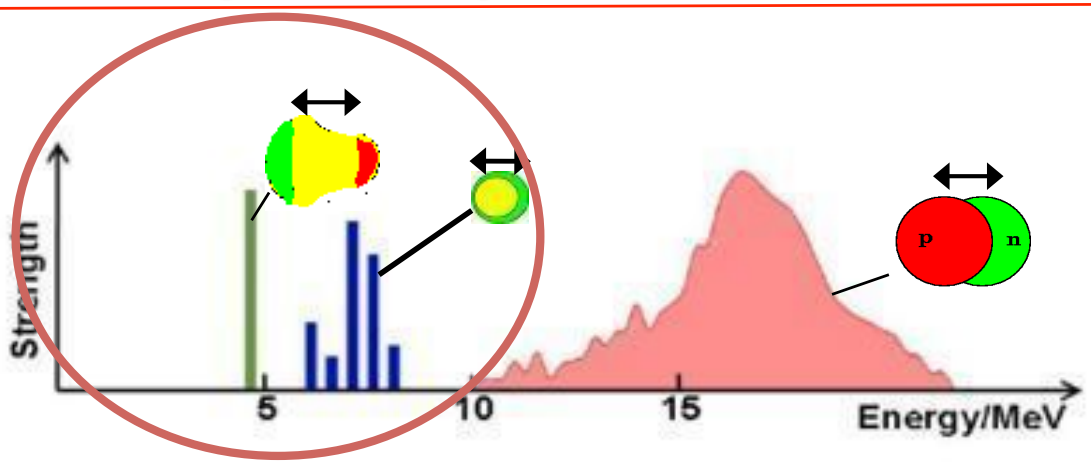
OUTLINE

- Motivation
- Summary of results of PDR from experiments with radioactive beams and the relation with Symmetry energy
- Probing the nature and features of PDR using with different probes
- experiments at LNL with the AGATA array

Conclusion

The low energy part of the dipole response in Nuclei

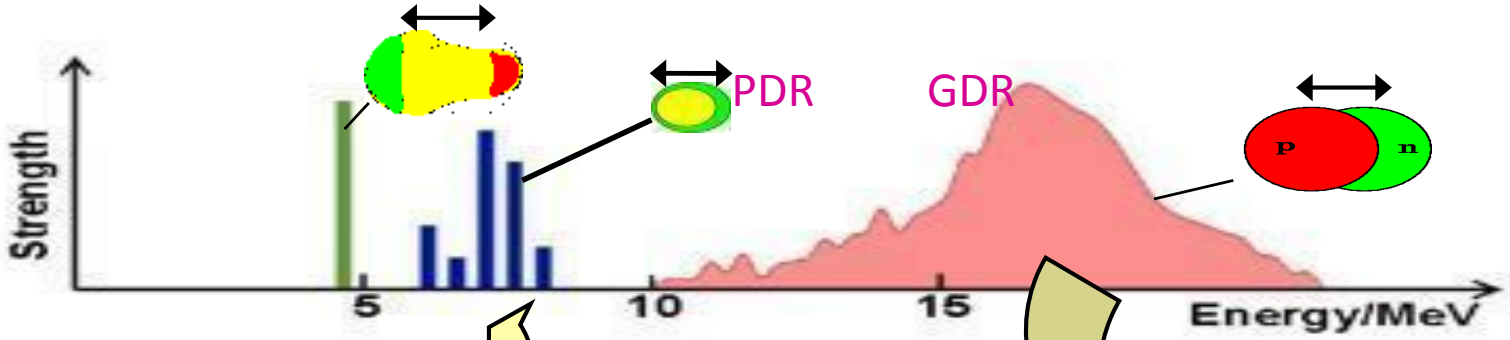
The relevant energy window for (γ,n) reactions in the stellar photon bath is located in the vicinity of the PDR.



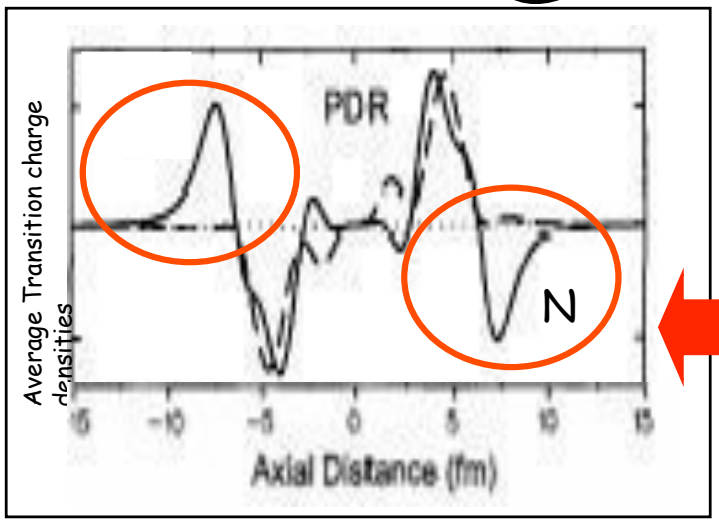
LOW ENERGY HIGH ENERGY

- it affects the synthesis of nuclei in explosive stellar burning phases
- Important for generating neutrons in stars
- information for the description of neutron stars
- interesting for nuclear structure phenomena

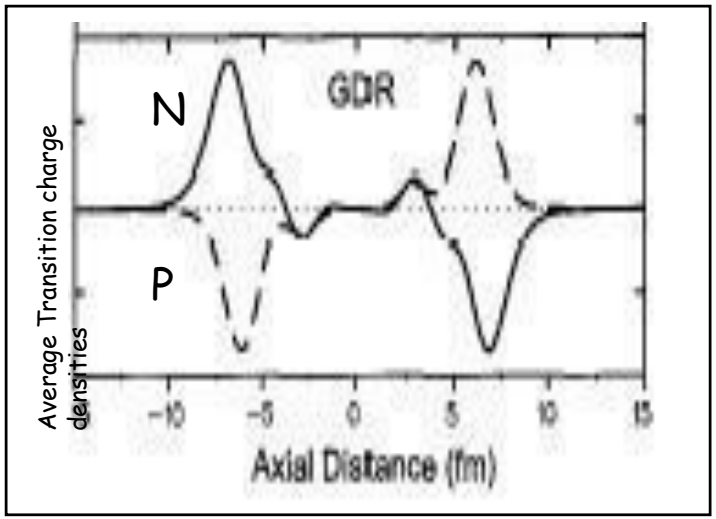
Nuclear Structure information from the Electric Dipole response in Nuclei



States of different nature Average Transition charge densities



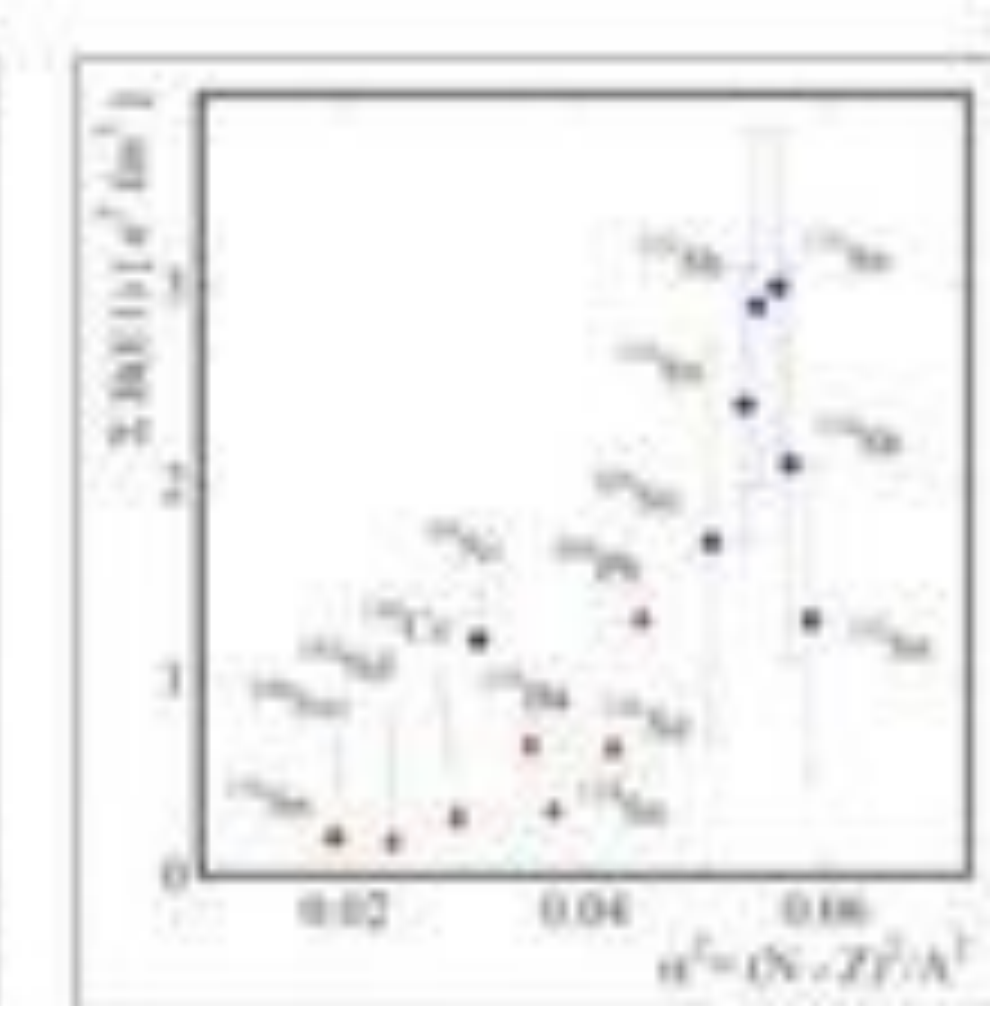
Oscillation on neutron skin



N. Ryezayeva el. al PRL89(2002)272502

Features of this mode

There is a trend in the strength to increase with the proton-to-neutron asymmetry



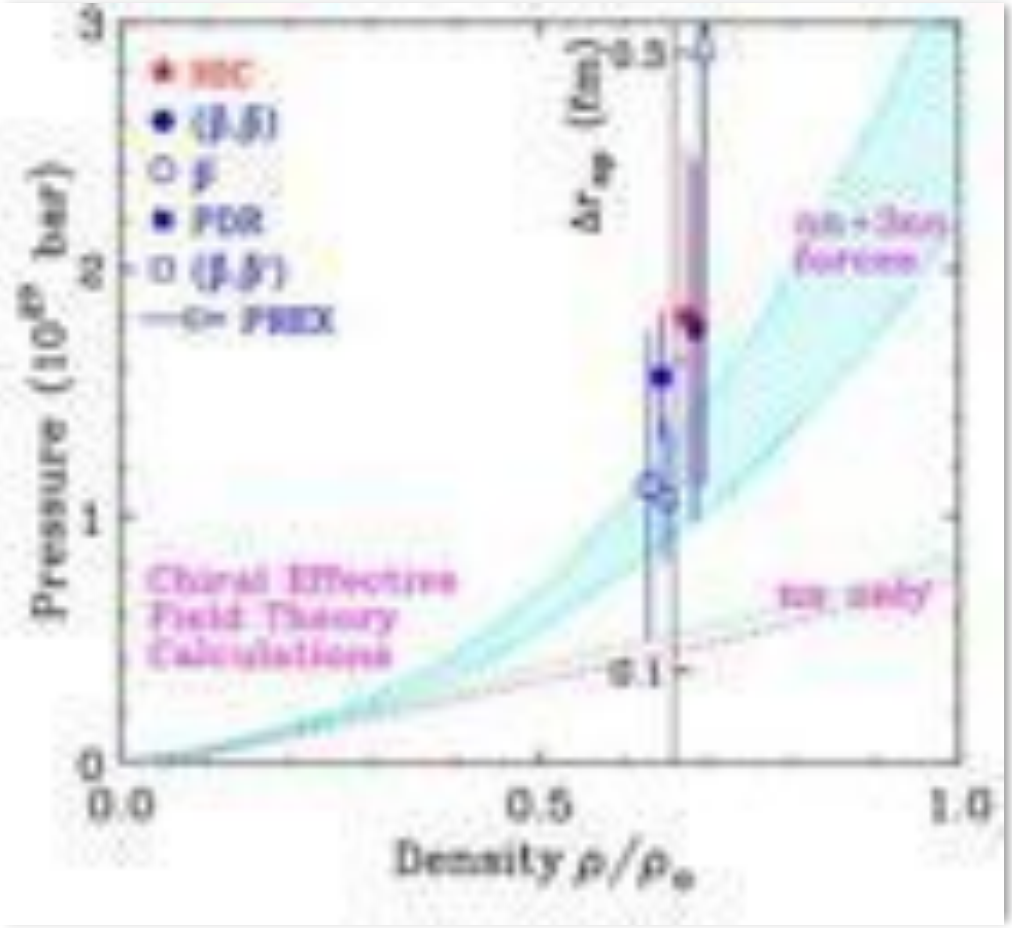
Stable nuclei ⇒
photon scattering,and
Photoabsorption
(γ,γ'),(γ,n)...

