5th Workshop on Nuclear Level Density and Gamma Strength
Oslo, May 18 - 22, 2015

Isospin Character of Low-Lying Pygmy Dipole States via Inelastic Scattering of ^{17}O ions

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Outline

- Motivation

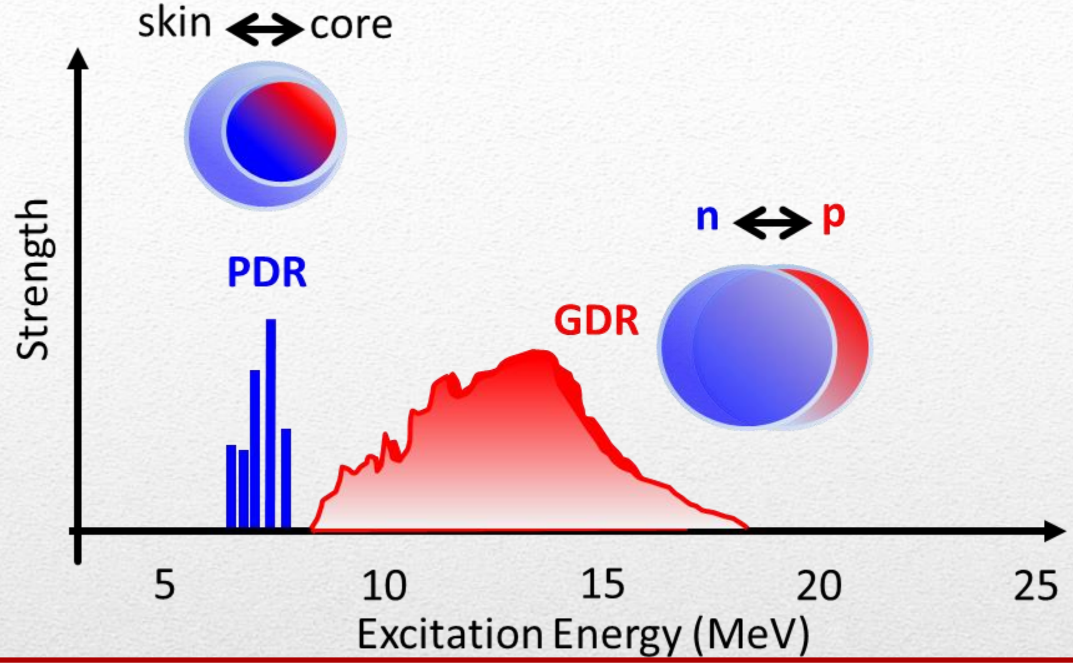
  E1 strength at particle threshold: the Pygmy Dipole Resonance

- Experimental technique

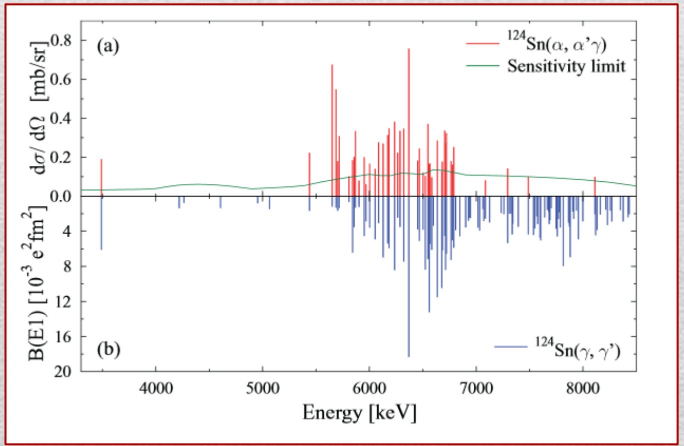
  Heavy Ion Inelastic scattering as a tool to study highly excited states up to the region of the Giant Quadrupole Resonance

- Results of experiments at LNL-INFN (^{90}Zr, ^{124}Sn, ^{208}Pb)
- Conclusions and Perspectives

