Gamma decay of pygmy states from inelastic scattering of ions

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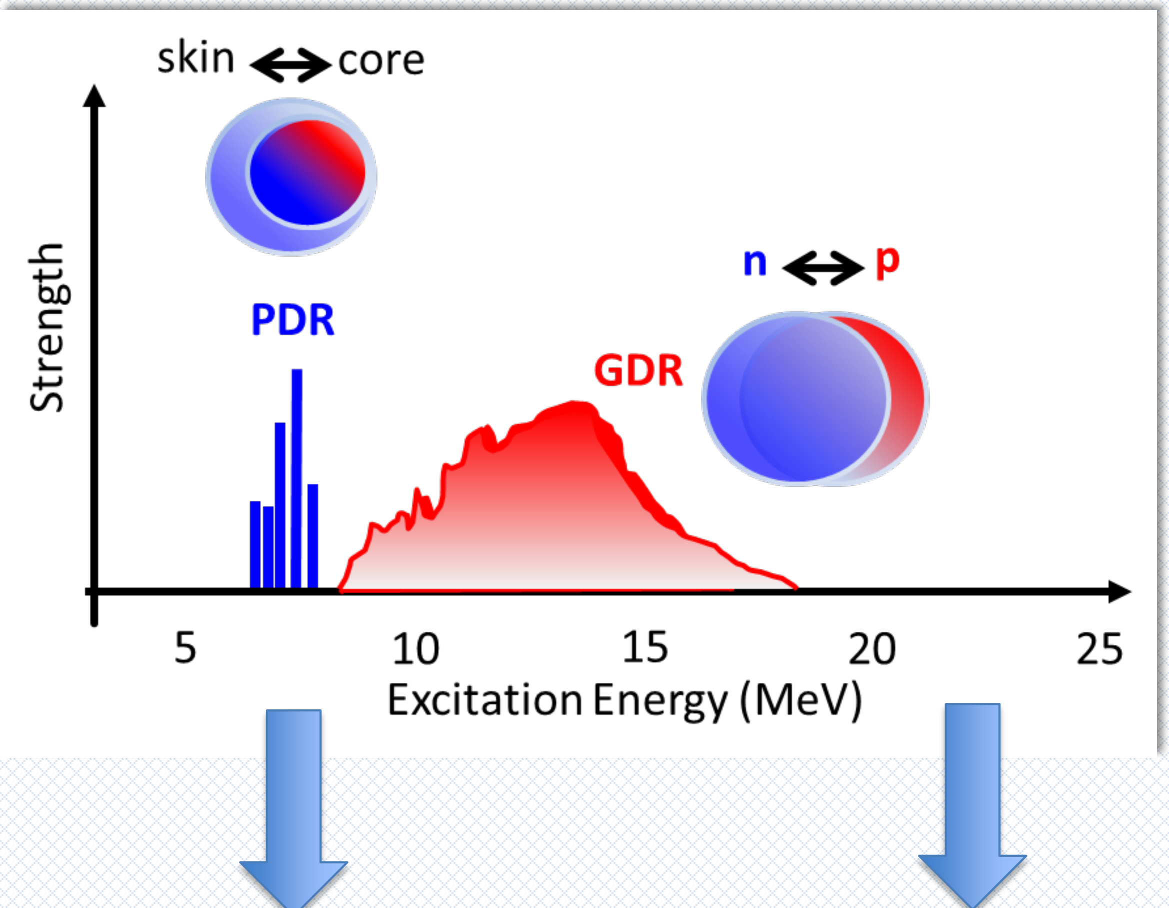
The 5th International Conference on
"COLLECTIVE MOTION IN NUCLEI UNDER EXTREME CONDITIONS"

September 14-18, 2015 Kraków, Poland

OUTLINE

- The pygmy dipole resonance and its excitation
- Experiments with AGATA using ^{17}O beams
- Results for ^{90}Zr,^{124}Sn,^{208}Pb and ^{140}Ce
- Pygmy quadrupole resonance in ^{124}Sn?
- Future perspectives

E1 nuclear response



Interesting for astrophysics

Interesting for nuclear structure

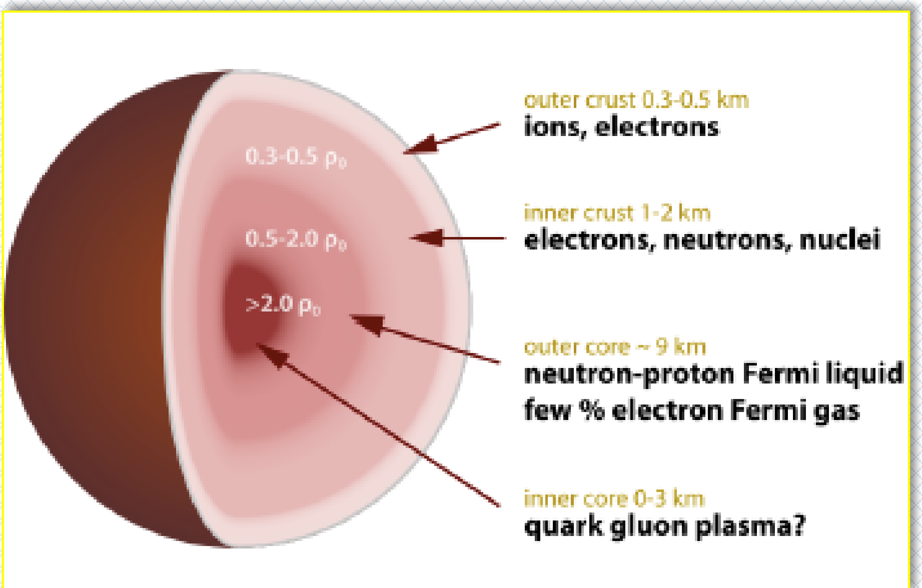
They are characterized by different types of excitations : question what are the probes and energy to be used to study the dipole response?

Implications for astrophysics

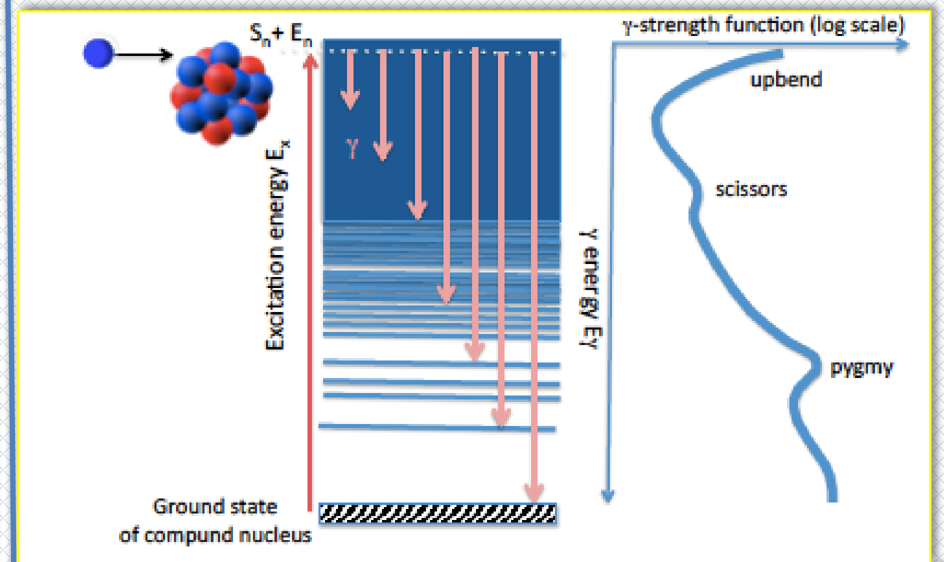
Neutron stars

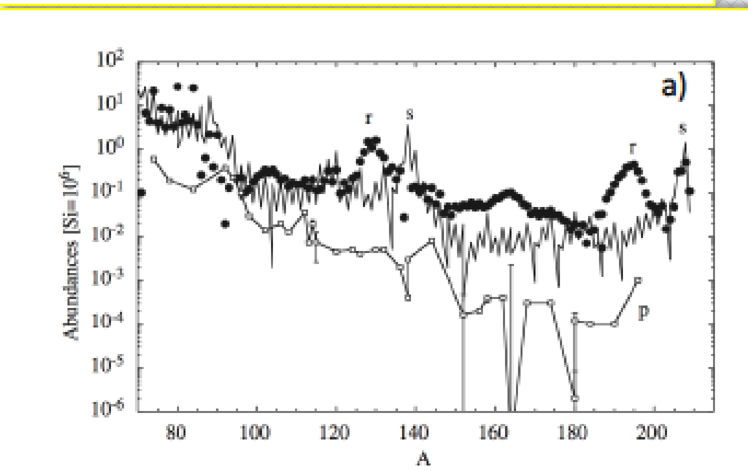
Pygmy contributes to the polarizability and thus tests the theory for the asymmetry part of the nuclear equation on states.

This is used to describe neutron stars

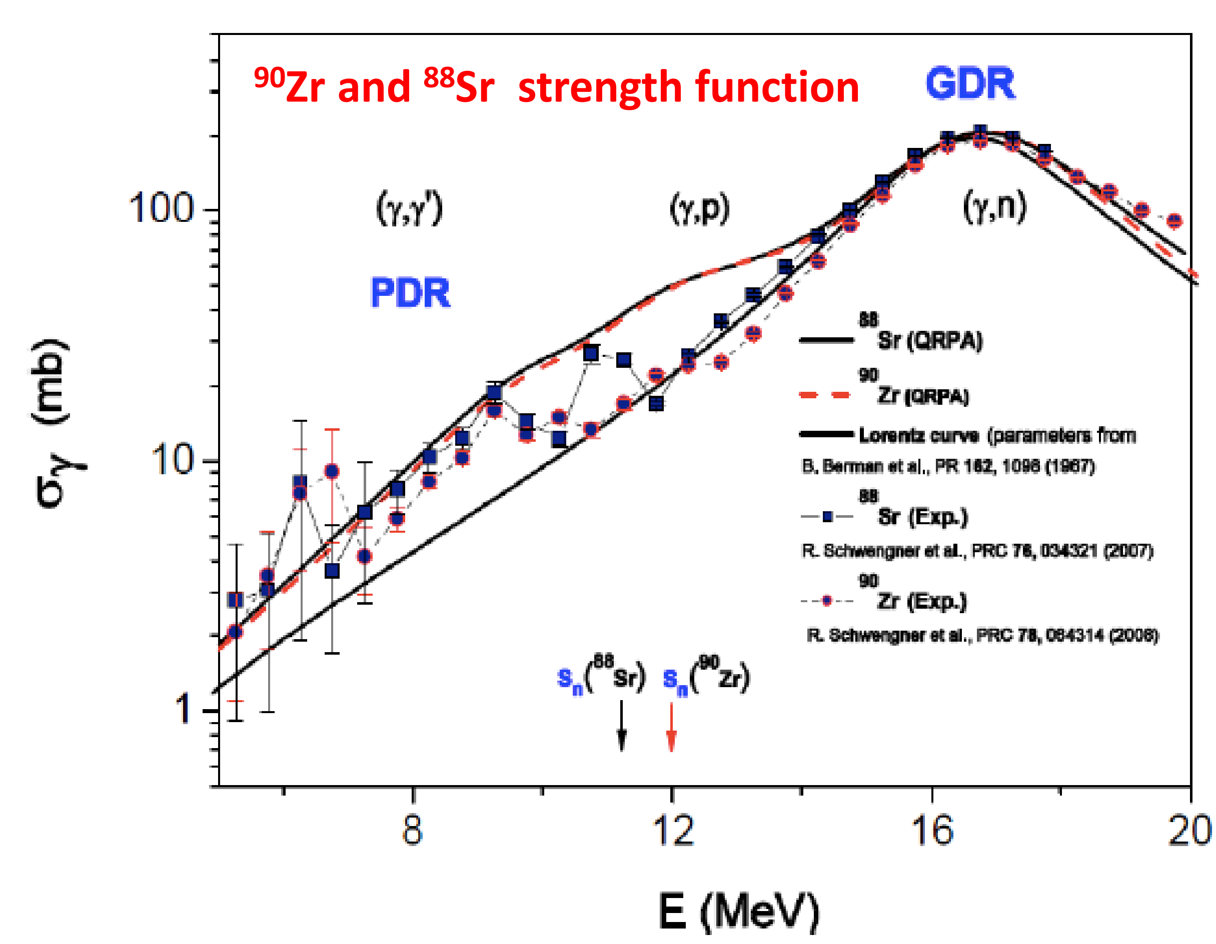


radiative neutron-capture reactions for r-process





Some example of gamma absoption cross section…….