Radioactive beams
(^{68}Ni Sn isotopes) ⇒
Virtual photon absorpion
Followed by neutron Emission (LAND) and by gamma decay (RISING)

NuPECC long range plan 2010

Neutron pressure from the skin

…from different measurements … extrapolation for ^{208}Pb (including pygmy in ^{68}Ni and ^{132} Sn)



$$L = 3\rho_0 \left| dS(\rho)/d\rho \right|_{\rho_0} = \left[3/\rho_0 \right] p_0$$

is related to P_o, the pressure from the symmetry energy for pure neutron matter at S_o

Betty Tsang

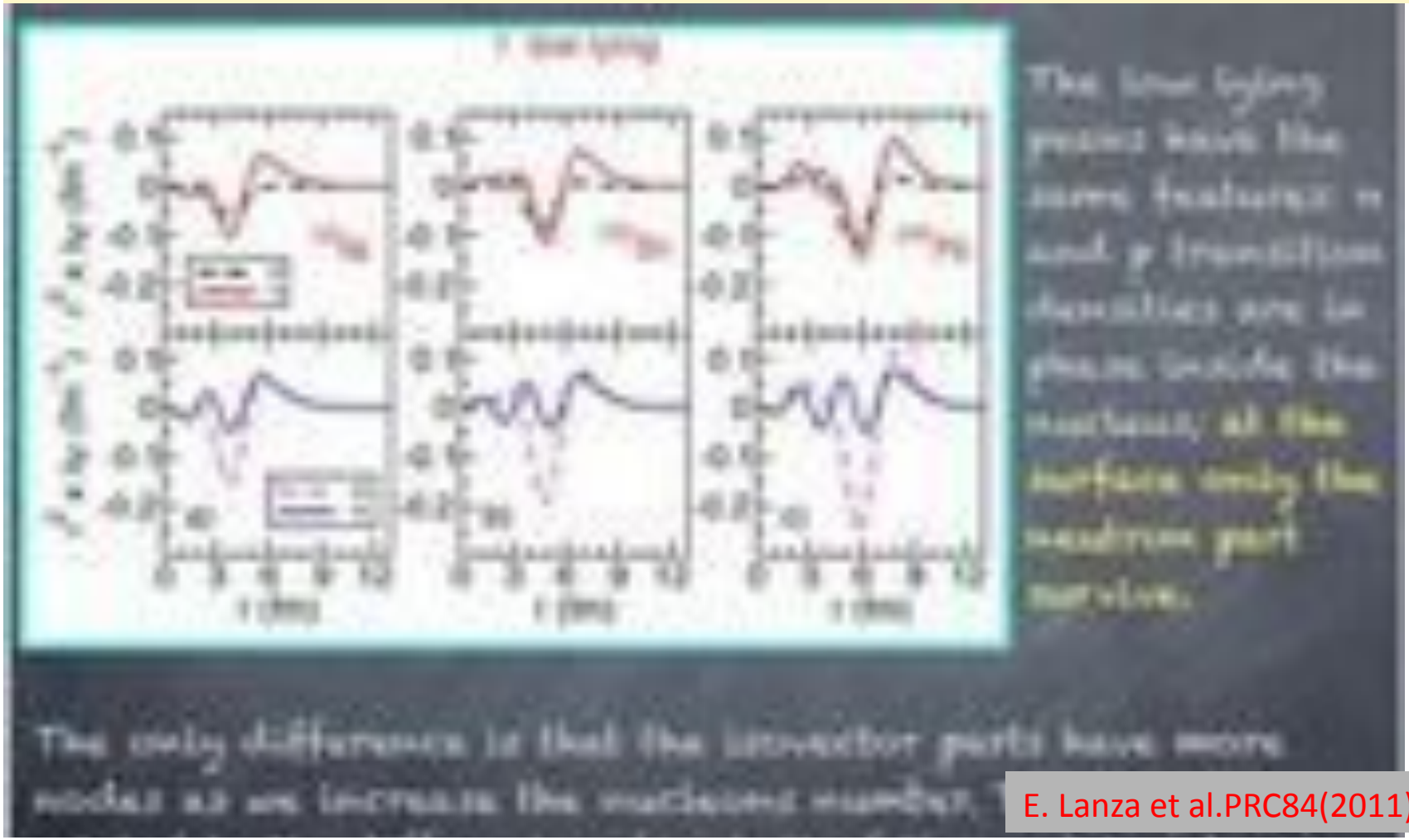
Summary of the NuSYM11 International Symposium on Nuclear Symmetry Energy

On the nature

of the pygmy states

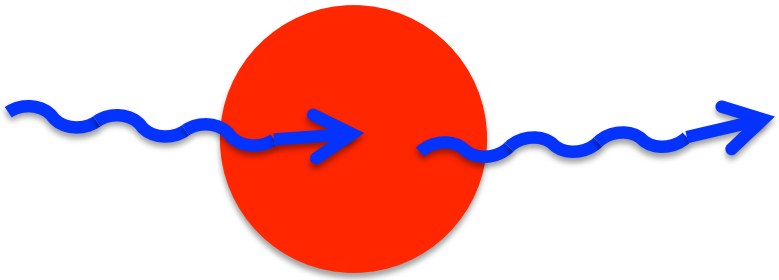
- More data
- efforts to investigate the details and microscopy of this modes
- in order to provide stringent test to theory and make more powerful the analysis providing information on the symmetry energy

Transition densities



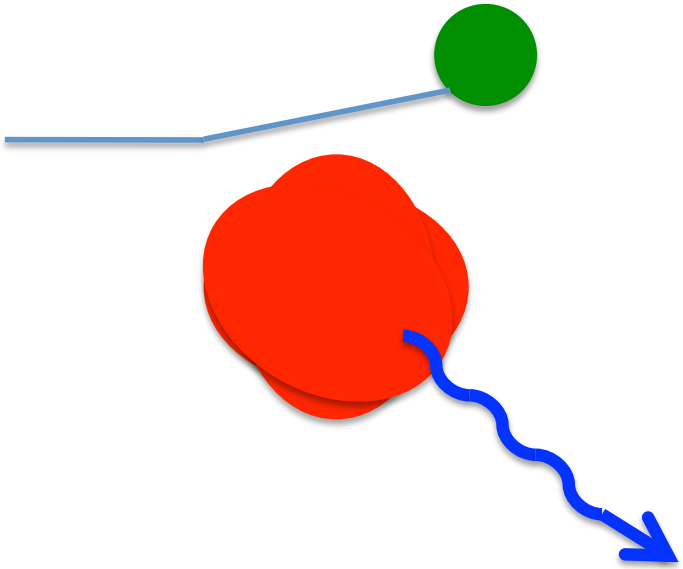
E. Lanza et al.PRC84(2011)064602

Interesting to probe the surface with a projectile interacting mainly at the surface !!!



Photon scattering

- dominant isovector excitation (for E1)
- interaction with whole nucleus (kR << 1)

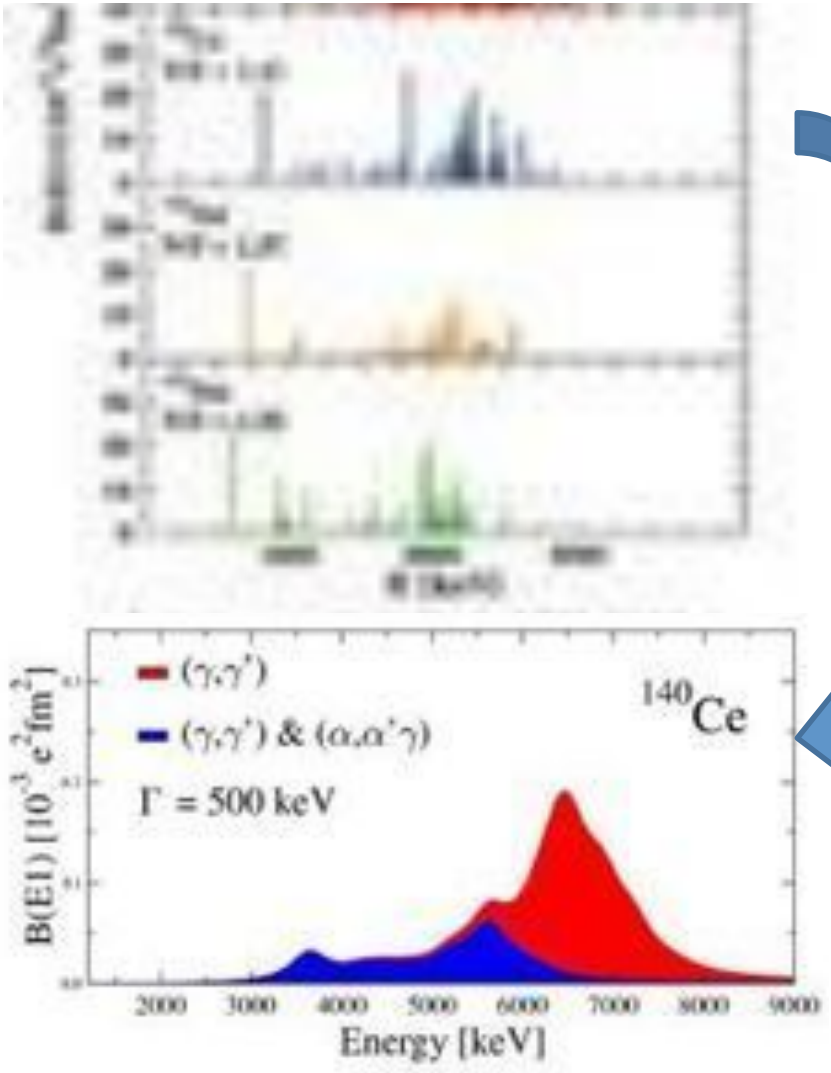


Inelastic scattering
hadronic isoscalar probe
(e.g. alpha)

- dominant isoscalar excitation
- interaction surface peaked

Gamma decay to the g.s. - selectivity to E1

..... is there a substructure in the pygmy ?



D. Savran et al. PRL97,172502(2006)

The technique of alpha-gamma coincidence experiments allows the separation of E1 excitation

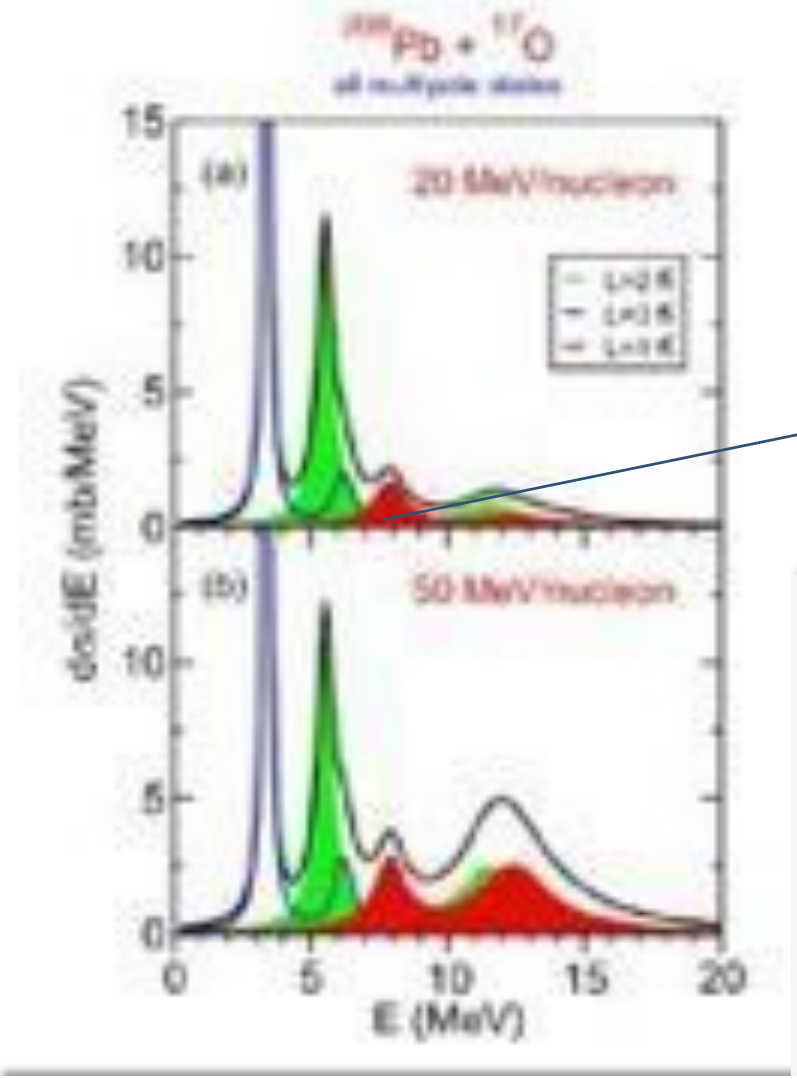
The PDR splits in two parts :