Nuclear Structure information from the E1 response in Nuclei



The splitting in the population of the states reveals a different underlying structure



- low energy part → isoscalar character (*neutron-skin oscillations*)
- high-energy states → isovector nature (*transition towards the GDR*)

(*) figure from J. Endres et al., Phys. Rev. Lett. 105, 212503 (2010)
See also e.g. "Experimental studies of the Pygmy Dipole Resonance"
D. Savran, T. Aumann, A. Zilges – Prog. Part. Nucl. Phys., 70(2013)210

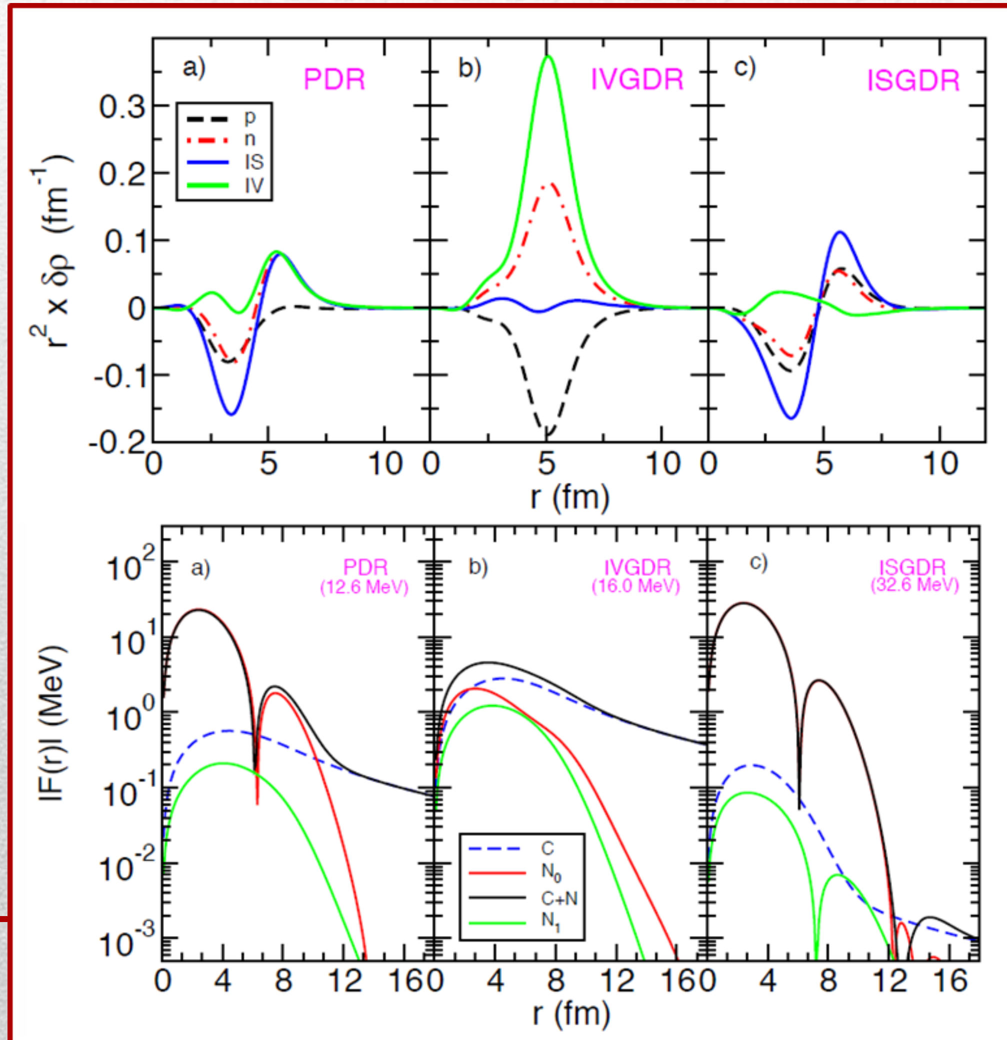
One important open problem for pygmy states is the cross section sensitivity to transition densities containing the nuclear structure information…