Calculations of cross sections using codes based on statistical reaction models do not describe the data below the neutron separation energy if a standard Lorentzian curve is used

Dresda data

Some history.....publications on PDR

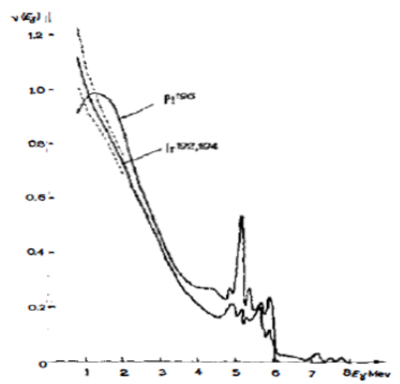
The Start 1961-1971

NEUTRON CAPTURE GAMMA RAYS[1]

By G. A. Bartholomew

Neutron Physics Branch, Chalk River Project, Atomic Energy of Canada Limited

Ann. Rev. Nucl. Sci. ***11*** *(1961) 259*



Effect of the pigmy resonance on the calculations of the neutron capture cross section

J. S. Brzosko, E. Gierlik, A. Soltan, Jr., and Z. Wilhelmi

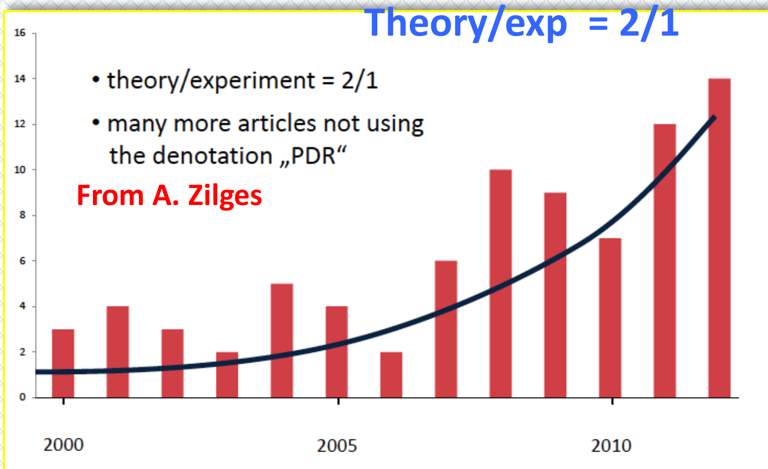
Can. J. Phys. ***47*** *(1969) 2850*

Three-Fluid Hydrodynamical Model of Nuclei*

R. Mohan, M. Danos, and L.C. Biedenharn,

Phys. Rev. C ***3*** *(1971) 1740*

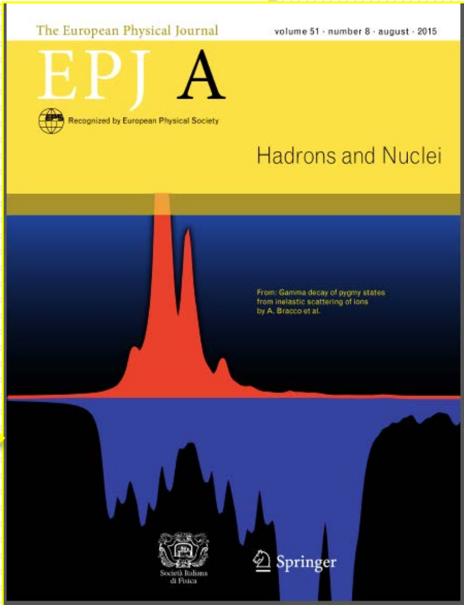
An increasing number starting from 2000...



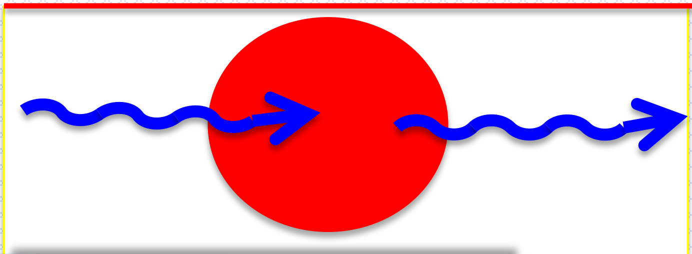
Review papers:

D. Savran, T. Aumann, A. Zilges
Prog. Part. Nucl. Phys. 70, 210 (2013).

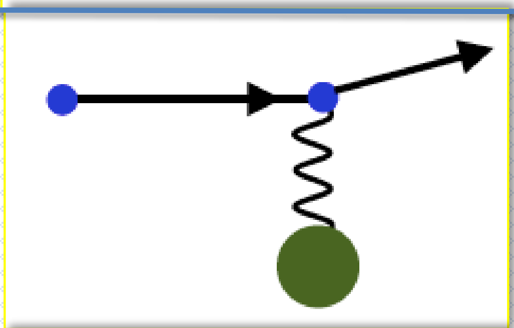
A.Bracco,
F. Crespi, E. Lanza
Eur. Phys. J. A (2015) 51:99



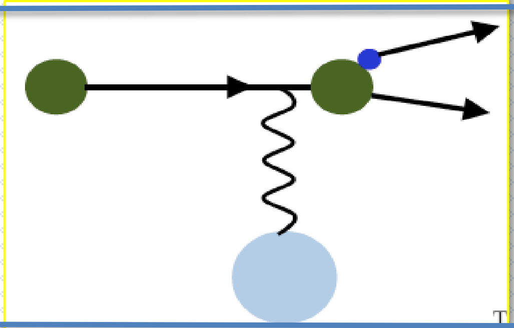
Experimental tools



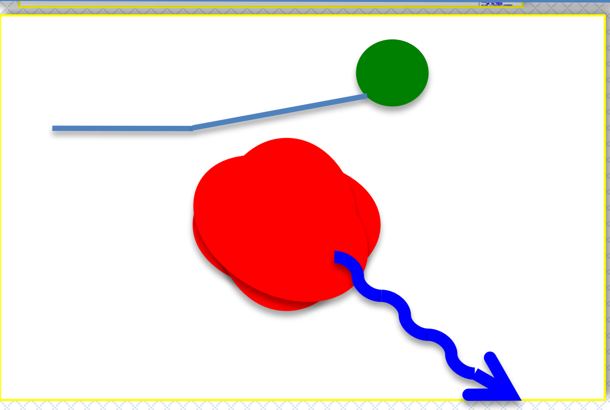
(γ,γ') real photons
on stable nuclei
Probing the entire nuclear volume



(p,p') virtual photons at E_{beam}> 200 MeV
on stable nuclei
Probing the entire nuclear volume
Work at Osaka RCNP



Coulomb excitation with radioactive beams
virtual photons
Exotic nuclei
E1 excitation at high energy (GSI, MSU)



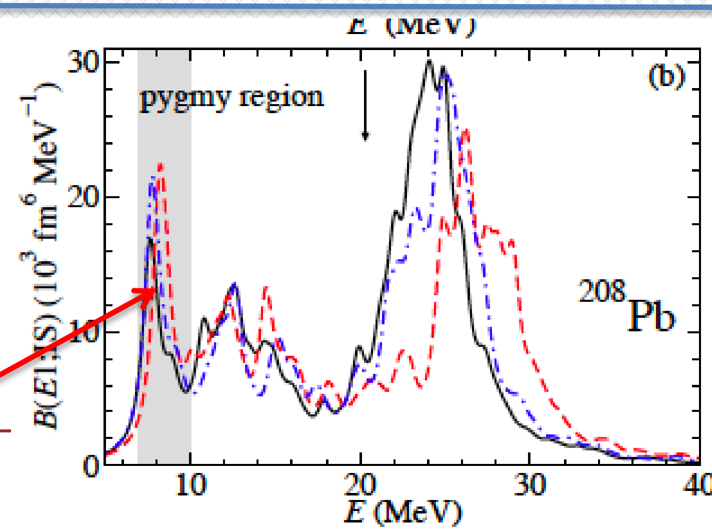
(α,α'γ) or (^{17}O,^{17}O'γ)
on stable nuclei
Probing the nuclear surface mainly

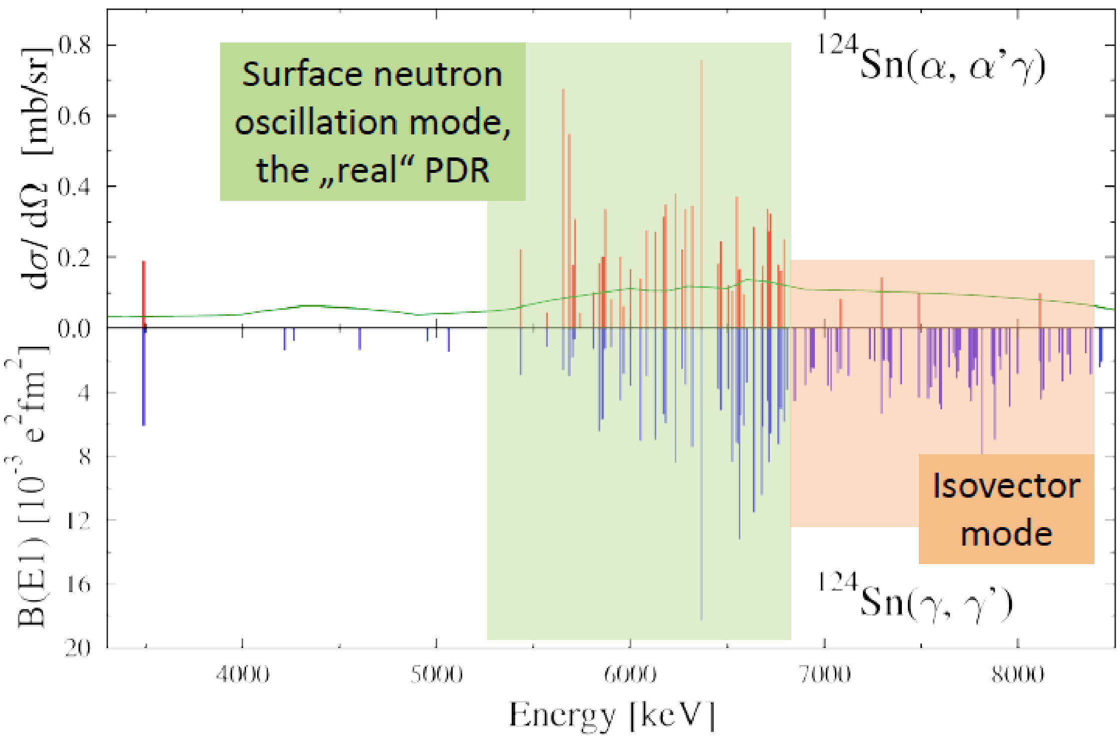
LNL

Do we need different probes ?

Isoscalar or isovector?

In ^{208}Pb
4.3-5.5 % IS EWSR strength at 9 MeV
Theory from Rocha-Maza, Colo'





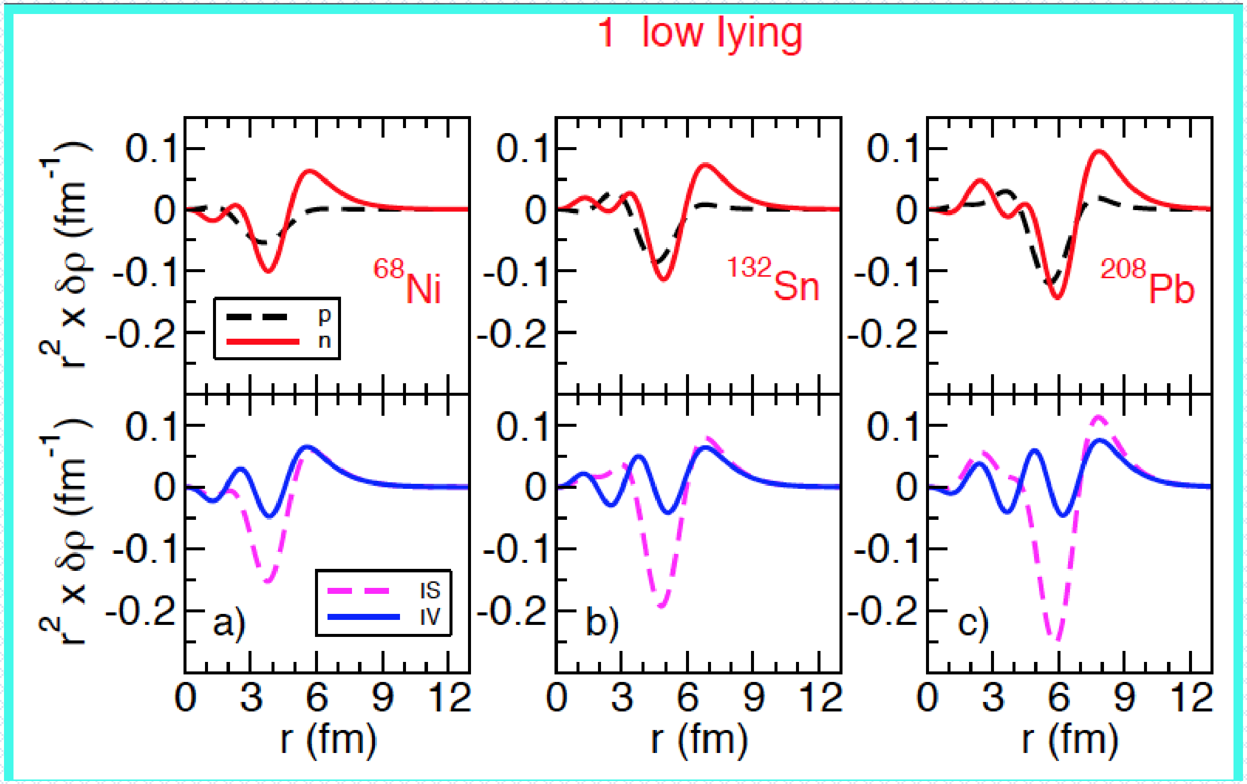
Janis Endres et al., PRL ***105*** *(2010) 1125[...]*
Janis Endres et al., PRC ***85*** *(2012) 06433[...]*

IS nature of the PDR due to outermost nucleons (neutrons in a neutron-rich nucleus).
The r_{np} is correlated with J and L.

Interesting to study the properties of the neutron skin

First work on (α,α'γ) – PLB278, 423 (1992).

On the Transition Densities....



The low lying peaks of 1^- character have the same features:

n and p transition densities are

- in phase inside the nucleus
- at the nuclear surface only the neutron part survives

➢ **Interesting to use a probe interacting mainly at the surface !!!**

*E. G. Lanza et al., Phys. Rev. C 79 (2009) 054615.
**E. G. Lanza et al., Phys. Rev. C 84 (2011) 064602.