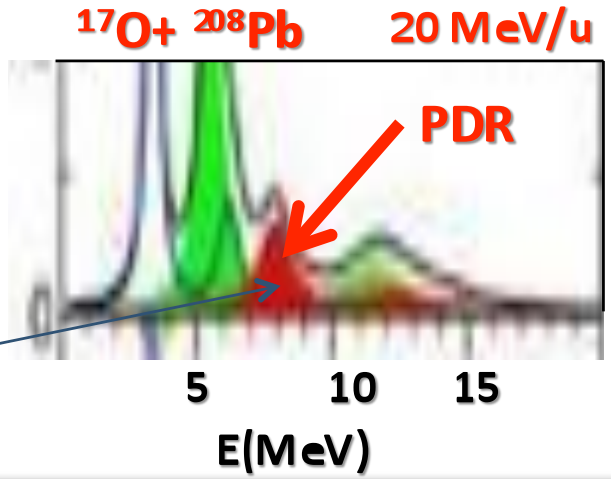
- **One excited both in (γ, γ') and in (α,α'γ)**
- **The other excited only in (γ, γ')**

Use also other hadronic probes –

inelastic scattering ^{17}O and gamma decay

… use of inelastic scatt. of ^{17}O to excite the pygmy





RPA response + Reaction processes with the semiclassical model

The PDR is predicted to be excited in the $^{17}O+^{208}Pb$ at 20 MeV/u

Nuclear part of the excitation does not depend on bombarding energies

Mesaurement of gamma-ray emission enhances the selectivity

Excitations of pygmy dipole resonance in exotic and stable nuclei via Coulomb and nuclear fields

E. G. Lanza [1,2], A. Vitturi [3,4], M.V. Andrés [5], F. Catara [2,1] and D. Gambacurta [2,1]

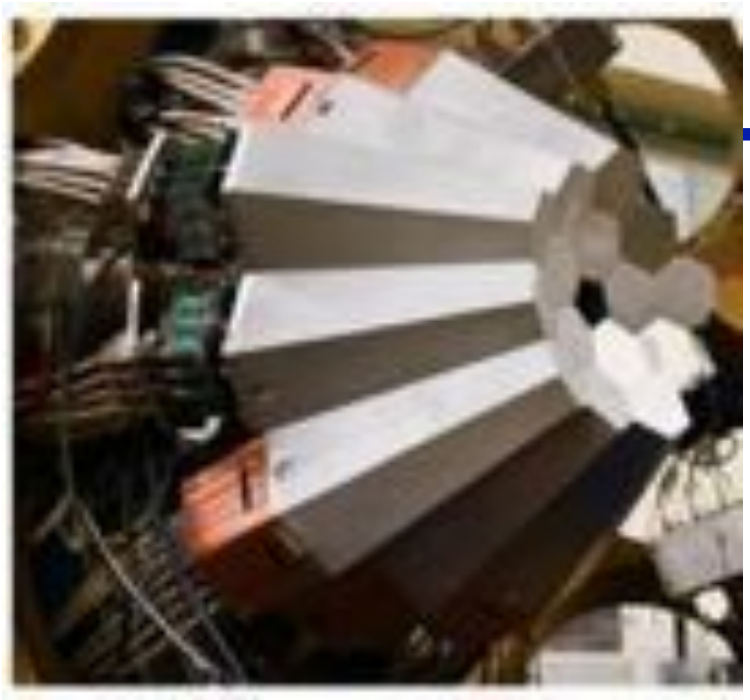
E. Lanza et al. PRC84 (2011)064602

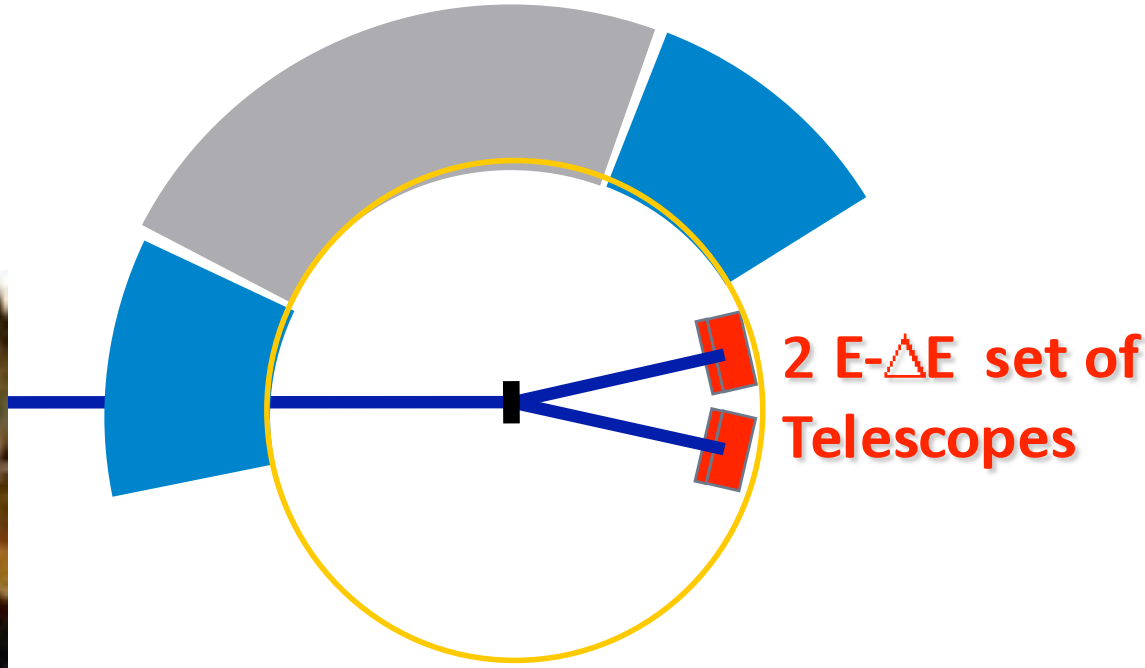
AGATA experiment at LNL : inelastic scattering of light ion beams: ^{17}O

Inelastic scattering ^{17}O @ 20 MeV/u on ^{90}Zr – ^{208}Pb targets
+ γ-ray coincidence

Binding enrgy of ^{17}O 4 MeV

AGATA Demonstrator





Scintillator array
Large volume $LaBr_3$,BaF_2

AGATA with Silicon Telescopes and Scintillator Arrays

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

(^{17}O, ^{17}O' γ)

Inelastic Scattering +

Gamma decay

- **3 $LaBr_3$:Ce detectors (up to 9x20 cm)**
- **20 BaF_2 clusters**

Si pixel detectors : 60 (5x12) PIXELS

- **Pixel area of 4x4 mm²**
- **E detector: 1 mm thick**
- **ΔE detector: 200 μm thick**

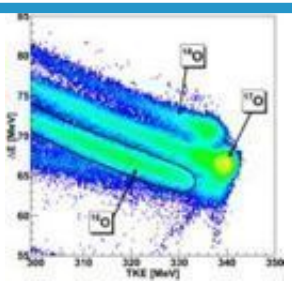
Doppler Correction

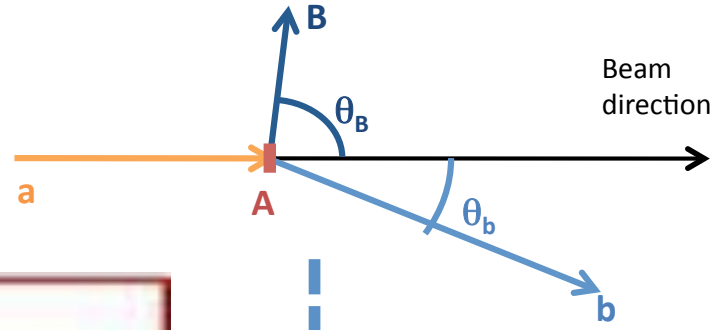
Projectile-like (^{16}O, v/c ~20%)

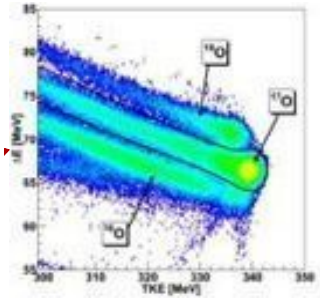
– > 500 keV @ 5 MeV

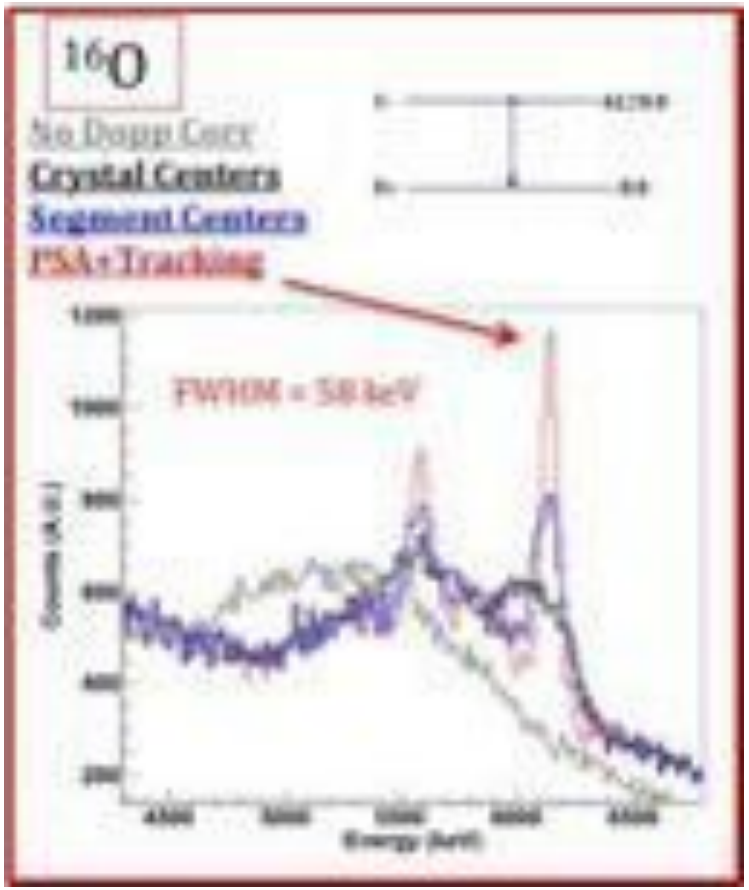
Target-like recoils (v/c ~0.5%)