Transition Densities and Form Factors

«Different Peaks» (at different excitation energies) → different excitation modes →
→ **different structure of Transition Densities→ Different Form Factors**
→ need of predictions obtained with form factors deduced from microscopic transition densities which incorporate the main features of these states

^{90}Zr
Transition Densities

^{17}O+^{90}Zr
Form Factors



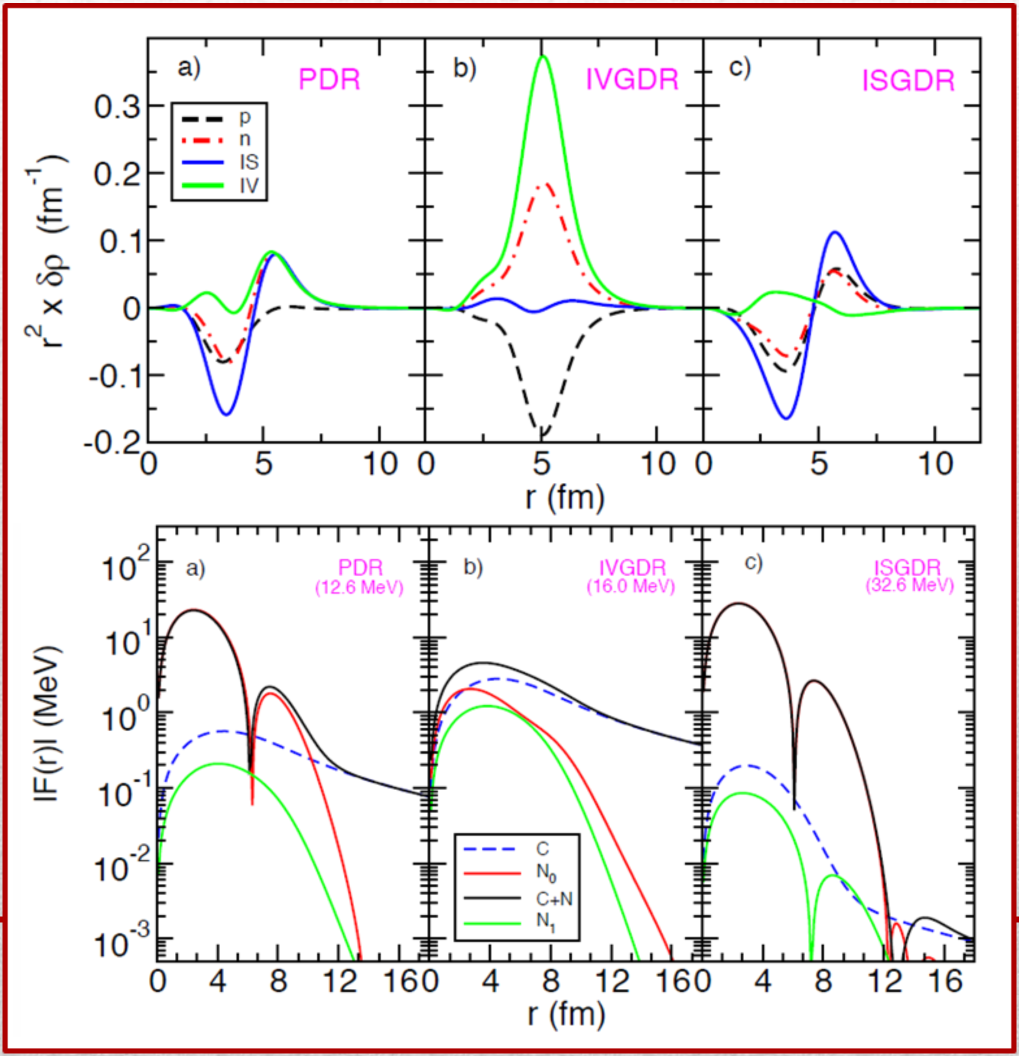
*E. G. Lanza et al.,
PRC 89 (2014) 041601
**A. Bracco,
F.C.L. Crespi and E.G. Lanza,
to be published in EPJA(2015)