Transition Densities and Form Factors

→ **different structure of Transition Densities→ Different Form Factors**

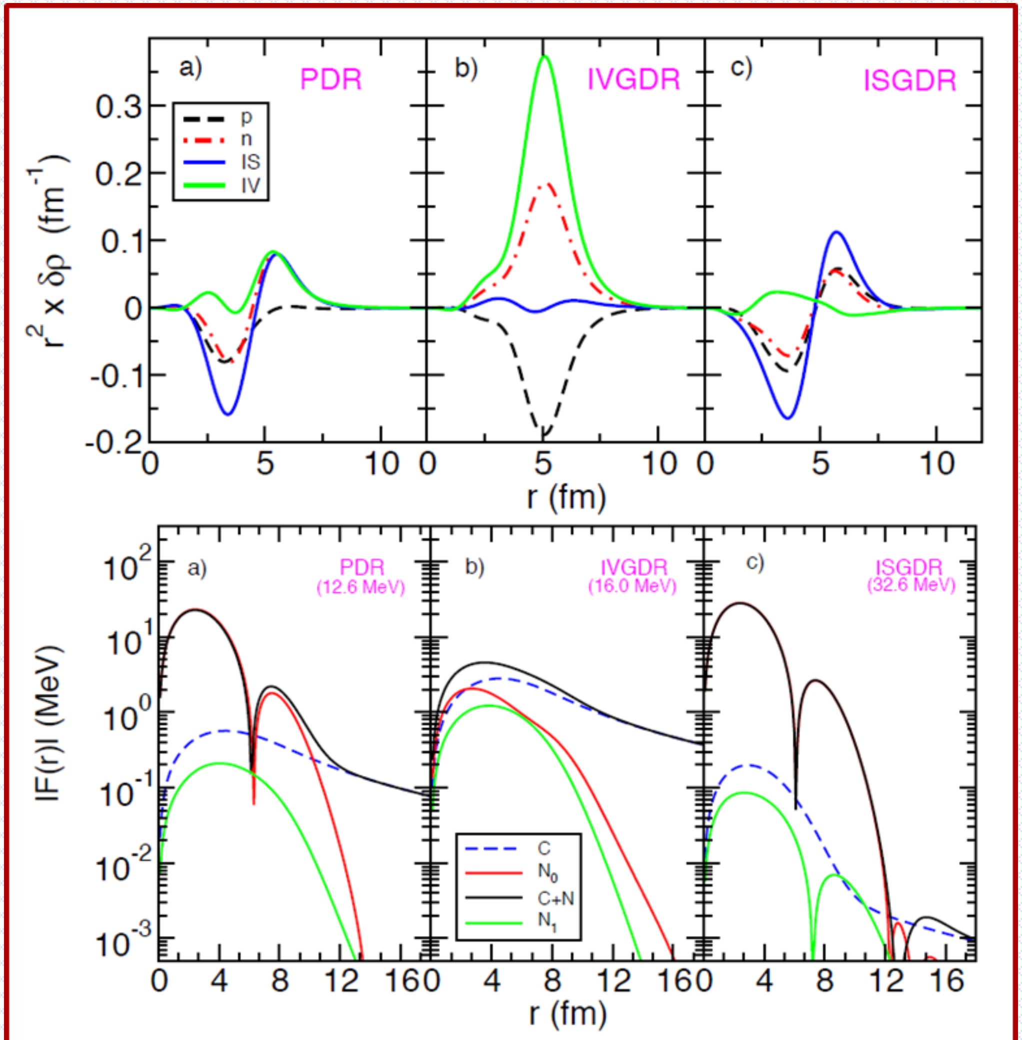
→ predictions obtained with form factors from microscopic transition densities which incorporate the main features of these states

^{90}Zr

Transition Densities

$^{17}O+^{90}Zr$

Form Factors



*E. G. Lanza et al.,
PRC 89 (2014) 041601
**A. Bracco,
F.C.L. Crespi and E.G. Lanza,
EPJA(2015)51:99

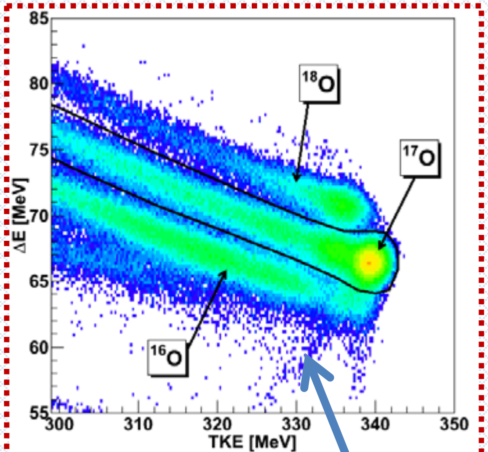
Recent measurements with ^{17}O

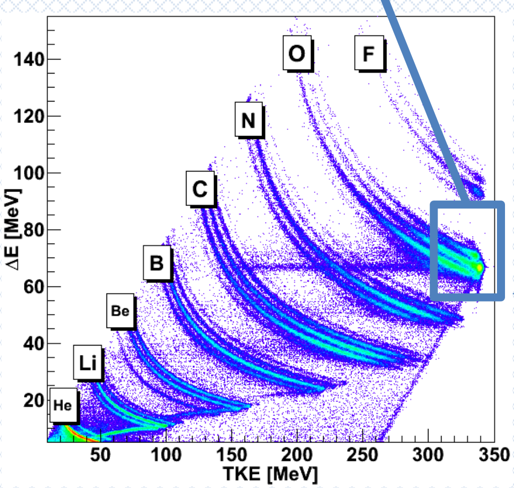
Using AGATA at LNL

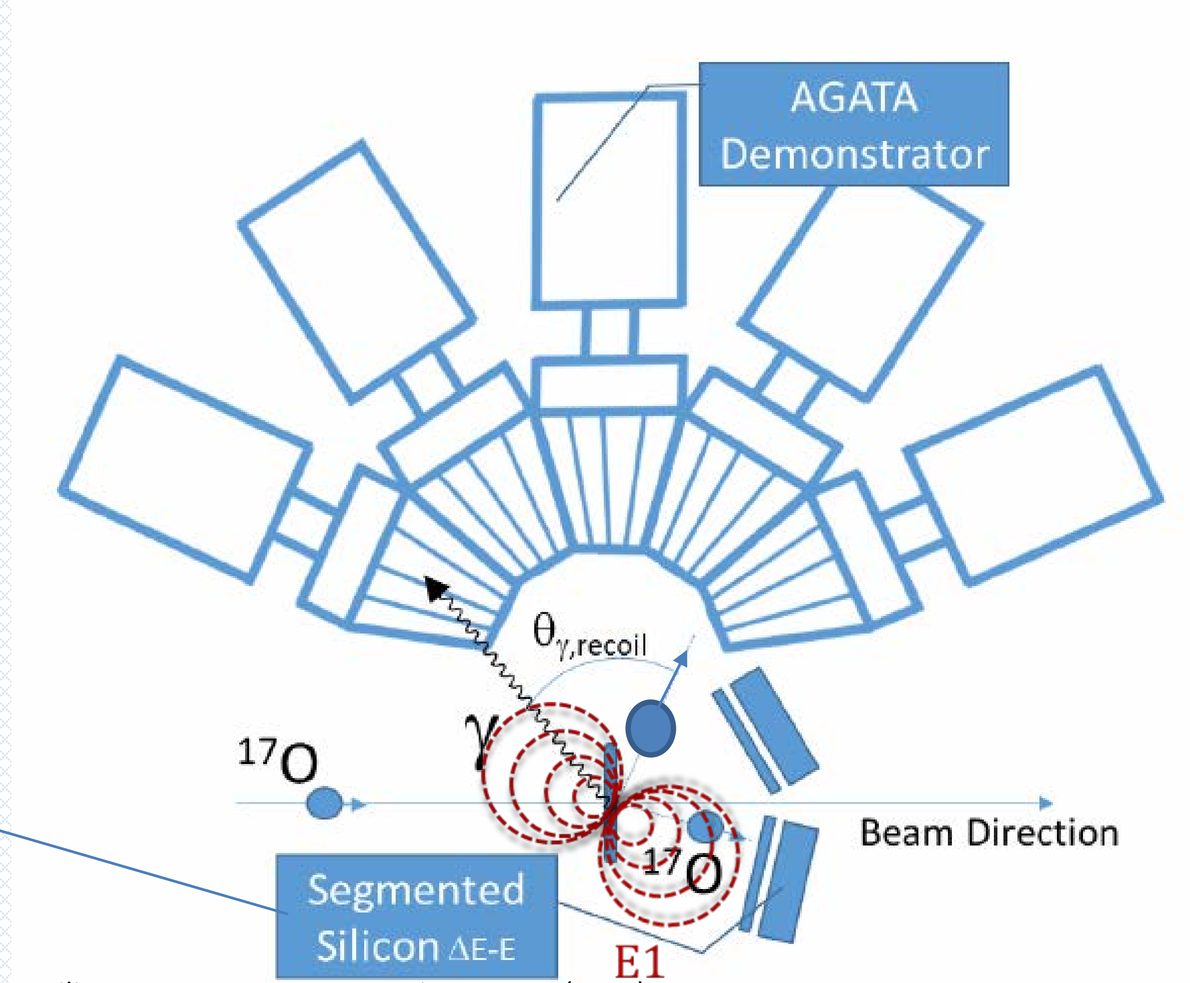
The AGATA experiments

^{17}O @ 20 MeV/u on different targets + γ-rays in coincidence

- Large cross-section for the population of the giant resonance region
- ^{17}O is loosely bound (S_n = 4.1 MeV)
- Clean removal of projectile excitation





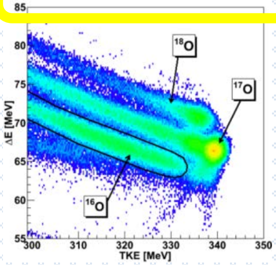


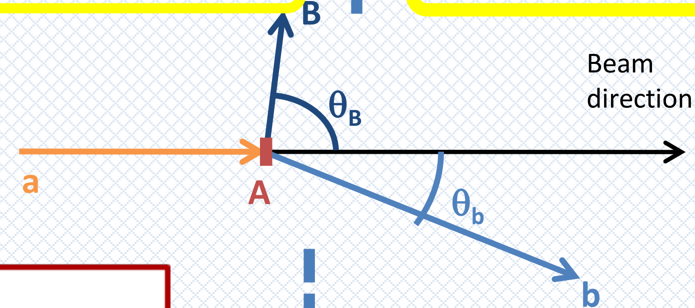
Silicon Detectors, D. Mengoni NIMA 764(2014)241

Doppler Correction.....AGATA performances

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

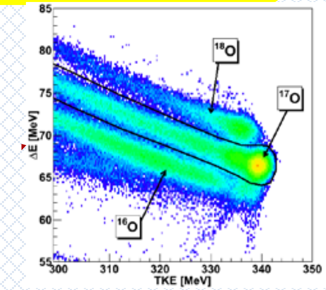
– > 500 keV @ 5 MeV

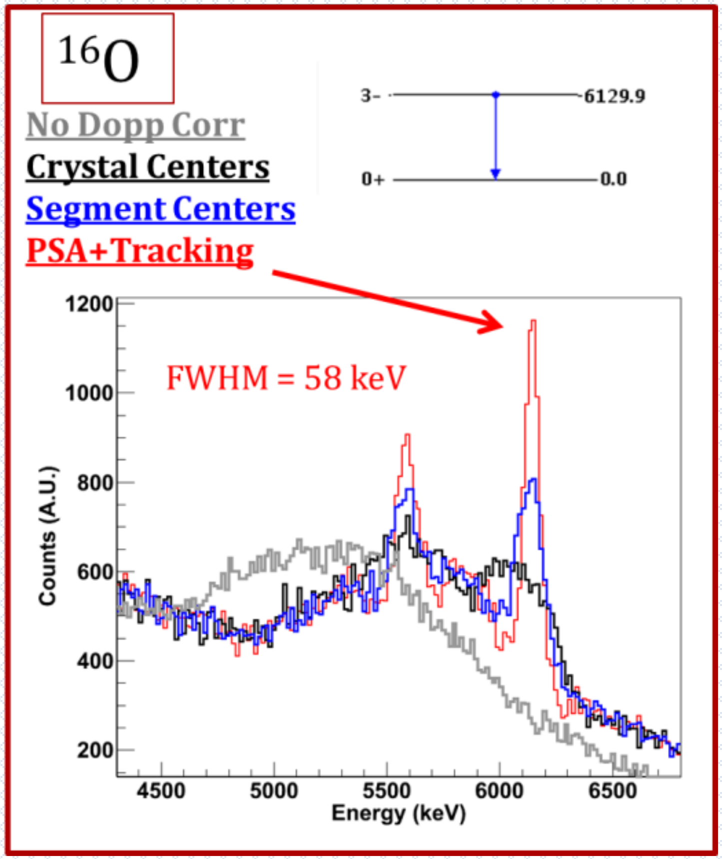


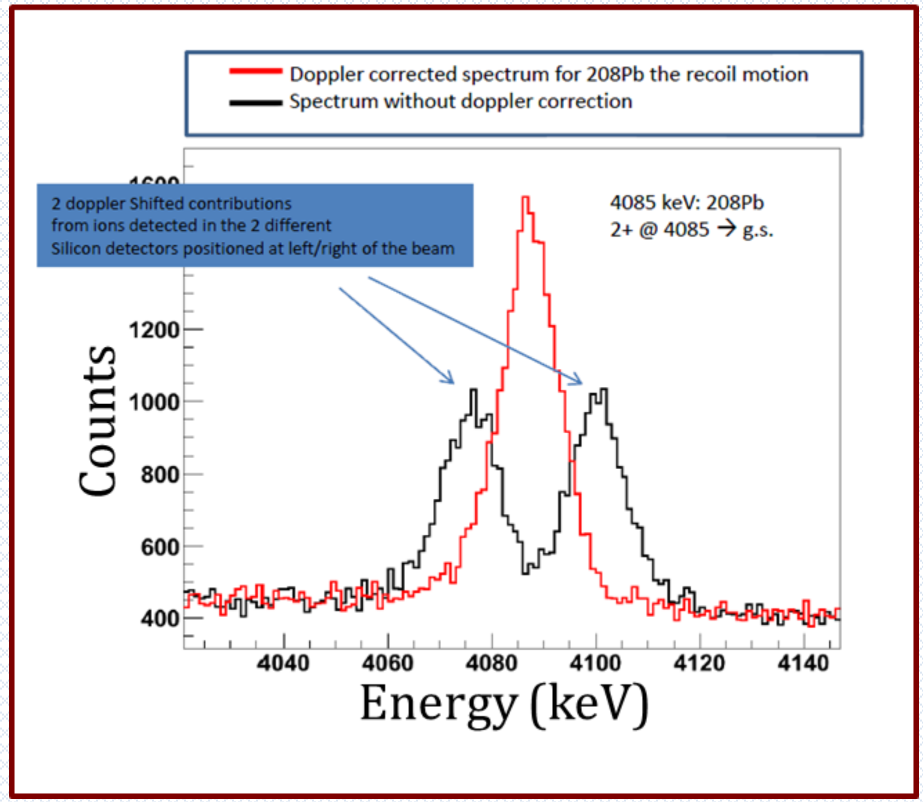


Target-like recoils (v/c ~0.5%)