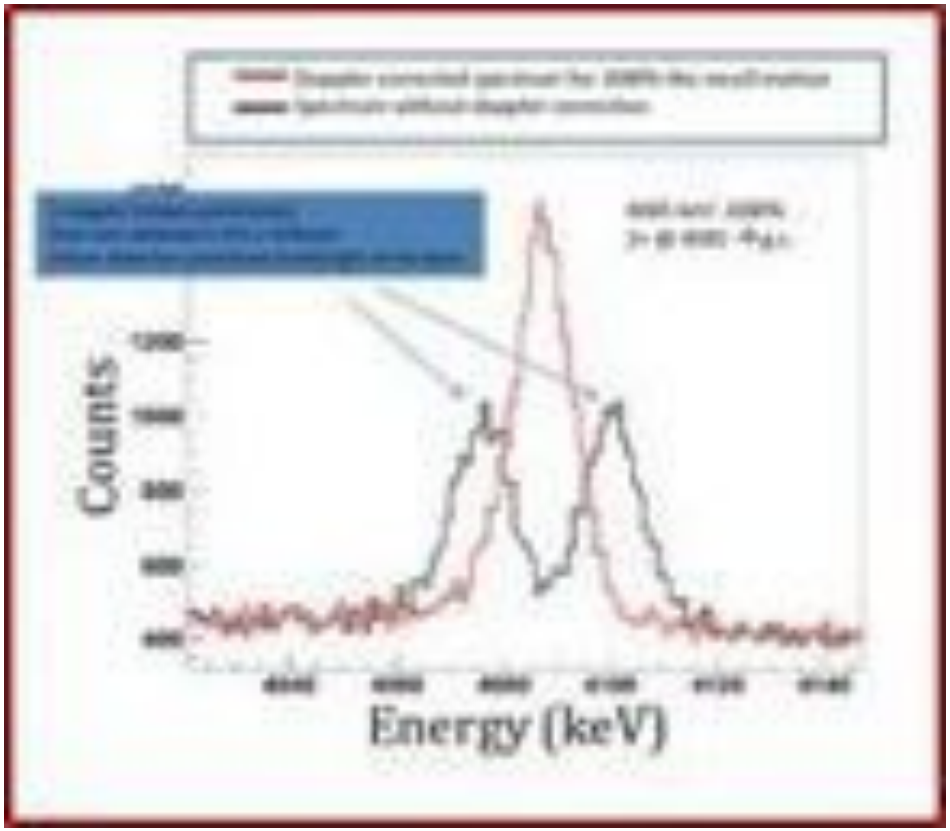
– ~25 keV @ 5 MeV









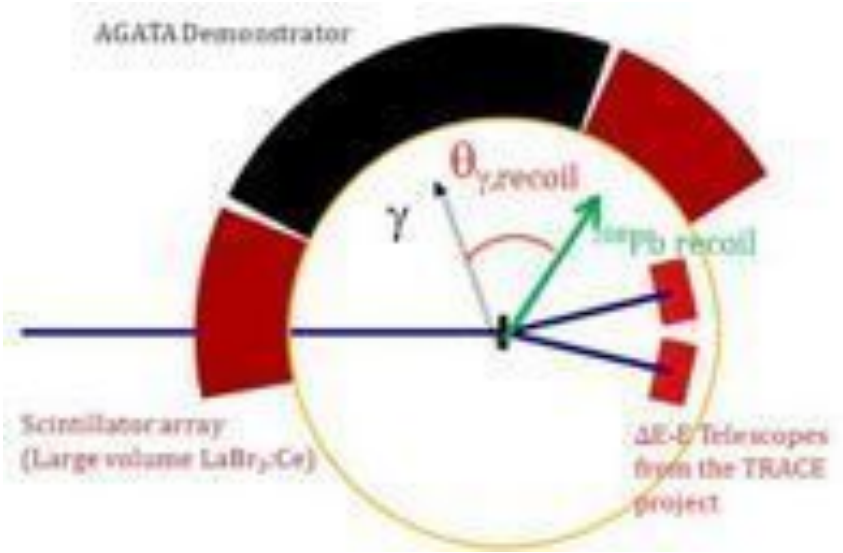


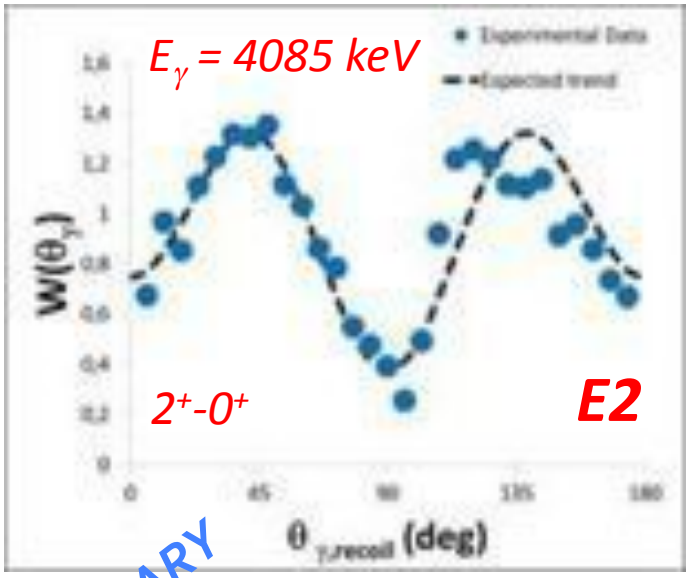
AGATA experiment at LNL:

inelastic scattering of light ion beams + γ-decay

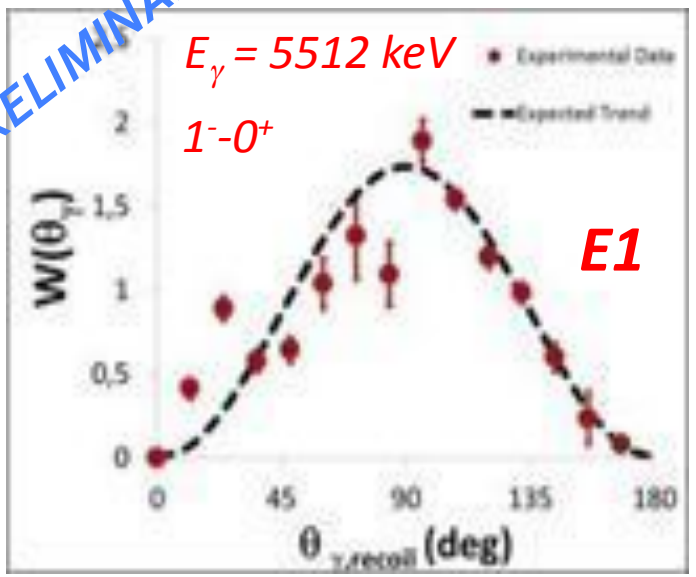
^{17}O @ 20 MeV/A on ^{208}Pb, ^{90}Zr, ^{140}Ce, ^{124}Sn

^{208}Pb





PRELIMINARY

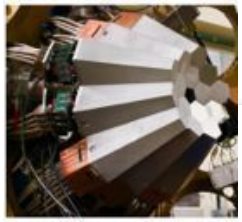


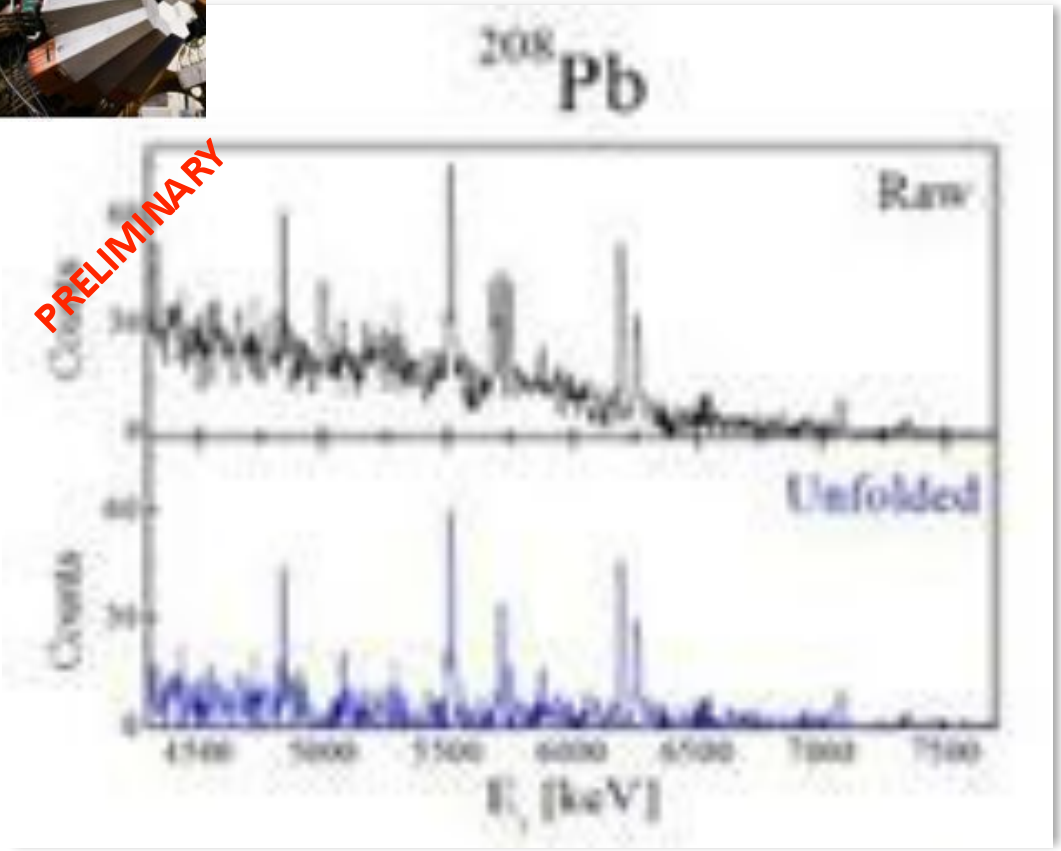
Angular Distribution of γ's obtained exploiting

position sensitivity of **AGATA**

and **E-ΔE Si** telescopes (pixel type)

$^{208}Pb(^{17}O,^{17}O'\gamma)$ - decays to the ground state ($E_\gamma \approx E_x$)





pygmy states in ^{208}Pb

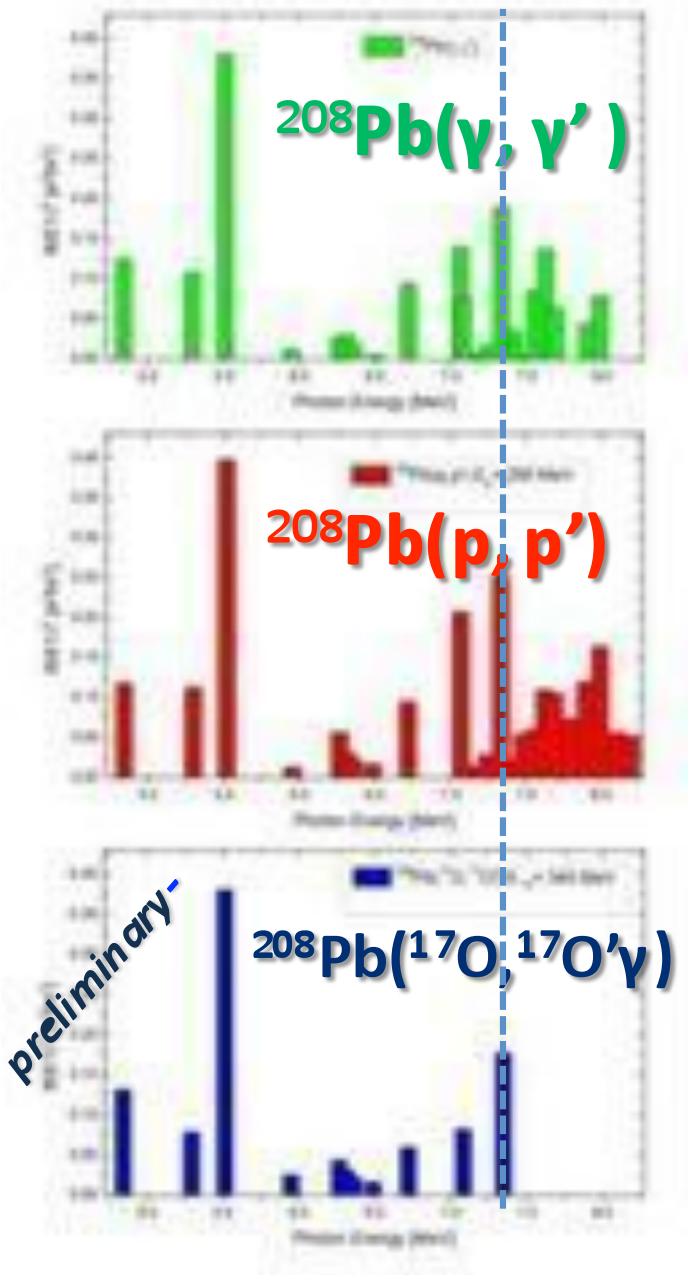
AGATA spectrum with gate on energy of ^{17}O

Corresponding to the direct decay to the ground state

$E_X = E_{gamma}$

A number of lines known by gamma scattering are seen in the region 4.5-7.5 MeV

^{208}Pb..... a test bench



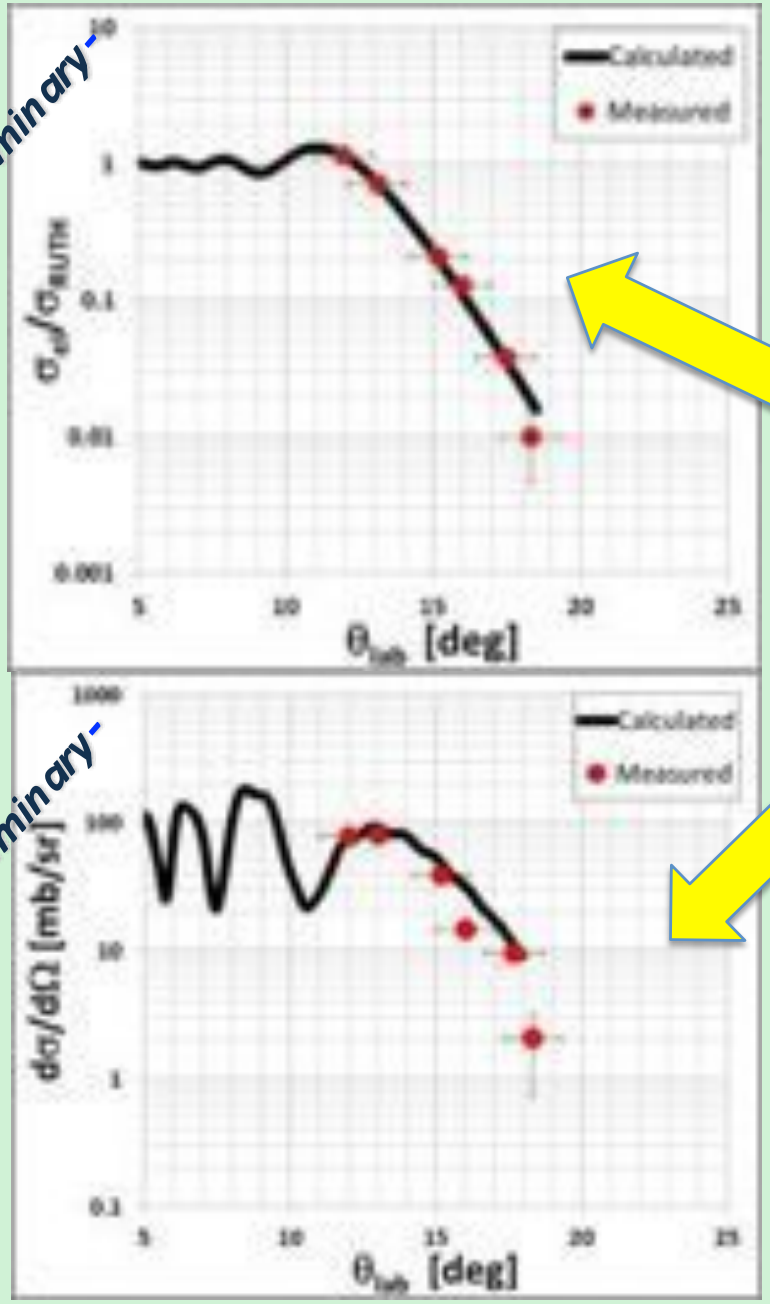
Comparison with the results of the excitation of the pygmy states with 3 probes :