Transition Densities and Form Factors

The use of a proper form factor in the study of the PDR is of paramount importance in order to determine the correct values for some relevant quantities characterizing these modes

^{90}Zr
Transition Densities

^{17}O+^{90}Zr
Form Factors



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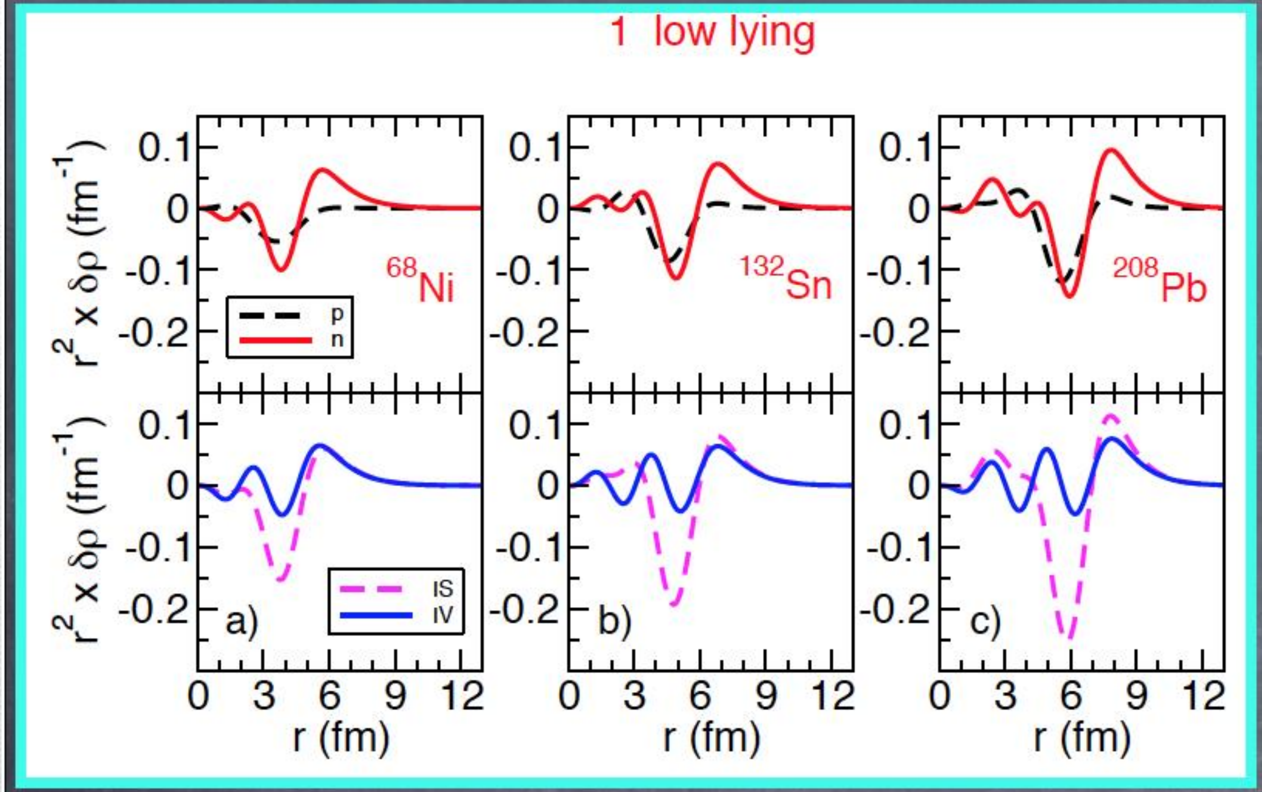
Transition Densities



The low lying peaks have the same features: n and p transition densities are in phase inside the nucleus; at the surface only the neutron part survive.