– ~25 keV @ 5 MeV

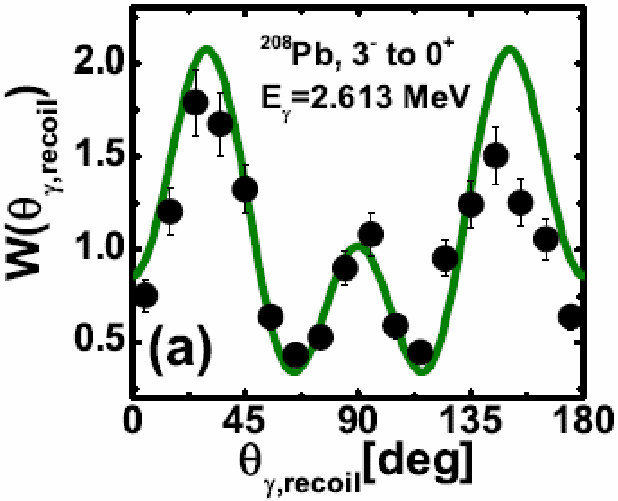


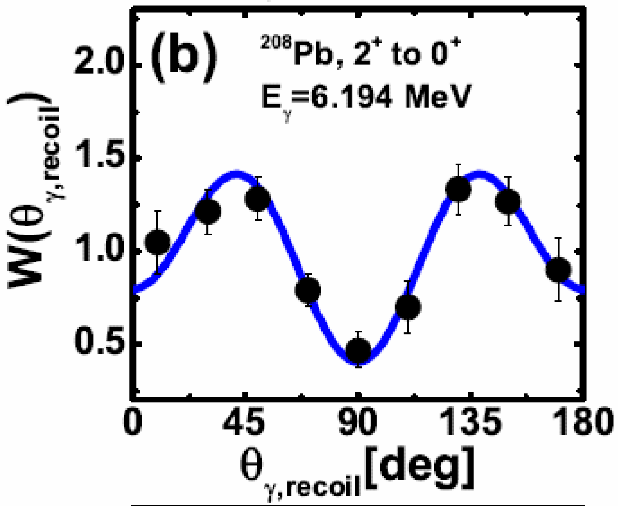


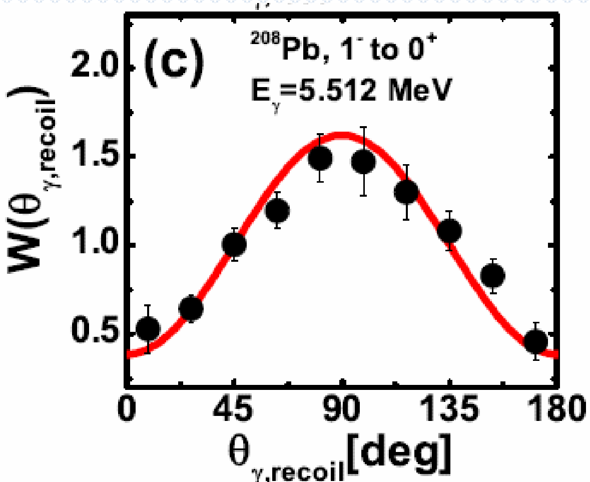


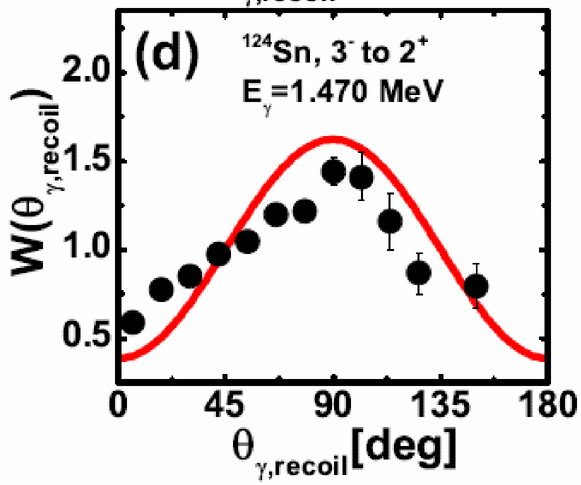
Angular distribution of γ-rays

Angular Distribution **of γ's obtained exploiting** ***position sensitivity*** **of AGATA and E-ΔE Si telescopes (pixel type)**



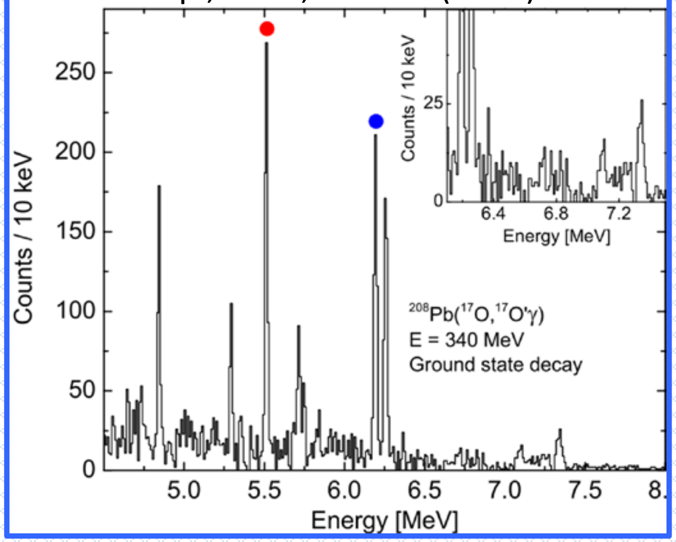




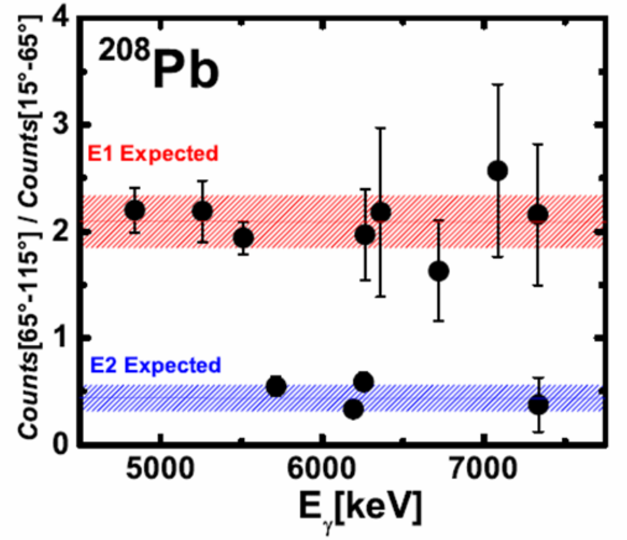


^{208}Pb and ^{124}Sn - pygmy region

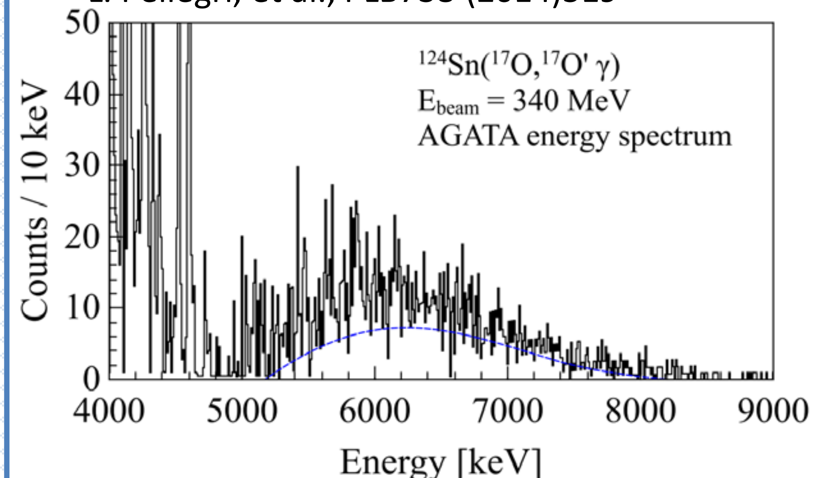
F.C.L. Crespi, et al., PRL113 (2014) 012501



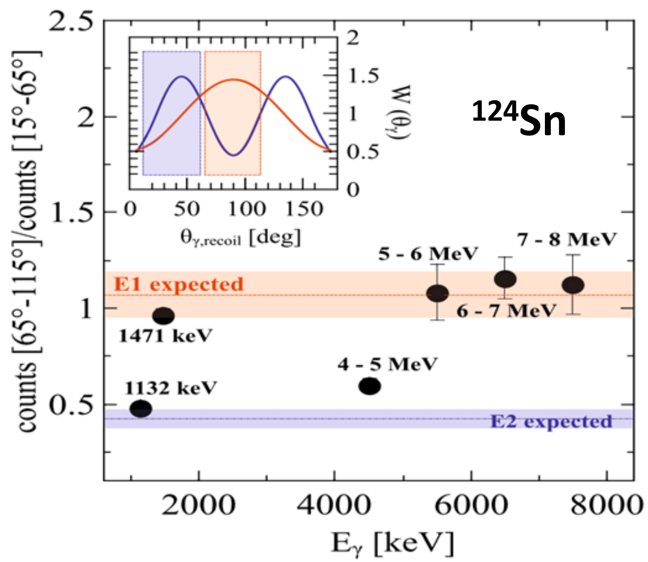
^{208}Pb



L. Pellegri, et al., PLB738 (2014)519



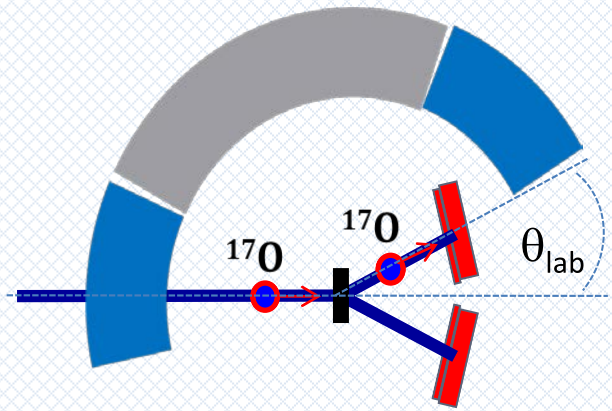
^{124}Sn



Excitation cross section as a function of angle of the detected scattered particles…….

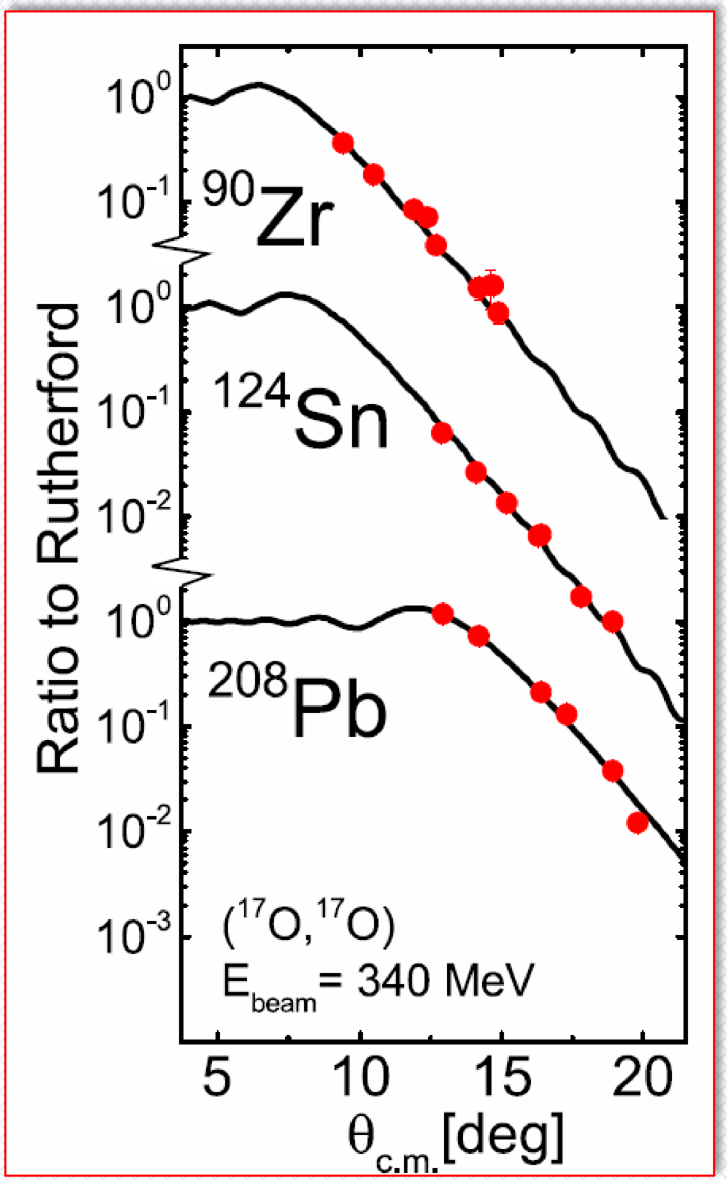
Start with elestic scattering and the first known excited states ….. to fix the main features of the reaction