(γ , γ') - probing the entire nuclear volume (PRL89(2002)272502)

(p,p') - at 295 MeV isovector probe possible branching at excited states (PRL107(2011) 062506)

(^{17}O , ^{17}O' γ) some isoscaler character– similar behaviour of (α, α' γ) in other nuclei

Inelastic scattering -



Angular distribution of the scattered ^{17}O on ^{208}Pb

Elastic scattering DWBA analysis

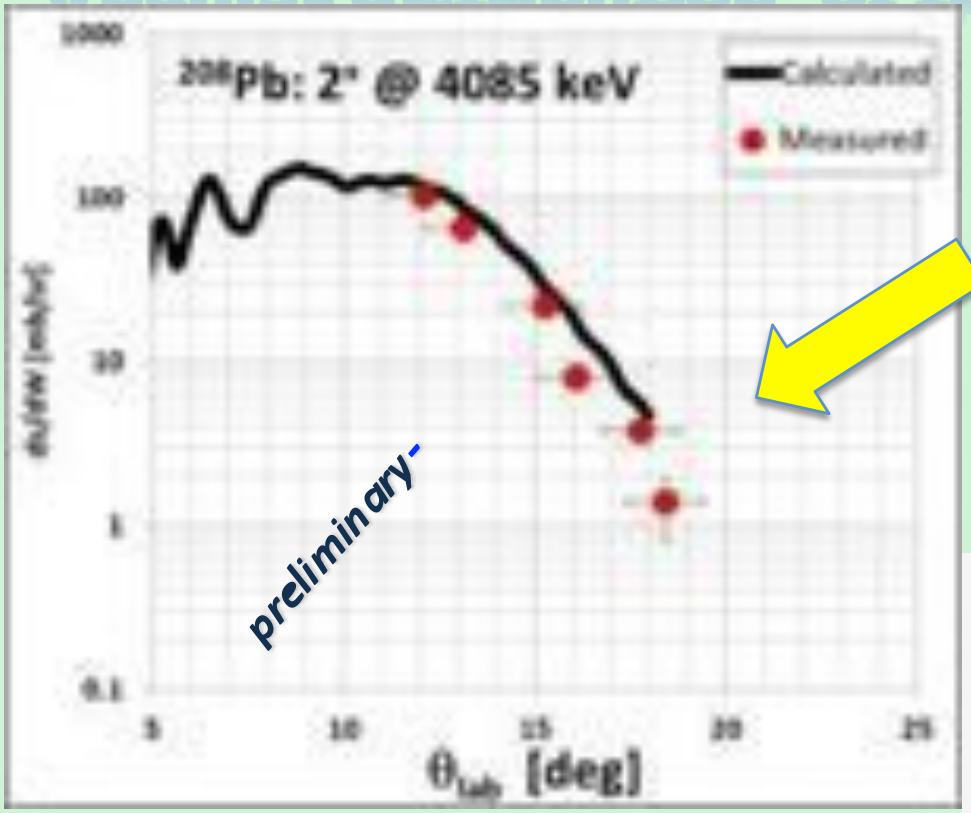
Good description of the 3- state in DWBA

Optical model in agreement with measurements at similar energy

known B(E3) used

B(3) corresponding to M_n/M_p = N/Z

Inelastic scattering - Angular distribution of the scattered ^{17}O



Good description of the 2+ state of ^{208}Pb

Optical model in agreement with measurements at similar beam energy known B(E2) used

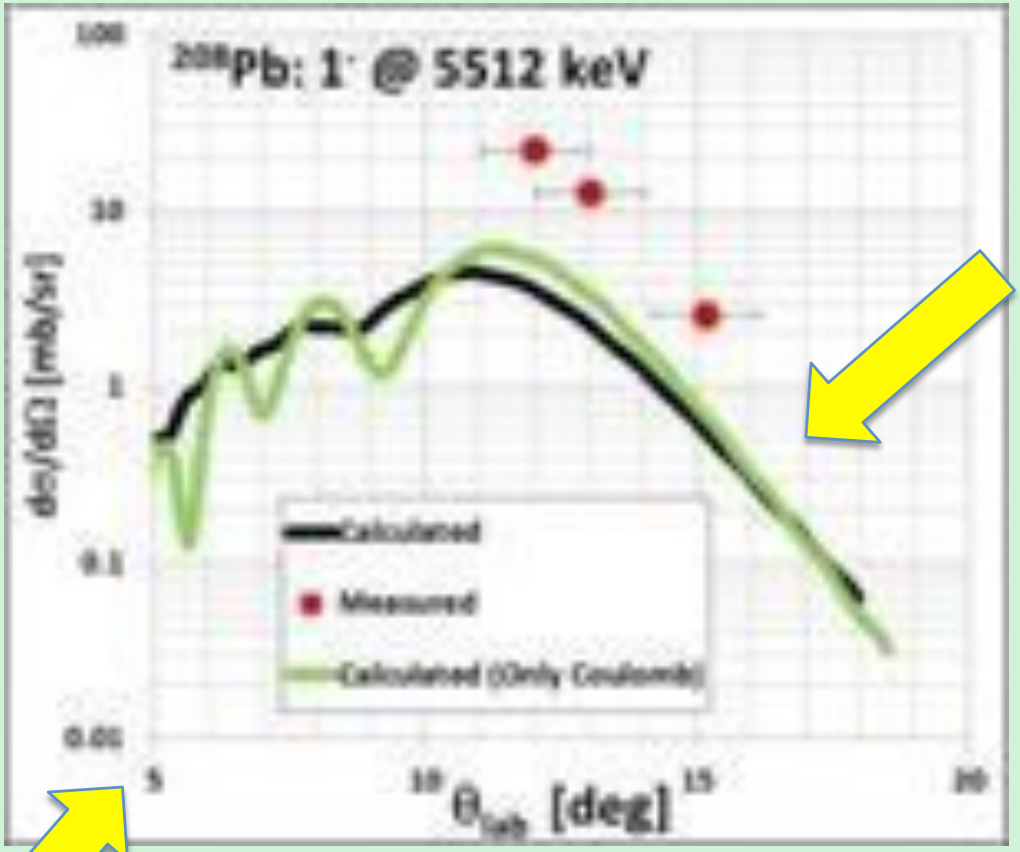
B(2), the mass multipole moment, corresponds to $M_n/M_p = N/Z$

$M_{n,p}$ multipole matrix element

$$B(L)\uparrow = |M_n + M_p|^2 \qquad B(EL)\uparrow = |M_p|^2$$

$$B(L)\uparrow = \delta_L^2 \left[\frac{3A}{4\pi} R^{L-1}\right]^2$$

Inelastic scattering - Angular distribution of the scattered ^{17}O



An analysis in DWBA which includes the E1 isoscaler strength and the form factor for isoscaler will be made- Extract the % of the ISLEDR sum rule

1^- state in ^{208}Pb

The calculation accounts only for 25% of the measured yield

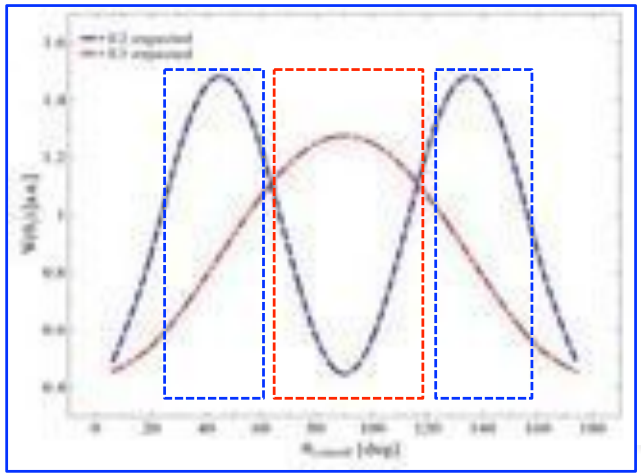
Why?

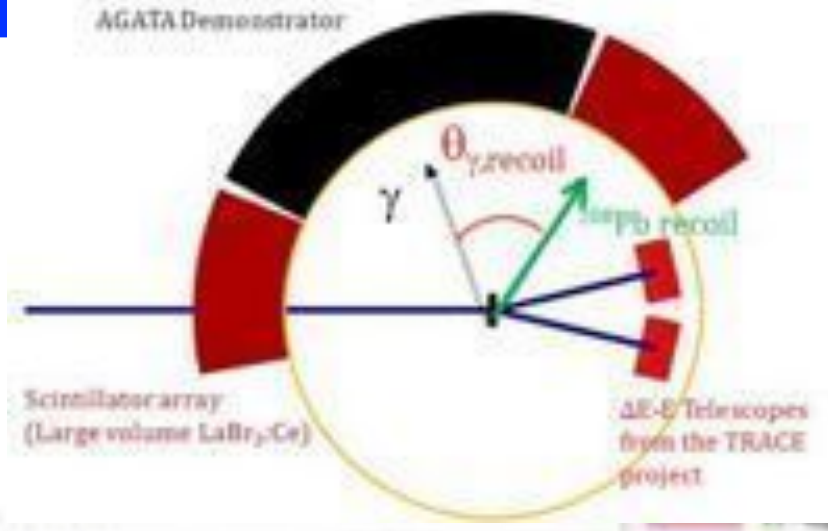
Only the isovector form factor with the B(E1) measured in electr. exc. was used.

This is affecting the Coulomb excitation cross section of the state.

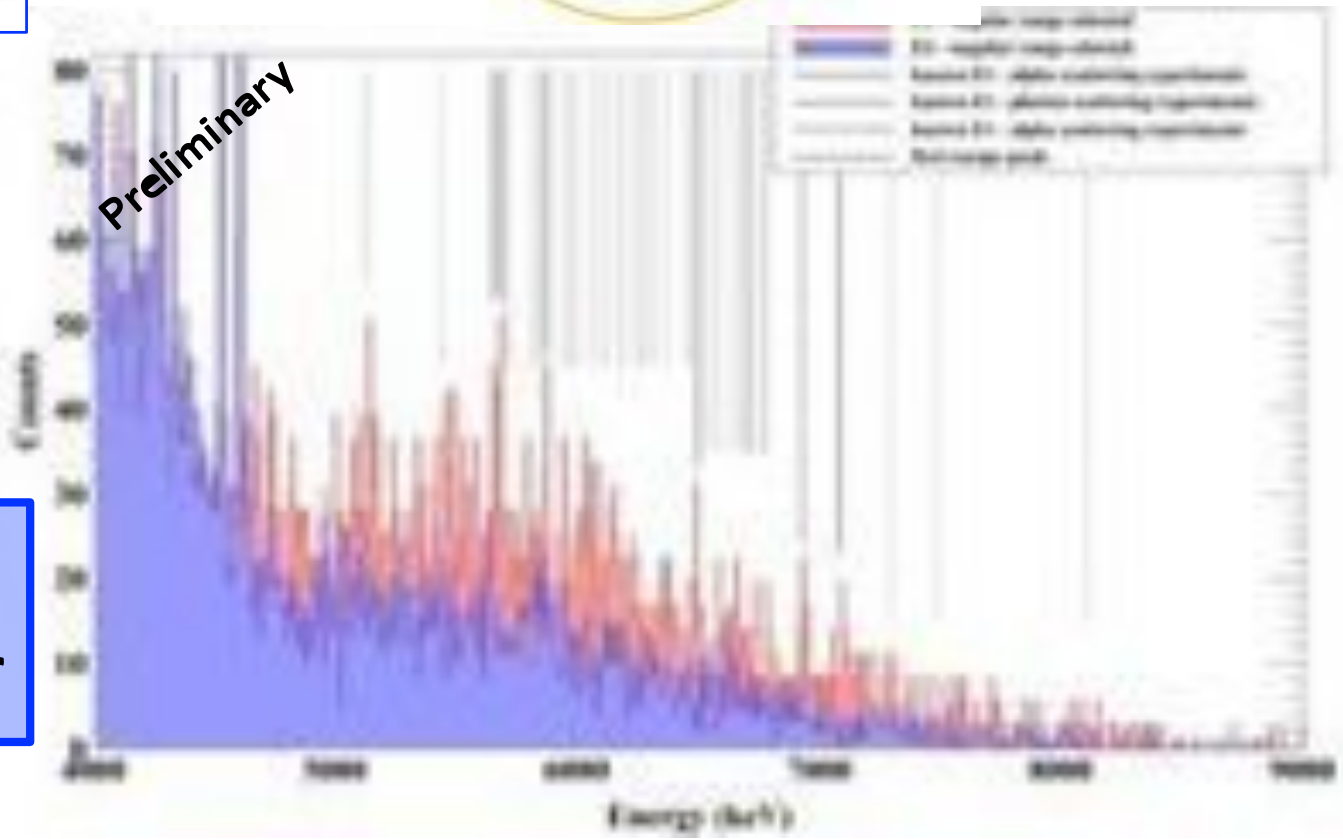
Inelastic scattering of ^{17}O at 20 MeV/u on ^{124}Sn