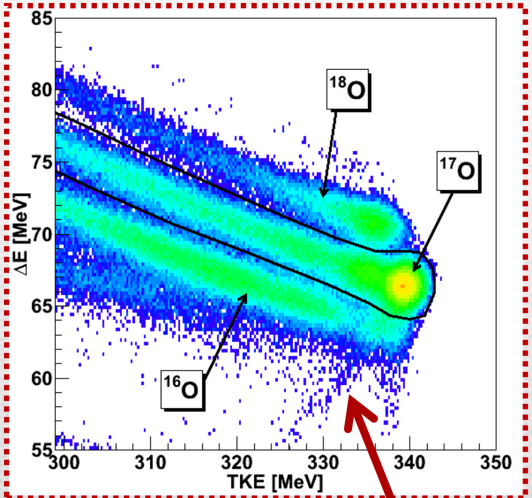
➢ **Interesting to use a probe interacting mainly at the surface !!!**

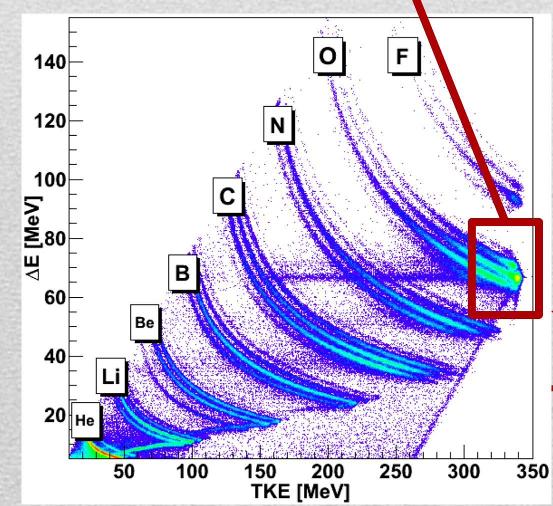
*E. G. Lanza et al., Phys. Rev. C 79 (2009) 054615.
**E. G. Lanza et al., Phys. Rev. C 84 (2011) 064602.