Elastic scattering angular distribution



Optical model calculation (*)
for the $^{A}X+^{17}O$ elastic scattering

→ *ratio to the Rutherford cross section*



*http://www.fresco.org.uk/

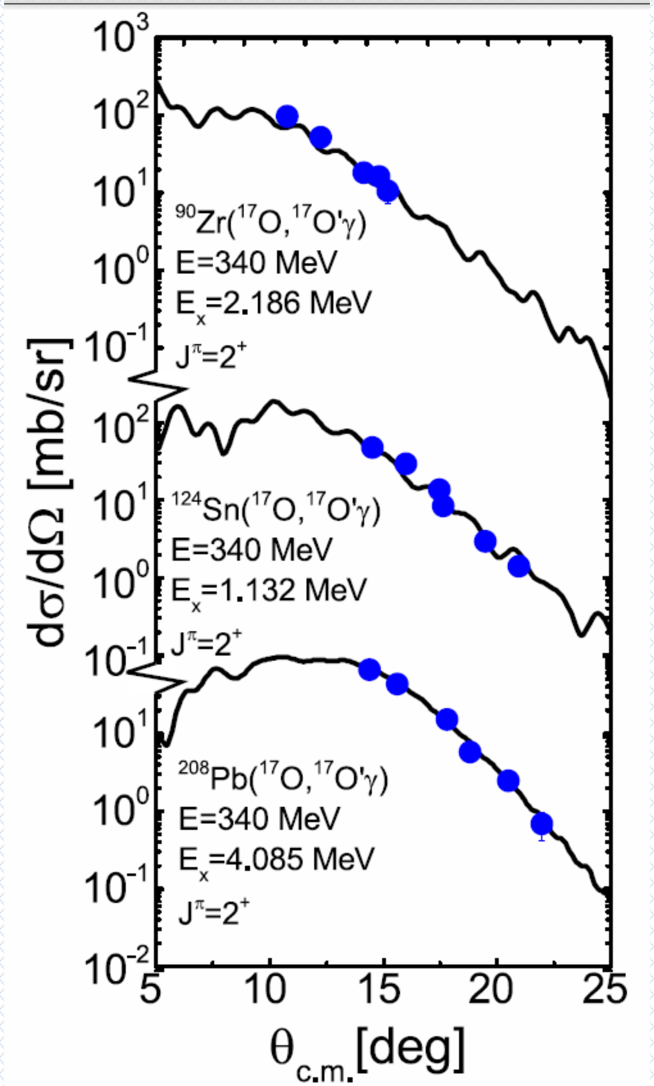
F.C.L. Crespi, et al., PRL113 (2014) 012501
L. Pellegri, et al., PLB738 (2014)519
F.C.L. Crespi et al, PRC 91 (2015) 024323
A. Bracco , F.C.L. Crespi and E.G. Lanza, to be published in EPJA(2015)

Excitation of the 2^+ states in ^{90}Zr, ^{124}Sn, ^{208}Pb

DWBA calculations using optical model potential parameters determined from the elastic data

In agreement with measurements at similar beam energy**

- The B(E2) known from other works*
- Calculations assumed pure isoscalar excitation namely the p and n matrix element are related by
  $M_n / M_p = N/Z$



* (e,e') and (γ,γ') experiments, see e.g.: http://www.nndc.bnl.gov/ensdf/

**for the case of ^{208}Pb: D.J. Horen et al. PRC44(1991)128

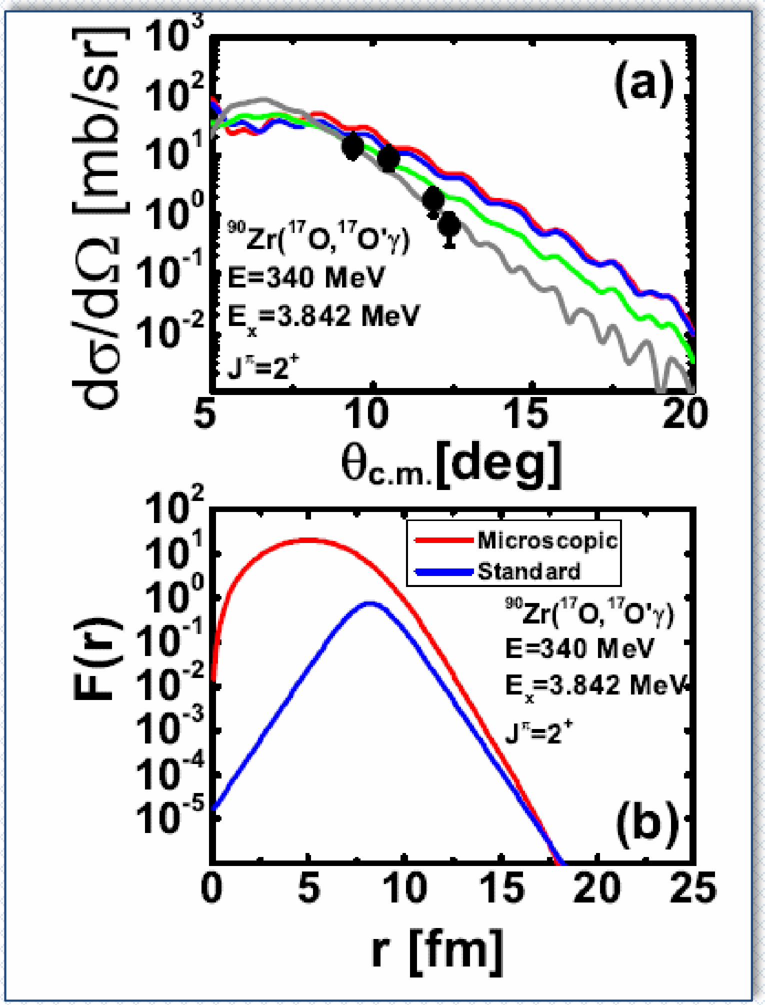
Not all 2+ states were excited or identified before using hadron probes

and not always good agreement of data and calculation is found !!!

Mn/Mp = 0.1 ∗ N/Z, green line
gray curve Coulomb excitation

this state has strong four-quasiparticle component cannot be populated by a one-step process assumed by DWBA approach!

It is excited only by Coulomb!!



Excitation of the 3⁻ states in ^{90}Zr,^{208}Pb

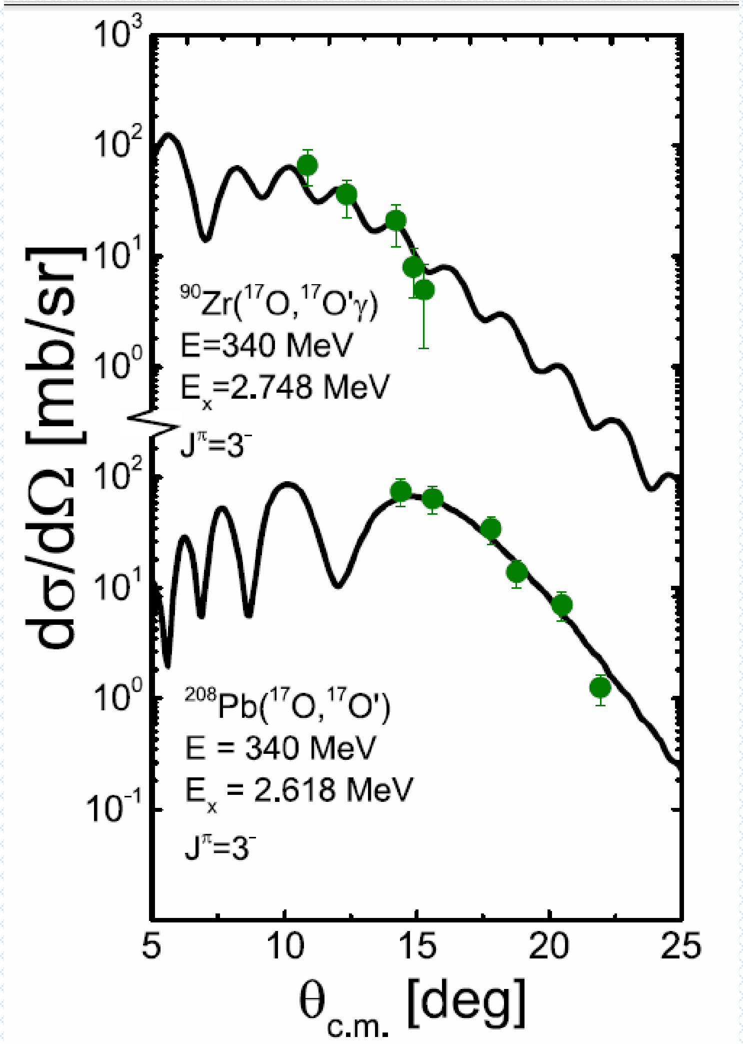
DWBA calculations using optical model from the elastic data

In agreement with measurements at similar beam energy**

- The B(E3) known from other works*

- Calculations assumed pure isoscalar excitation namely the p and n matrix element are related by

  $M_n / M_p = N/Z$



* (e,e') and (γ,γ') experiments, see e.g.: http://www.nndc.bnl.gov/ensdf/

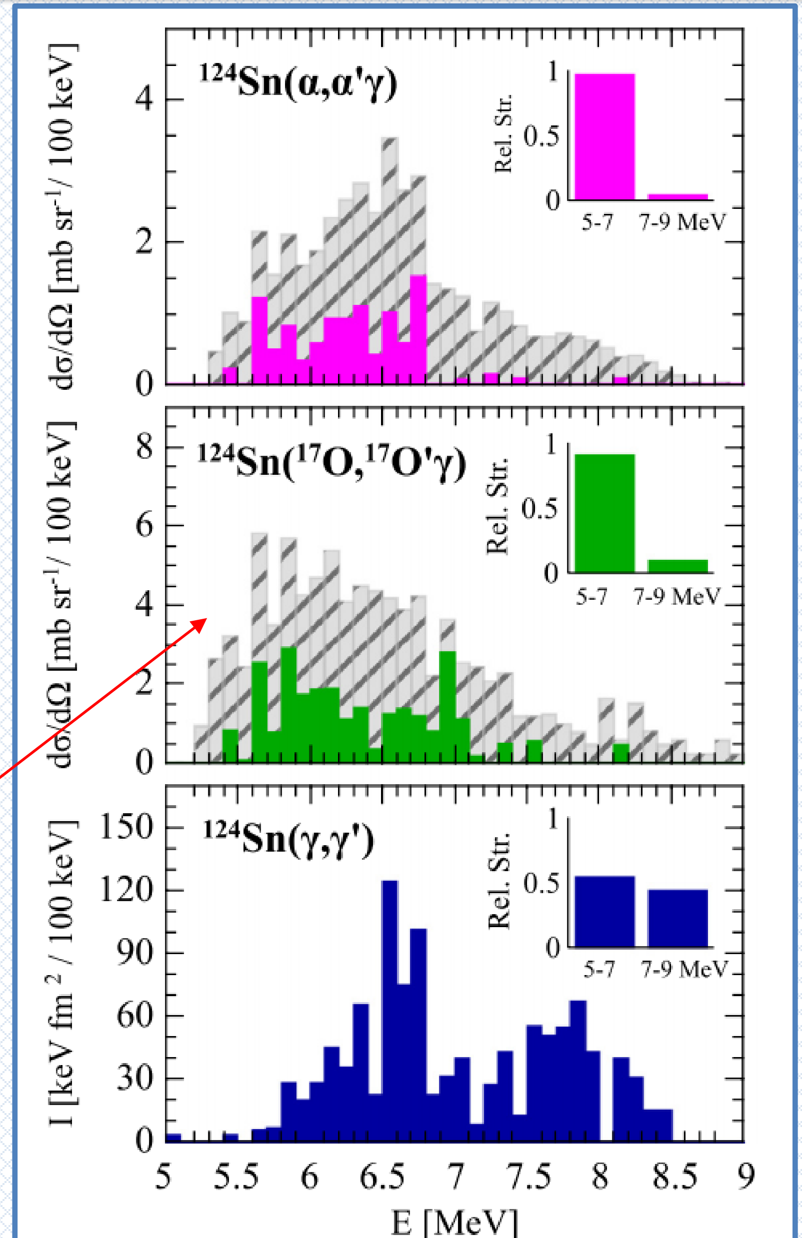
**for the case of ^{208}Pb: D.J. Horen et al. PRC44(1991)128

Results for ^{124}Sn

1^- excitation with ^{17}O at 20 MeV/u

Comparison with alpha and Gamma scattering

The splitting of the PDR region becomes even more evident if we integrate the strength in the discrete peaks measured in each experiment into two regions, 5–7 and 7–9 MeV



(**) J. Endres et al., Phys. Rev. Lett. 105, 212503 (2010)