Angular Distribution

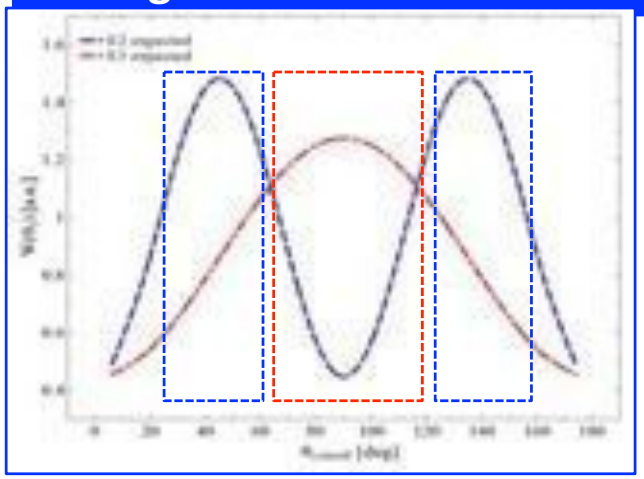




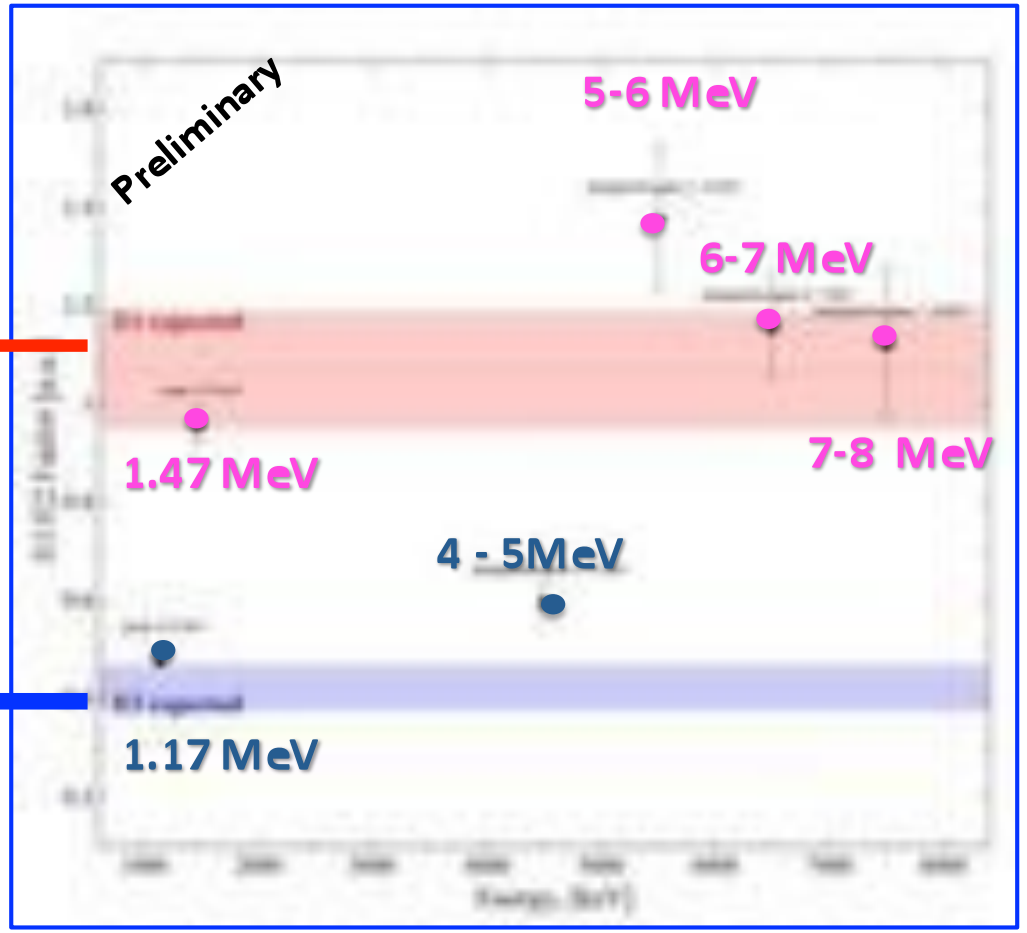
PYGMY Region shows a E1 character



Angular Distribution

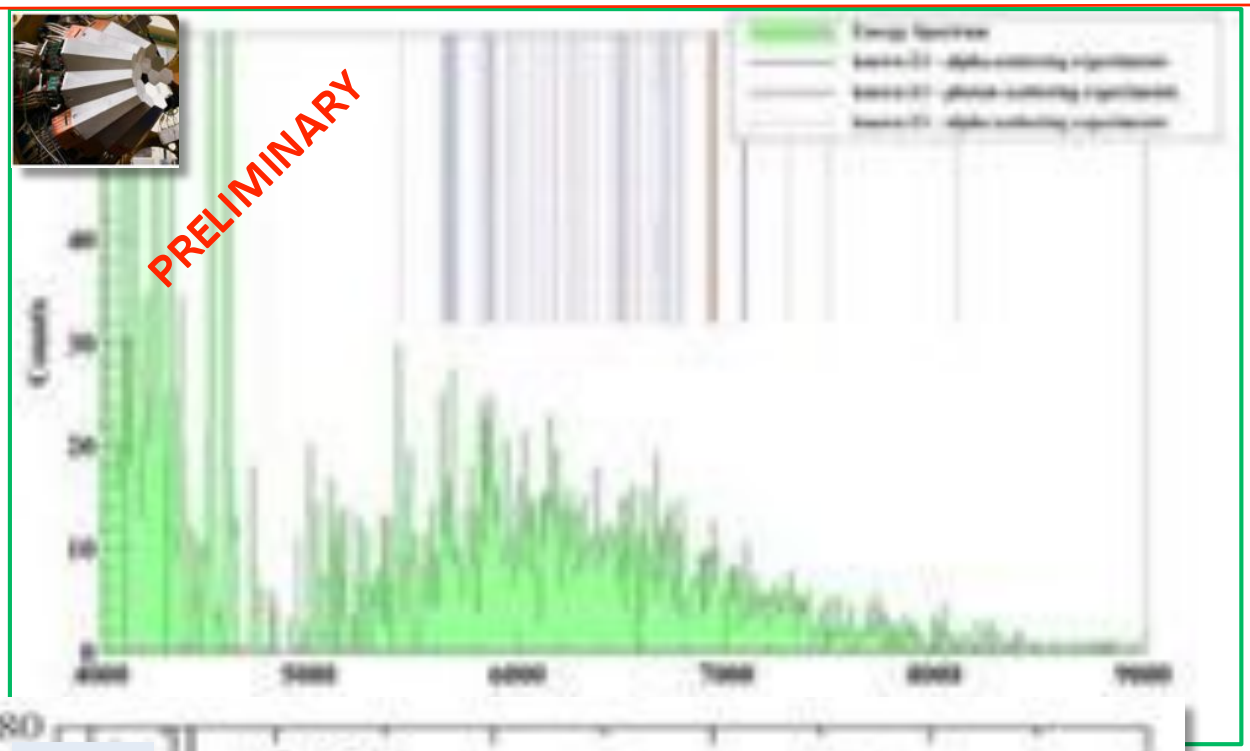


Angular Distribution for different energy of the gamma-rays

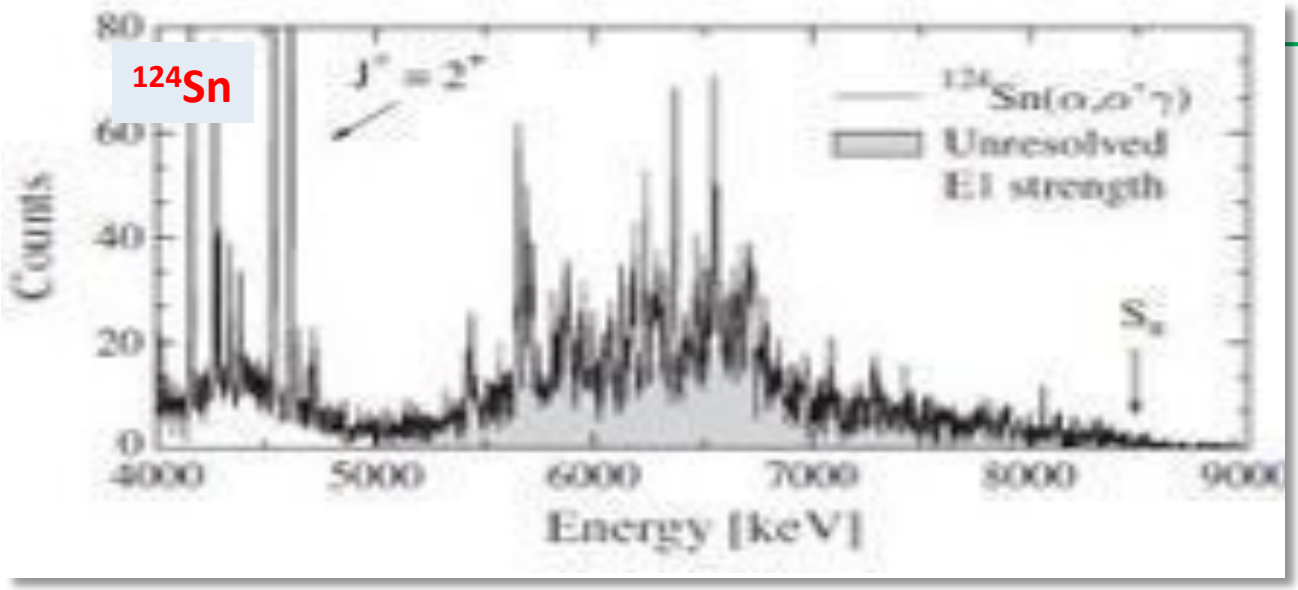


The gamma-rays of pygmy region in ^{124}Sn shows E1 character

The pygmy in ^{124}Sn



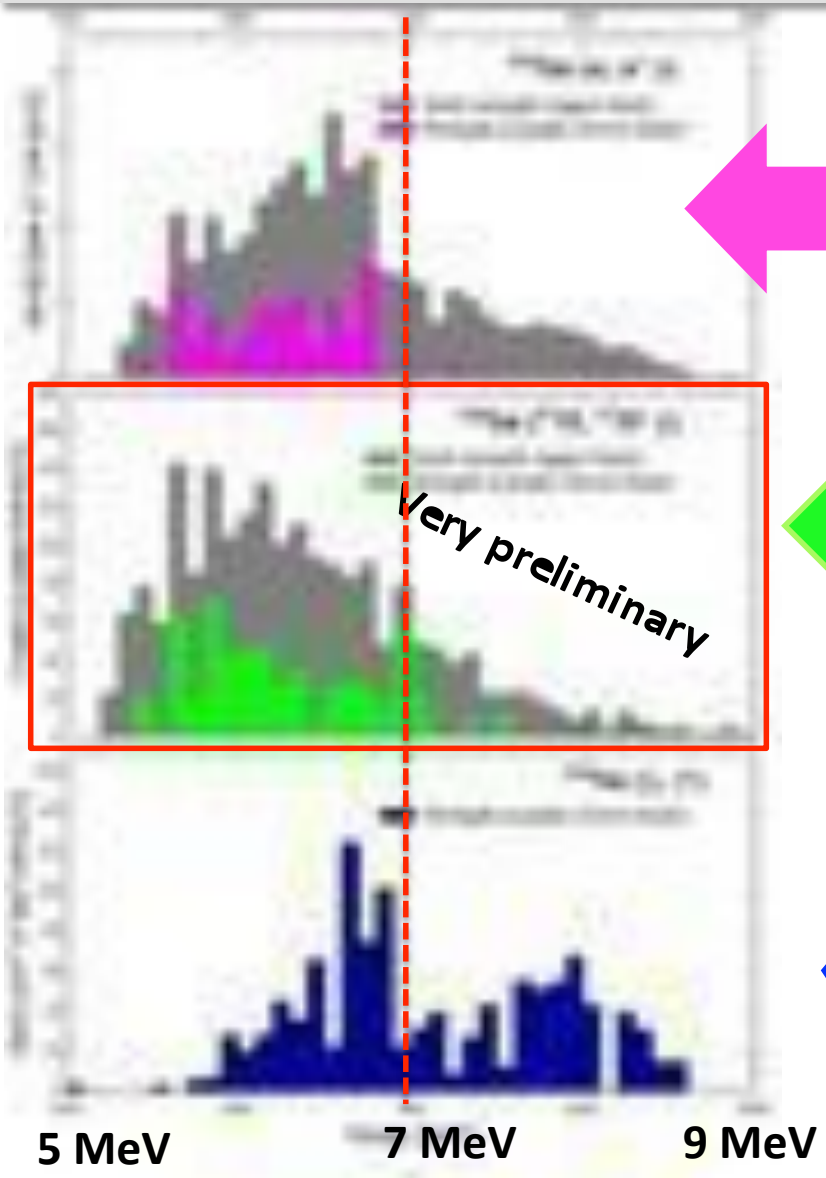
Inelastic scattering
^{17}O @ 20 MeV/u
+ γ-ray
coincidence