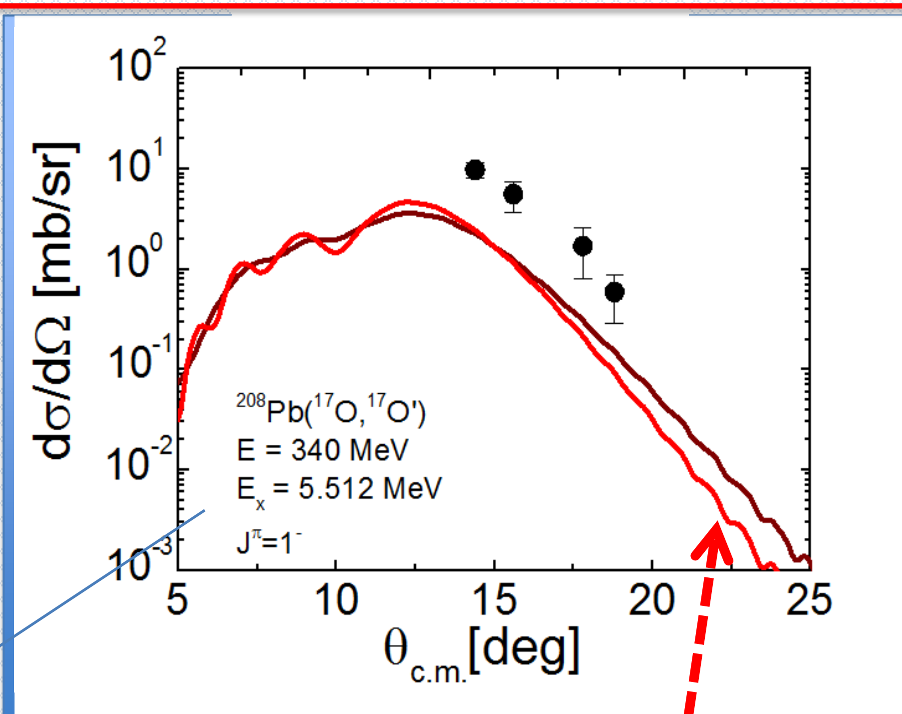
L. Pellegri, et al., PLB738 (2014)519

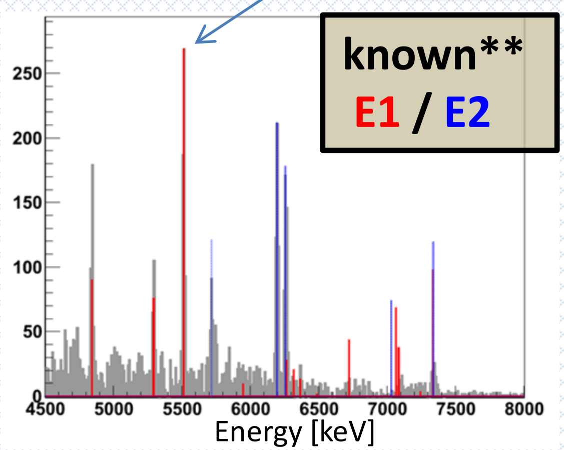
1^- states in ^{208}Pb

The calculation accounts only for a fraction of the measured yield

Why?

Calculations obtained using a <u>standard form factor</u> are found to be very similar to the Coulomb excitation alone

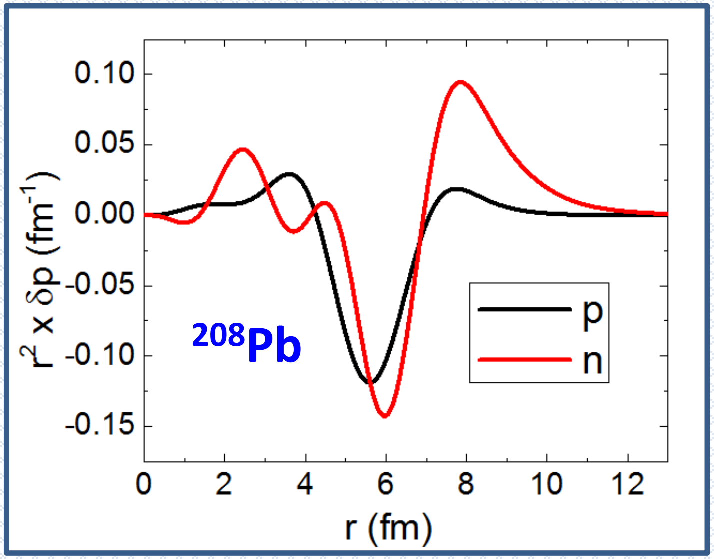




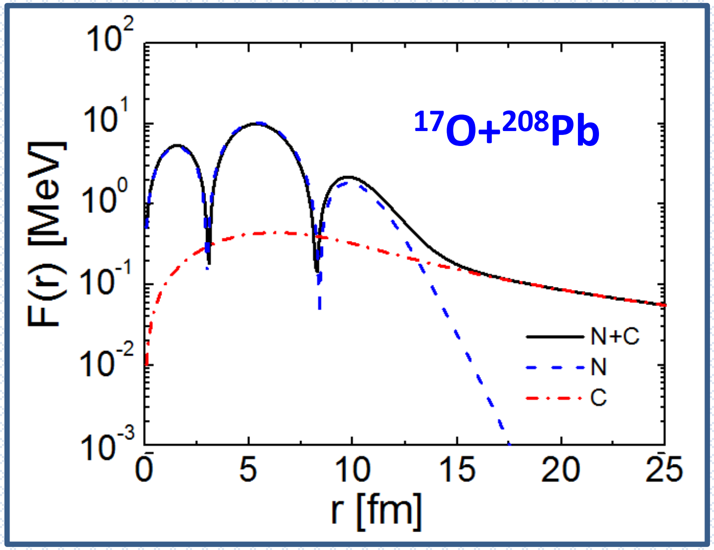
B(E1)↑ values known from (γ,γ)**

** photon scattering experiments:
N. Ryezayeva et. al PRL89(2002)272502,
T. Shizuma et al. PRC78(2008)061303

Use a microscopic form factor



Transition density

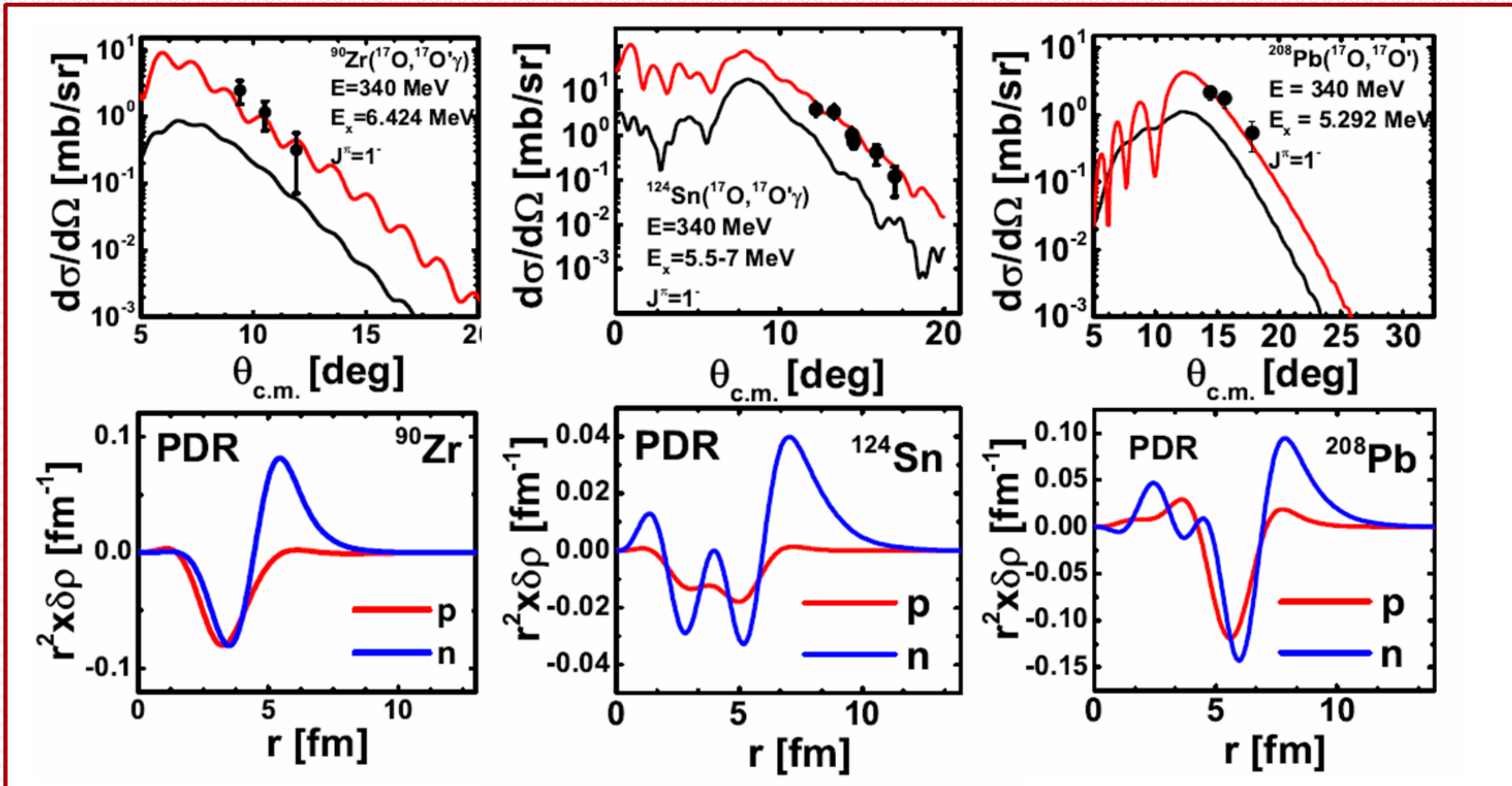


Form factor

Scattering of ^{17}O at these energies is probing mainly the nuclear surface!!

*E. G. Lanza et al., Phys. Rev. C 79 (2009) 054615
**E. G. Lanza et al., Phys. Rev. C 84 (2011) 064602
***E. G. Lanza et al., PRC 89 (2014) 041601

Some results for selected 1^- with high statistics in ^{90}Zr, ^{124}Sn and ^{208}Pb



Calculated transition densities:

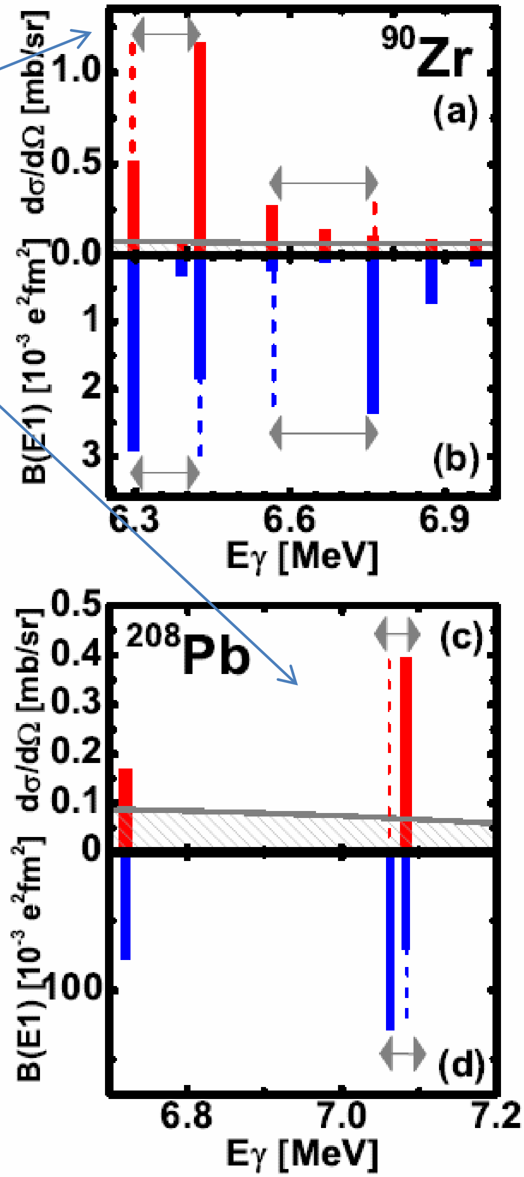
*(for 124Sn)E. Litvinova, et al., PRC 78 (2008)014312, **E.G. Lanza, et al.,PRC 89 (2014) 041601

Isospin Mixing

E1 gamma- decay of an isoscalar state is possible because of the presence of isospin impurities in the state.

Determination of the isospin-mixing matrix element assuming a two-state mixing with initially unperturbed pure isovector and isoscalar states

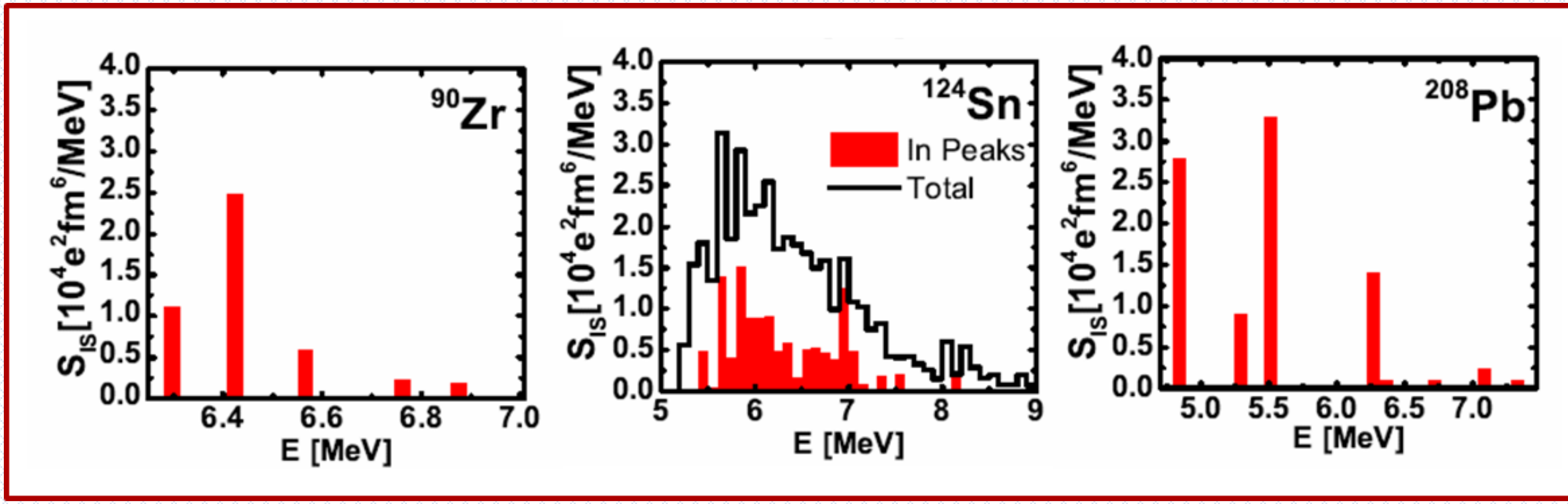
Isotope	*Mat. El.* (keV)	R	*Reaction*	*Energy* (MeV)
^{48}Ca*	85(3)	3.67	$(\alpha,\alpha'\gamma)$	7.3,7.6
^{90}Zr**	41.2	0.46	$(^{17}O,^{17}O'\gamma)$	6.30,6.42
^{90}Zr**	73.0	2.76	$(^{17}O,^{17}O'\gamma)$	6.57,6.76
^{208}Pb**	11.6	0.62	$(^{17}O,^{17}O'\gamma)$	7.06,7.08



*V. Derya et al., PLB 730(2014)288

**F.C.L. Crespi and E.G. Lanza, to be published in EPJA(2015)

values of the isoscalar strength from the measured cross section



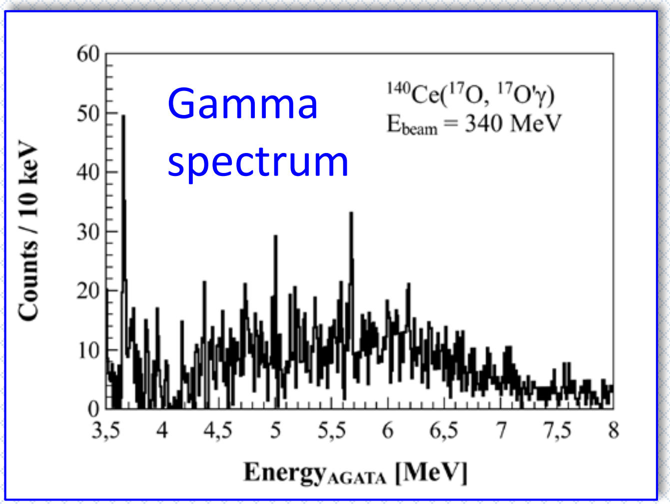
4.0 +/- 0.6 % ISEWSR	4.7 +/- 0.5 % ISEWSR	9.0 +/- 1.5 % ISEWSR

Consistent with what found for the IS GDR whose strength is at around 20-22 MeV

F.C.L. Crespi, et al., PRL113 (2014) 012501
L. Pellegri, et al., PLB738 (2014)519
A. Bracco F.C.L. Crespi and E.G. Lanza, EPJA(2015)51:99

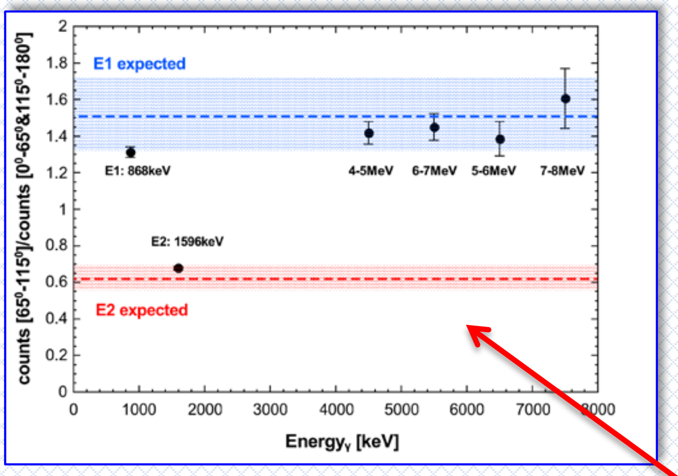
See also PLB278, 423 (1992)

……other new results on ^{140}Ce



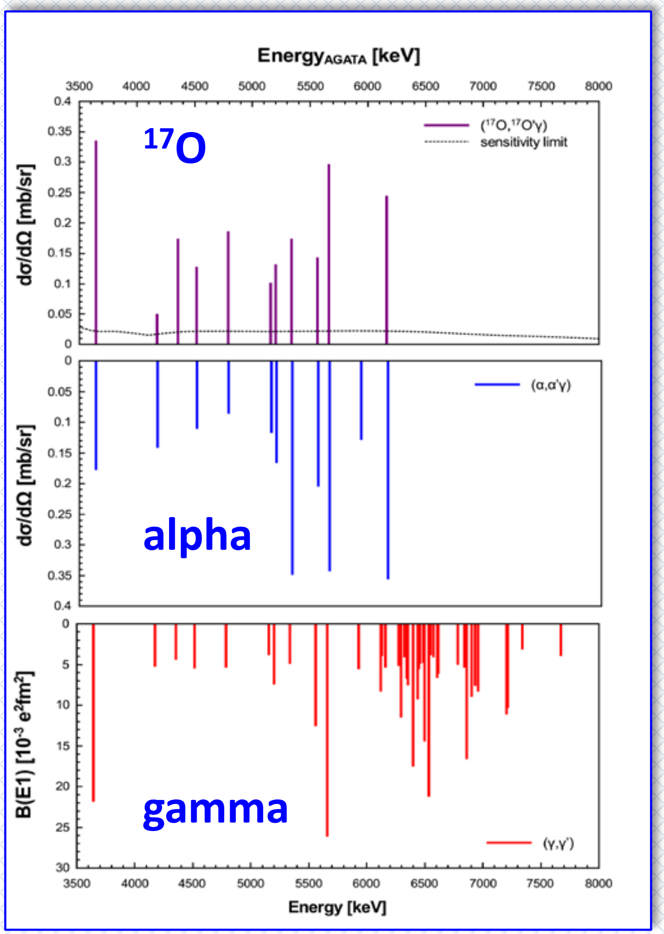
Experiment
3.24 % EWSR IS

Theory (Paar) :
4.1 % EWSR IS



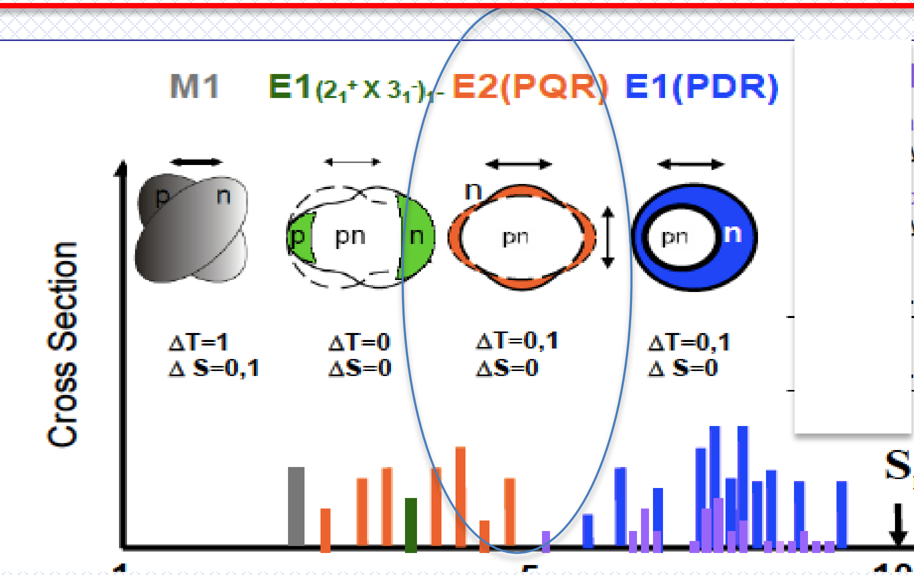
Angular
distribution

Comparison of results obtained with different probes



See poster of Mateusz Krzysiek

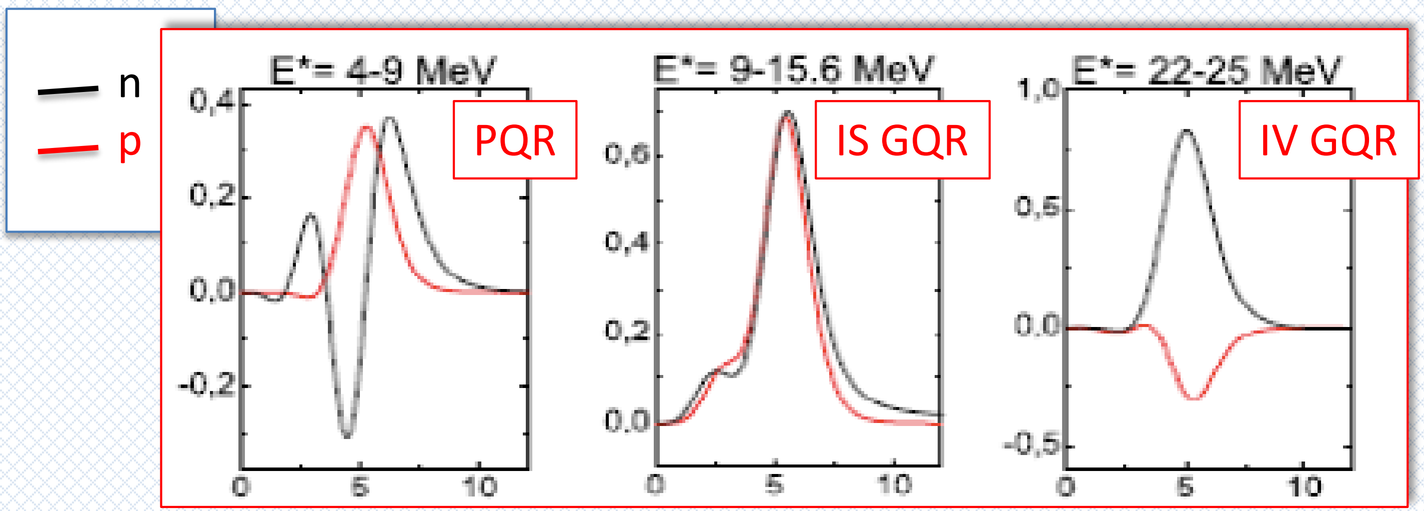
Pygmy quadrupole states ?



Other types of excitation of the neutron skin ?

Quadrupole type?

Predictions from
N. Tonseva and H. Lenske PLB695(2011)174



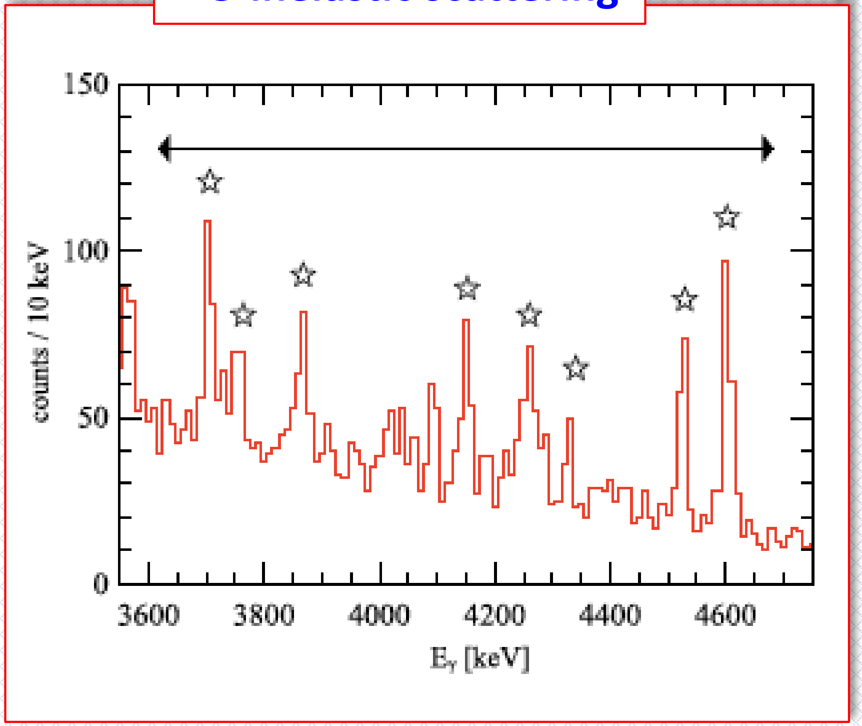
Transition densities For quadrupole states in ^{120}Sn

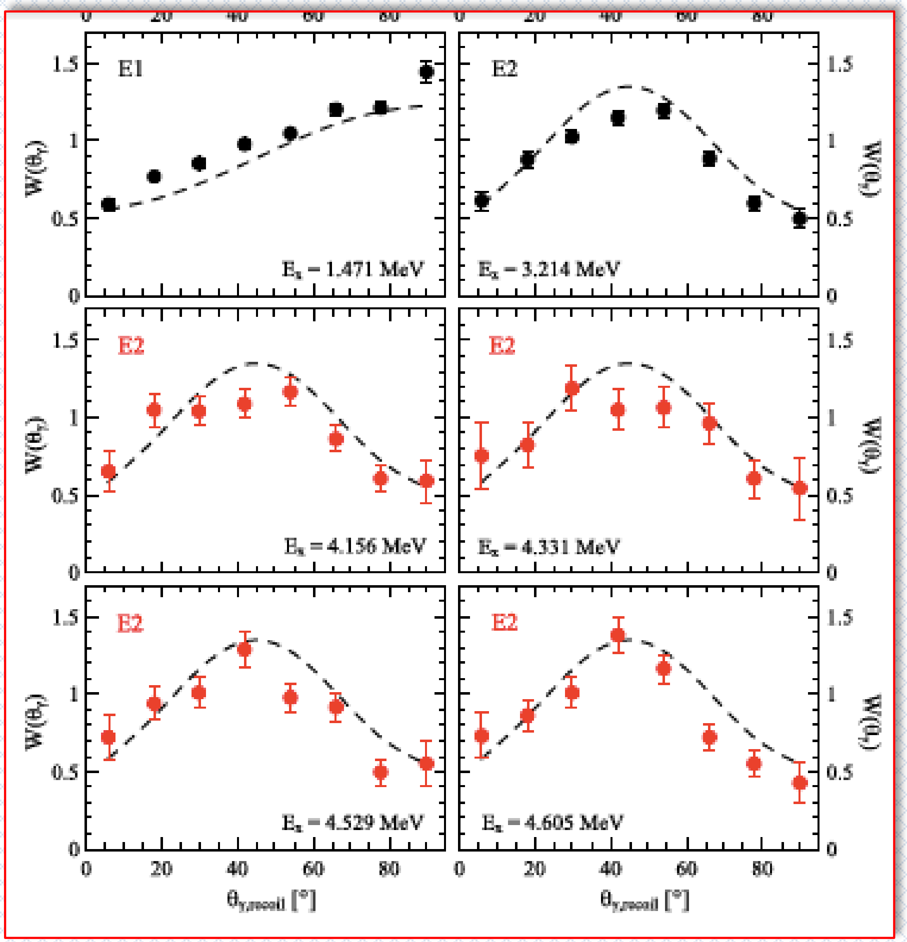
Pygmy quadrupole states in ^{124}Sn ?