Inelastic scattering
^{4}He @ 36 MeV/u
+ γ-ray coincidence

PRL105(2010)212503

Nature of pygmy resonance: ^{124}Sn



Comparison of the strength from (^{17}O , ^{17}O' γ) and (γ, γ') , (α, α' γ) experiments

(α, α' γ a) at 136 MeV

J. Endres et al., Phys. Rev. C 85 (2012) 064331

Some missing strength for (^{17}O , ^{17}O' γ) above 7 MeV

Similar behaviour as (α, α' γ)

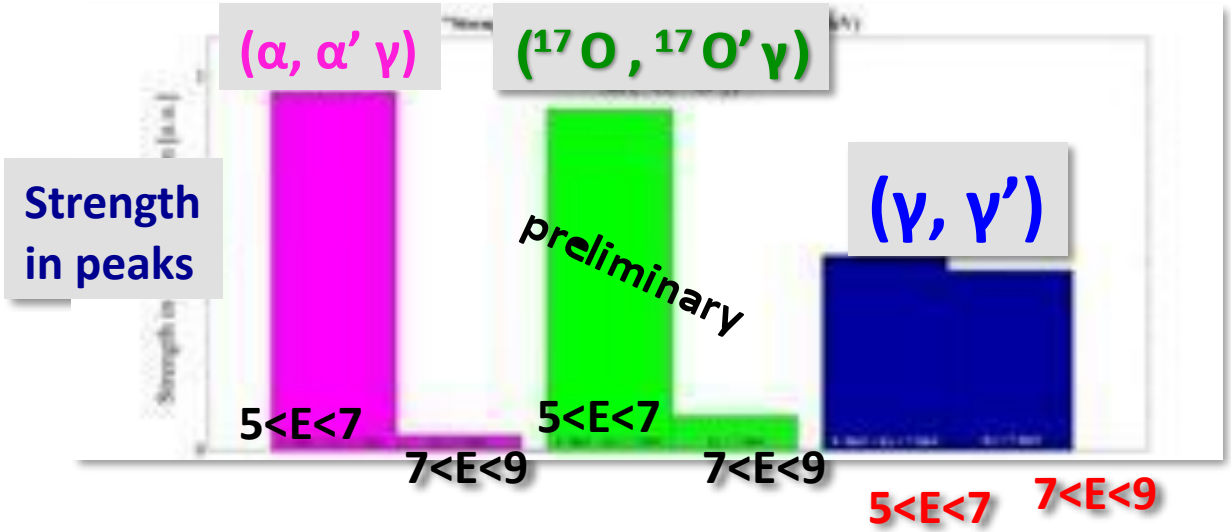
(γ, γ')

K. Govaert et al., Phys. Rev. C57, 2229 (1998)

(p,p') data from Osaka

Nature of pygmy resonance: ^{124}Sn exp summary + theory

Summary experimental results

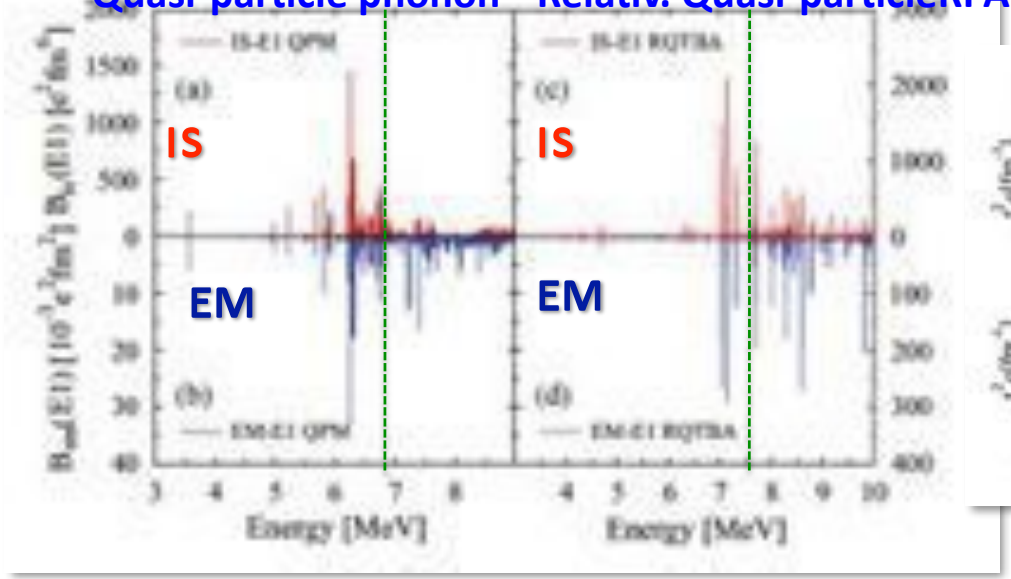


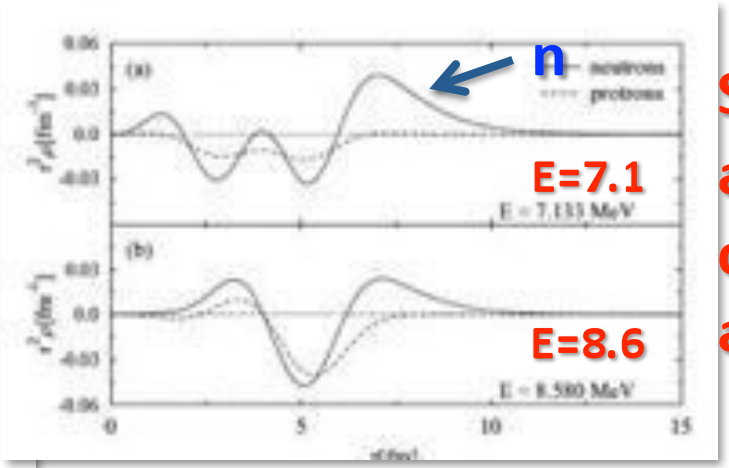
Evidence for isoscalar character for 5<E<7 –
7<E<9 stronger isovector character

To be more quantitative
Isoscalar strength
has to be extracted in the future

Theoretical predictions- similar trend of the data

Quasi-particle phonon Relativ. Quasi-particleRPA

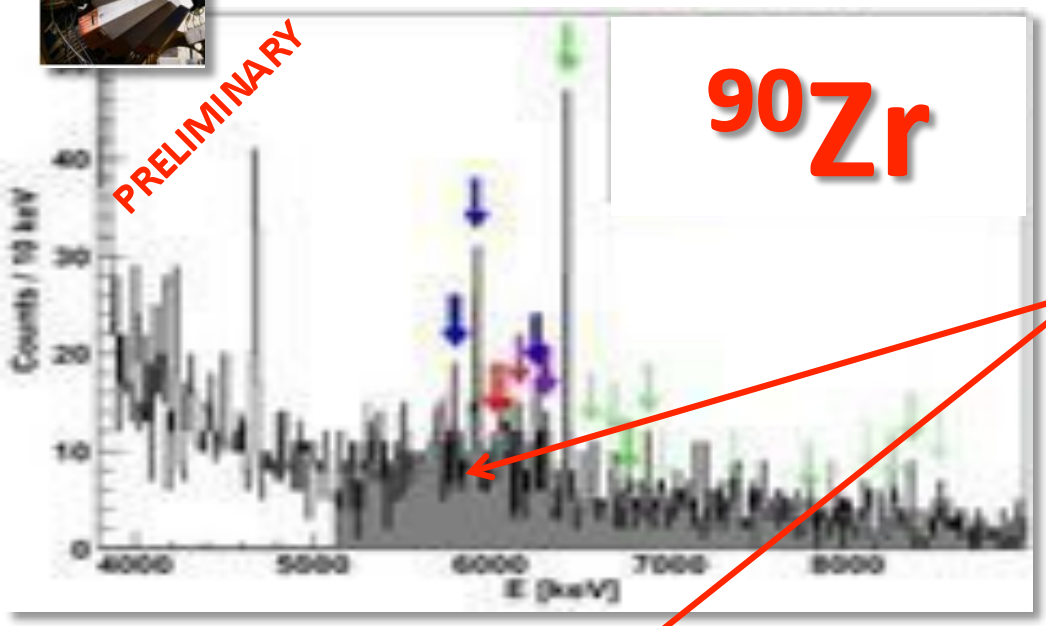




Same B_{em} and B_{is} differs by a factor 4

J. Endres et al., Phys. Rev. C 85 (2012) 064331

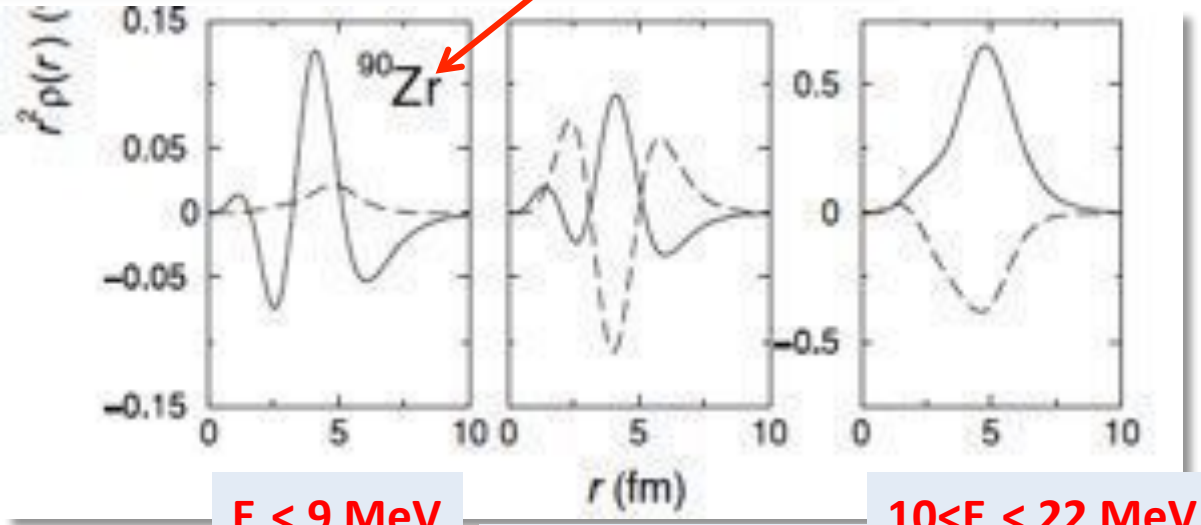
The pygmy in ^{90}Zr



A concentration of states was seen in (γ,γ')

Complex case to study

- The states at 6 to 7.5 are dominated by neutron component
- At higher energy strong mix with the GDR



$E_x < 9$ MeV

$9 < E_x < 9.5$ MeV

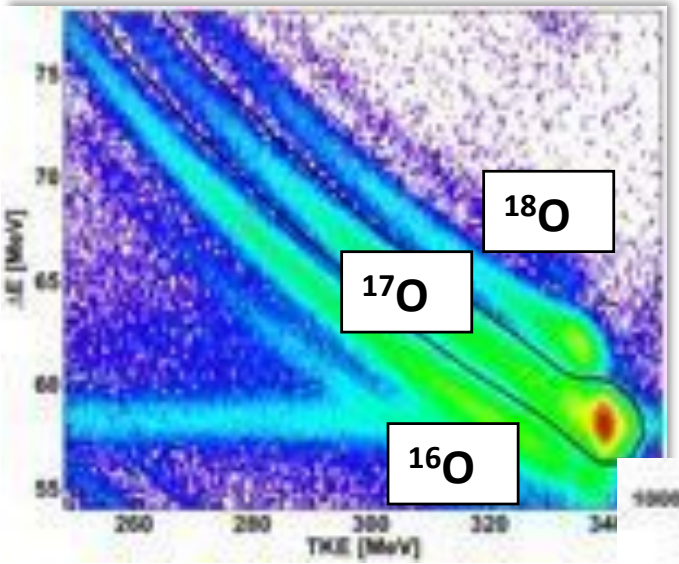
$10 < E_x < 22$ MeV

Quasi article phonon Model predictions

R. Schwengner et al, PRC78,064314(2008)

Excitation of high lying modes

Isoscalar Giant Quadrupole and Monopole Resonance

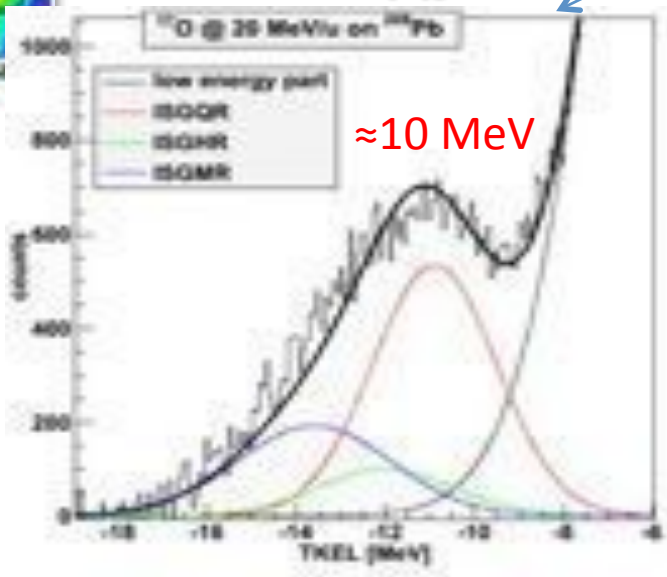


Silicon telescope-
ion identification

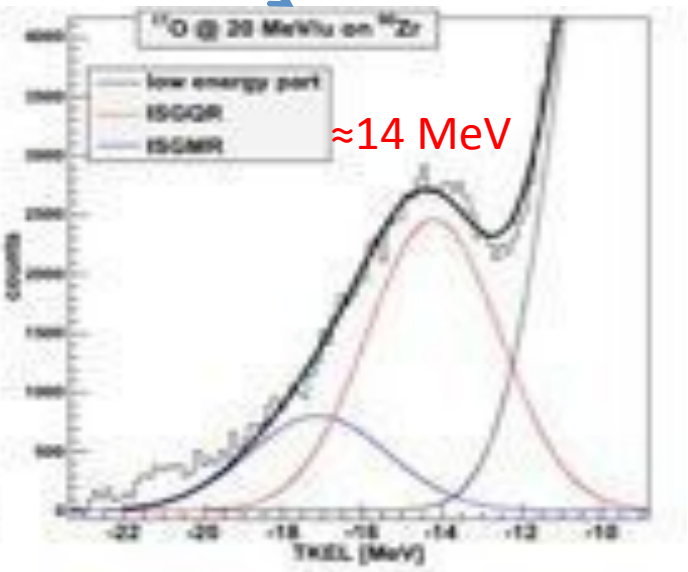
Energy spectra of ^{17}O
in GQR e GMR regions