Many Gamma –rays of E2 character!!

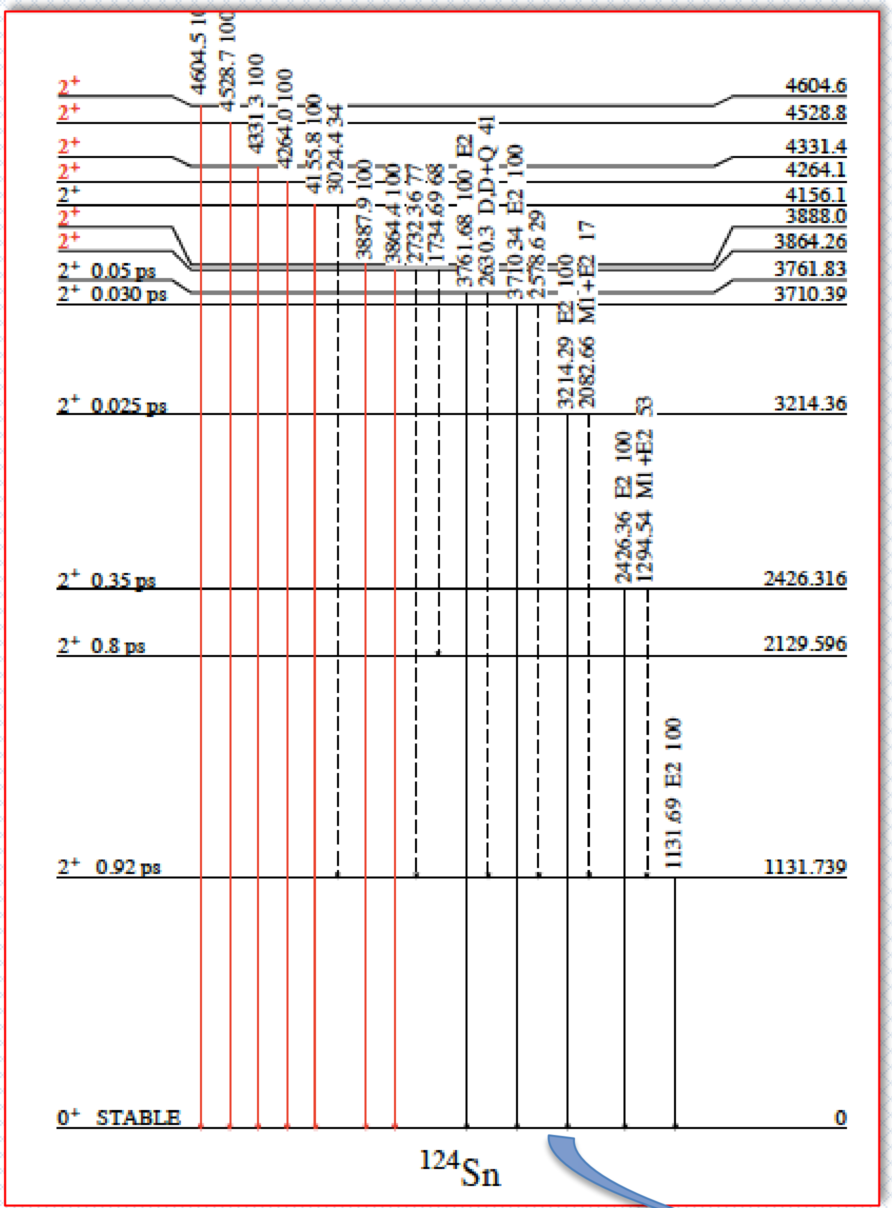
E2 character well established by the angular distribution

^{17}O inelastic scattering

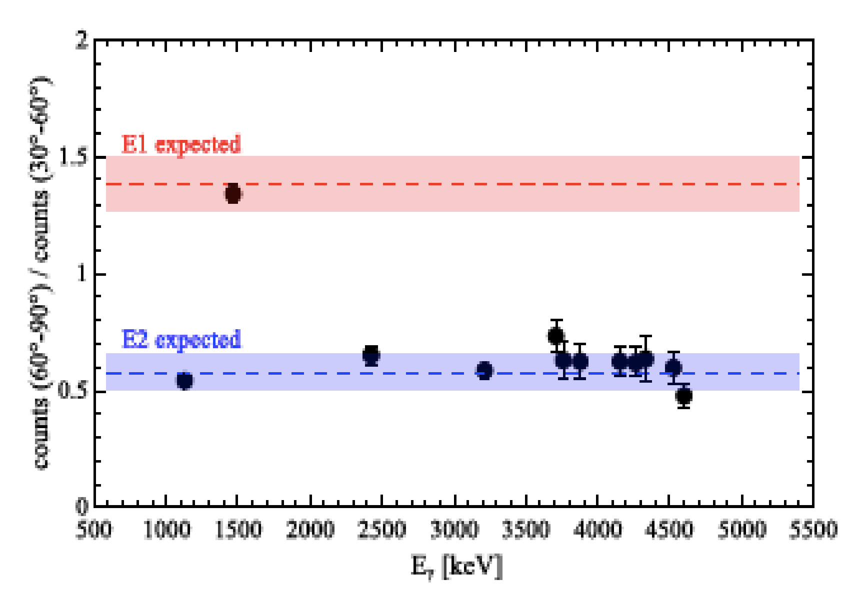




The 2^+ States in ^{124}Sn

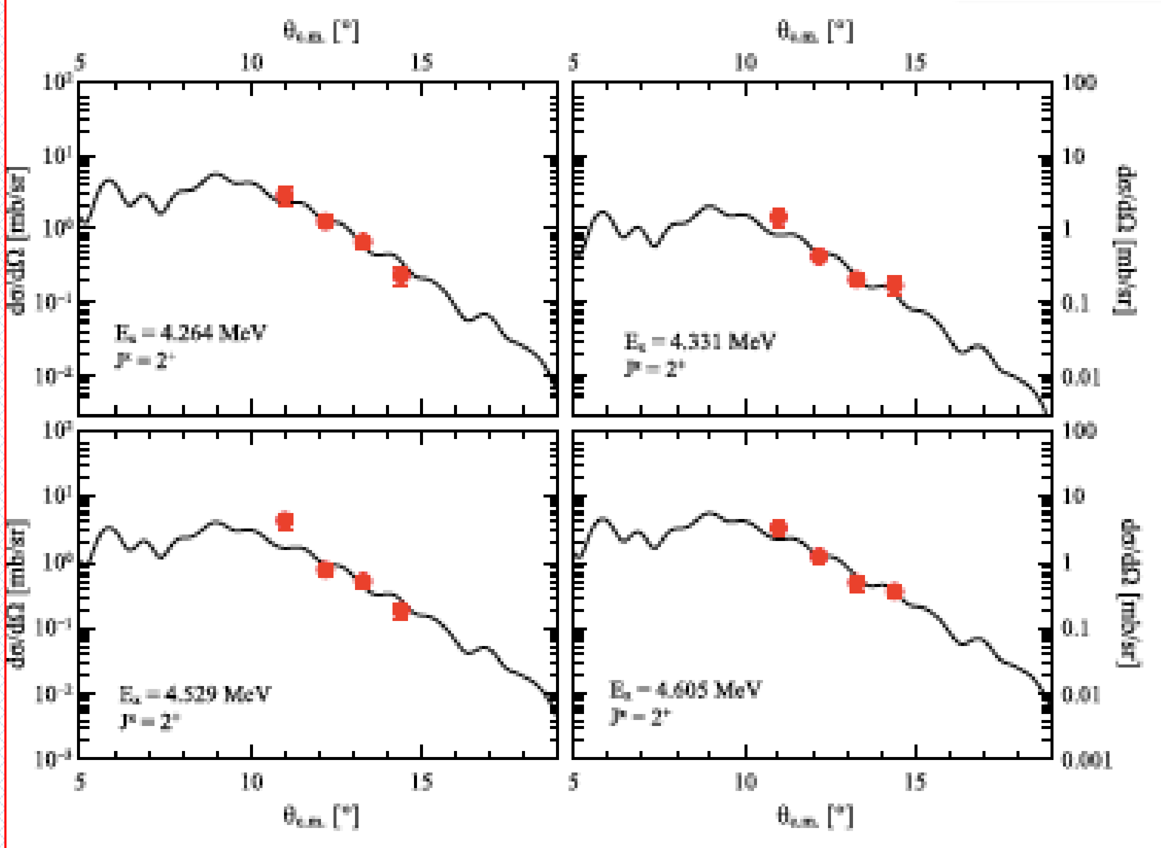


Several states in ^{124}Sn for which the multipolarity was not assigned !!!



Pygmy quadrupole states in ^{124}Sn ?

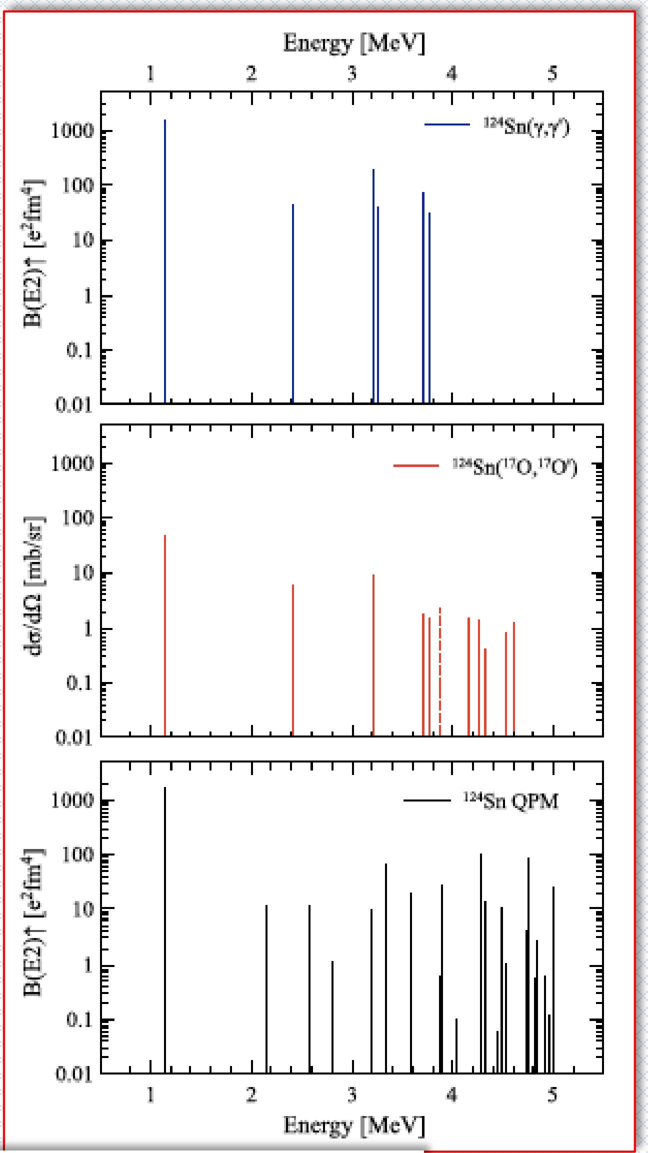
Measured angular distribution of the Cross section for 2+ states



Comparison with DWBA Predictions

Standard 2+ form factor used for isoscalar 2^+ in the FRESCO code

Pygmy quadrupole states in ^{124}Sn



Data from gamma beam scattering

Data from ^{17}O inelastic scattering

QPM model Predictions

N. Tonseva and H. Lenske

As compared with the data in literature for (gamma, gamma') more states are seen in (^{17}O,^{17}O')

theory predicts even an higher fragmentation of the 2^+ strength

L. Pellegri et al. PRC92 (2015)014330

Try to get information on the transition density in the future!!

Future perspectives

- Systematics on isotopic chains (mass, N/Z, exoticity to be understood)
- Decay pattern, feeding
- more on comparison of electromagnetic and hadronic excitation (CAGRA at OSAKA!)
- Strength of the PDR and asymmetry in the number of neutron and proton
- More experimental information on the transition density
- The transition region in excitation energy from pygmy to GDR
  for this data also above the particle threshold are needed ….

ELI_NP is suitable for the expected small cross sections

- Work on the PQR has just started…

Inverse kinematics using ^{13}C targets at 15 MeV/u with measurement of gamma decay at ISOL facilities…. to search for pygmy states of isoscaler character in exotic nuclei

All this will provide a very stringent test to theory….

Conclusions

- **Reaction with ions followed by gamma decay**

such as (^{17}O, ^{17}O'γ) at around 20 MeV/u are a good tool for ***Nuclear structure for states of isoscalar character***

- ***On the pygmy quadrupole states also from*** **as (^{17}O, ^{17}O'γ) and** ***more work has to be made !***

Collaboration

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