^{17}O loosely
bound
above 4.5 MeV
mainly
only target
excitation

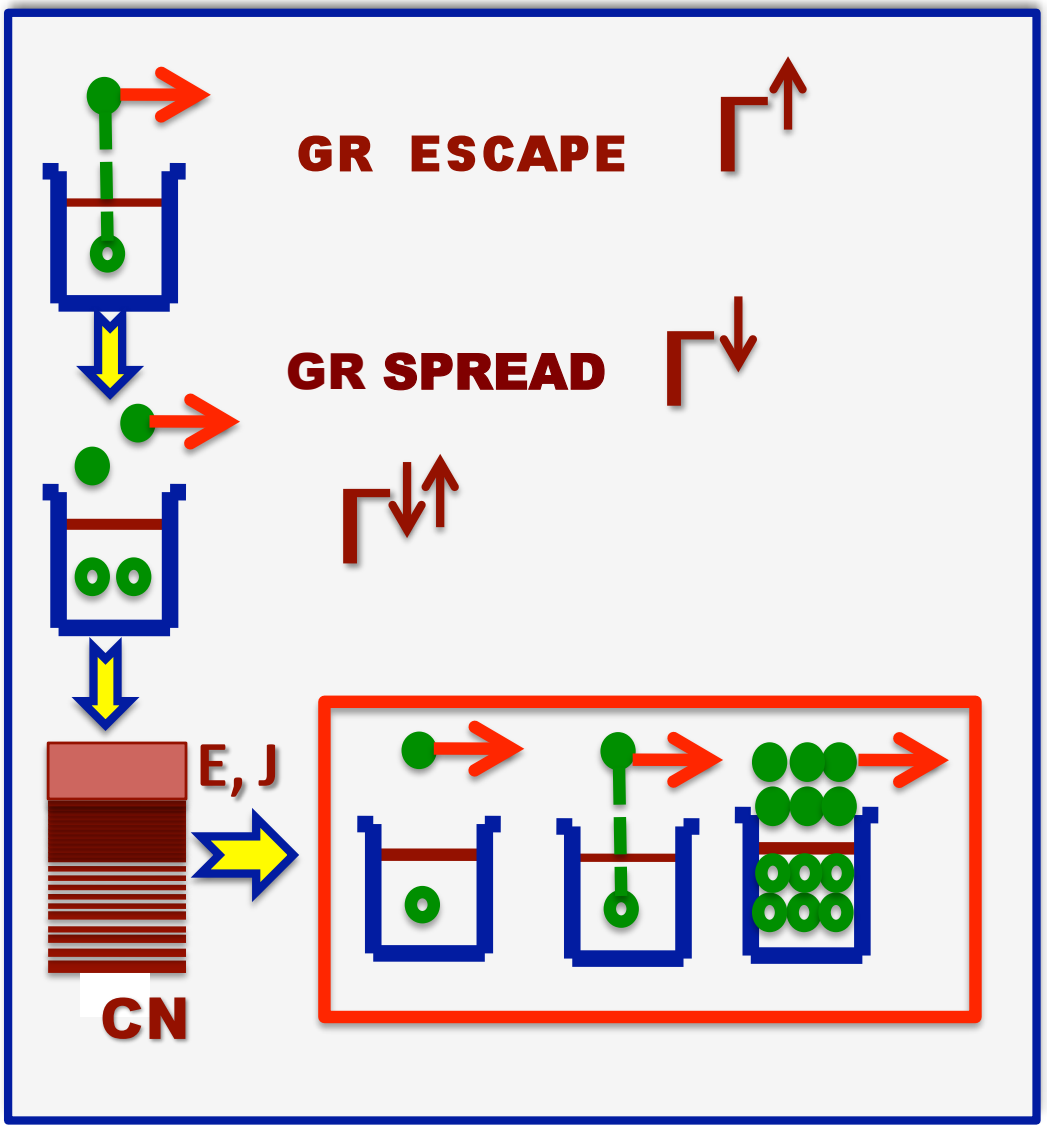
^{208}Pb



^{90}Zr



Particle decay from Giant Resonances



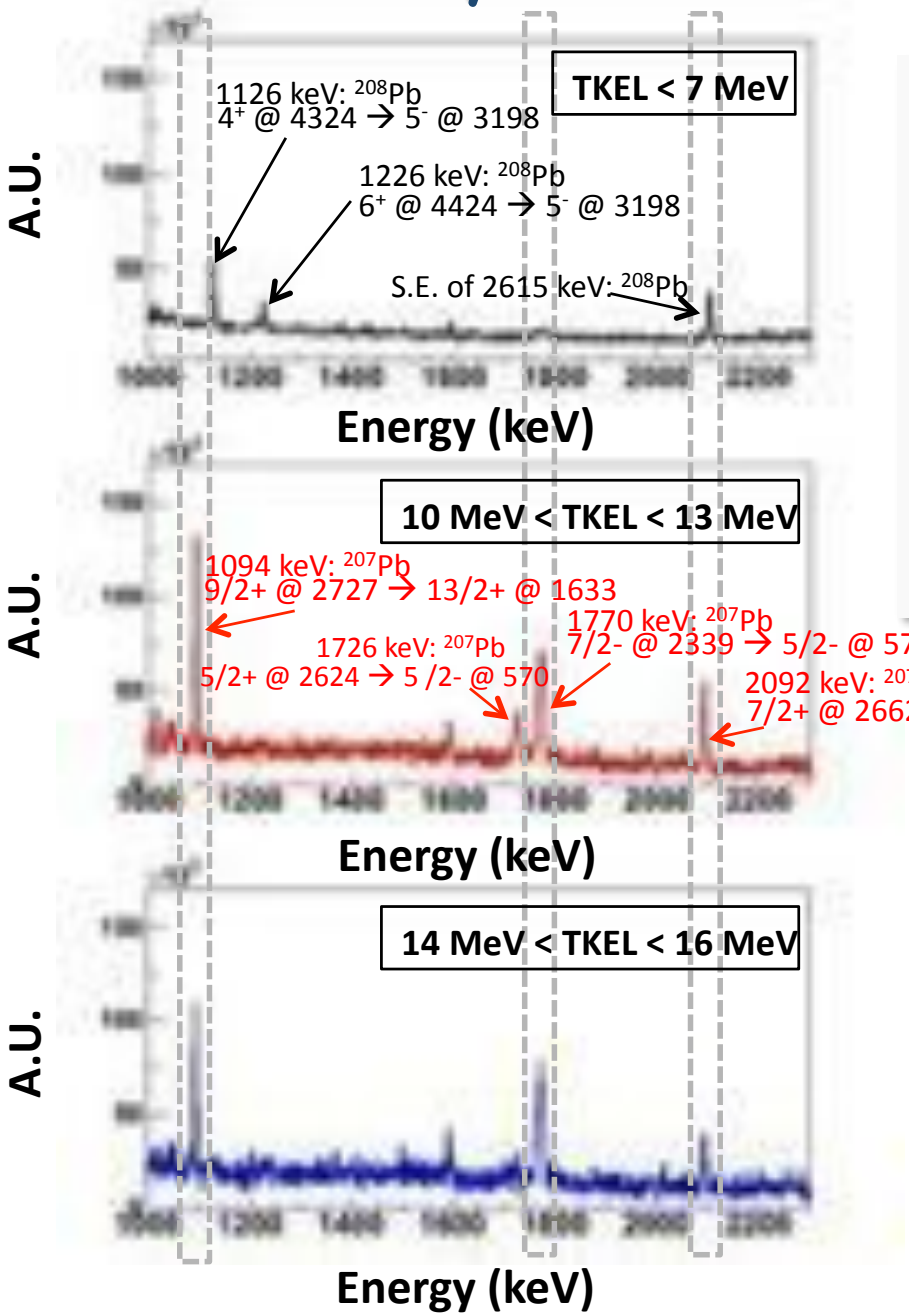
Particle decay from GIANT RESONANCES to specific final states

Identify them with high resolution
with residual energy as deduced
from the mesurement of gamma transitions

$$E_F = E_{GR} - E_b - E_g$$

Latest work PRL from Ganil double GR

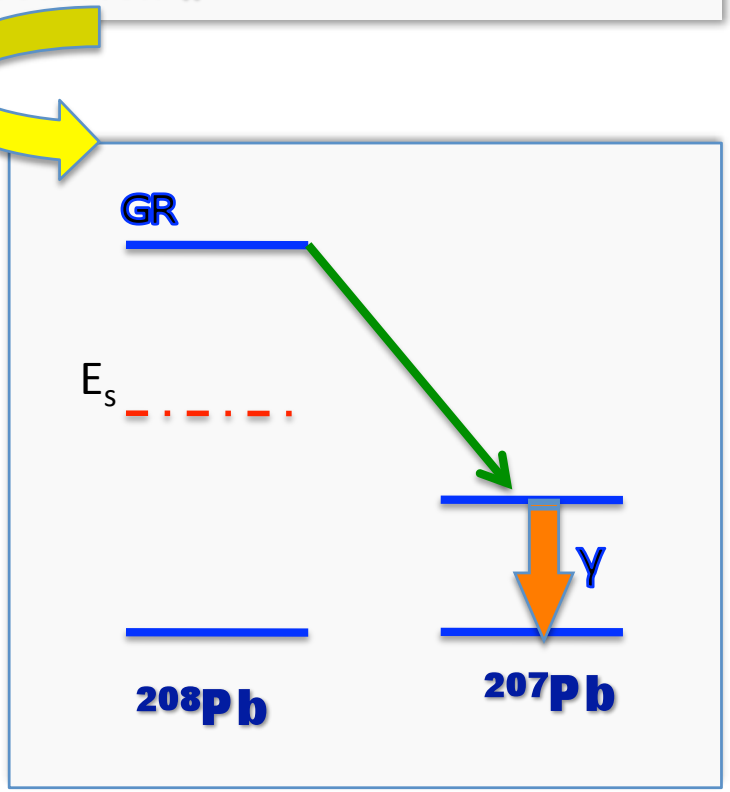
Particle decay from Giant Resonances in ^{208}Pb



Intensity of the lines to be compared with Statistical model

This comparison will allow to extract If there is direct component.

For the first time this particle decay is measured with high resolution !!



For the future ….

Study of particle and gamma decay from GQR

Work in progresss

- Pb test bench- extract the fraction of ISLDR sum rule

- Complete the analysis of ^{90}Zr

- DWBA Analyse the data on ^{124}Sn (Milano)
- Analyse the data on ^{138}Ce (M. Kmieck et al. Cracow)

The two last data sets are very interesting in view of the comparison with (alpha, alpha') reaction for which data with high resolution gamma decay exist.

Conclusion

The Study of the E1 response in Nuclei is very interesting :

r-process- Physics on neutron star and neutron skin

- Much work to be done with RIB to reach very neutron rich nuclei- AGATA will be employed to see fine structures (future exp.with AGATA at GSI)

The use of ion as ^{17}O at 20 MeV/u has given preliminary results in agreement with alpha for ^{124}Sn. For 208Pb high resulution data non available for alpha scattering.

- Much work is still in progress for stable nuclei to understand the nature of these states –

- Particle decay from Giant resonance is being studied

Useful method also for future application with RIB with beams at low energies (eg. ^{13}C target inverse kinematics + gamma decay)!!!

Collaboration

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