Experimental Technique

Inelastic scattering of ^{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



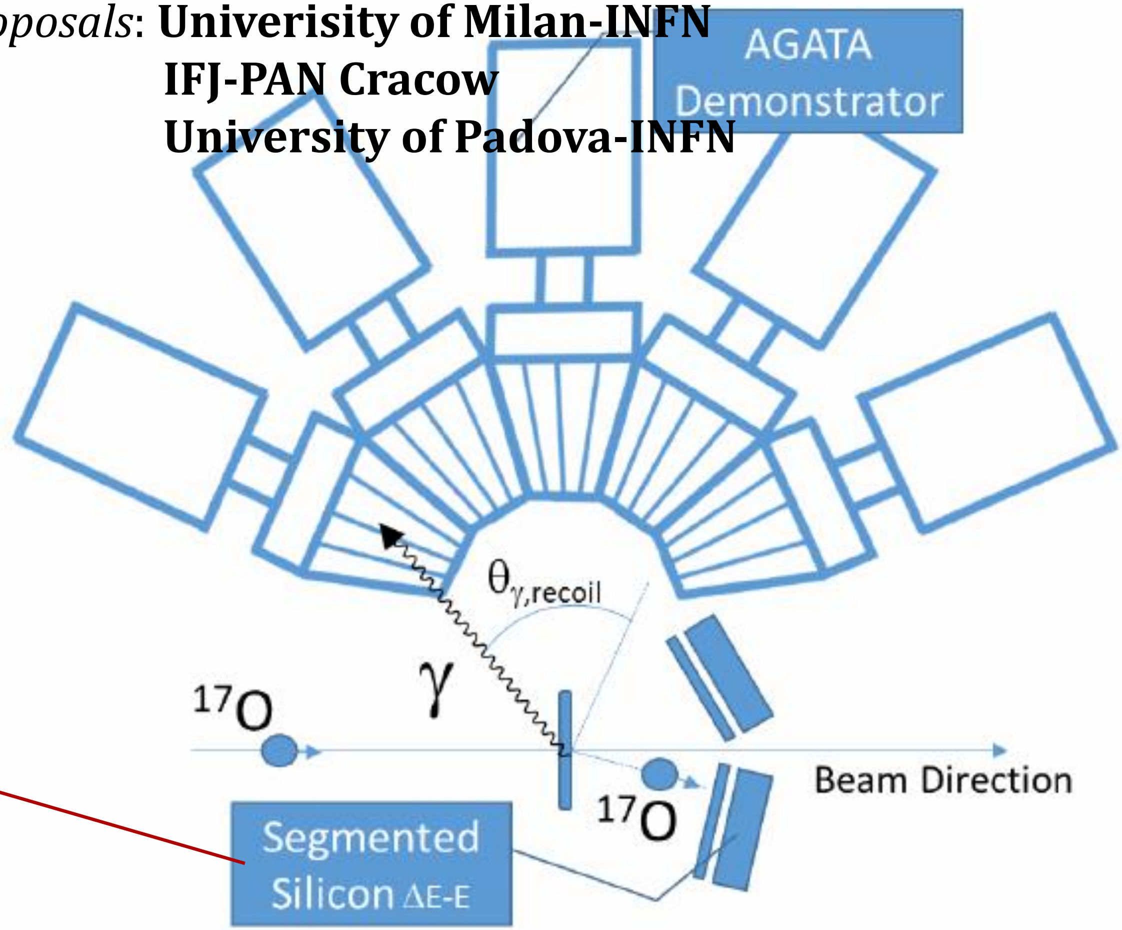


Experiments at Legnaro,

Proposals: **Univerisity of Milan-INFN**

IFJ-PAN Cracow

University of Padova-INFN



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

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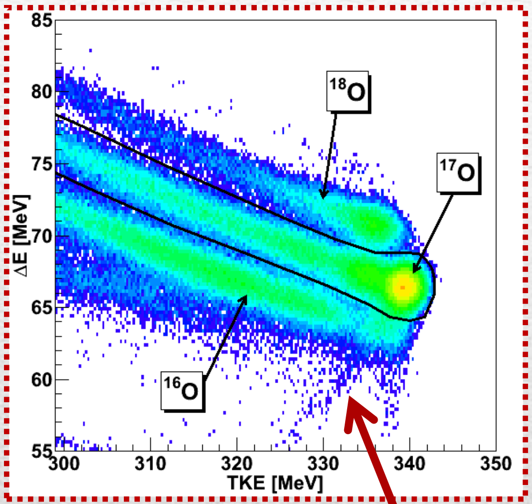
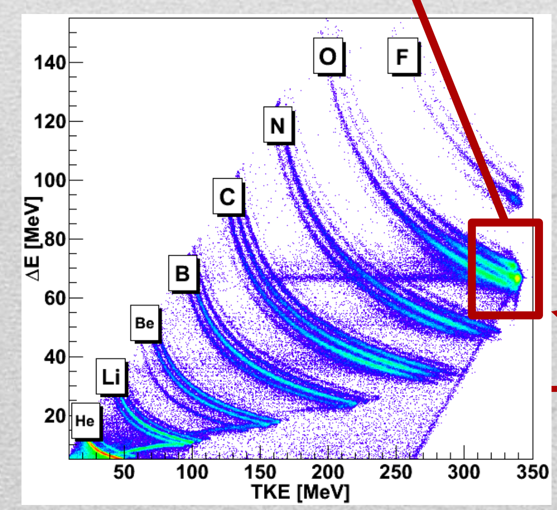
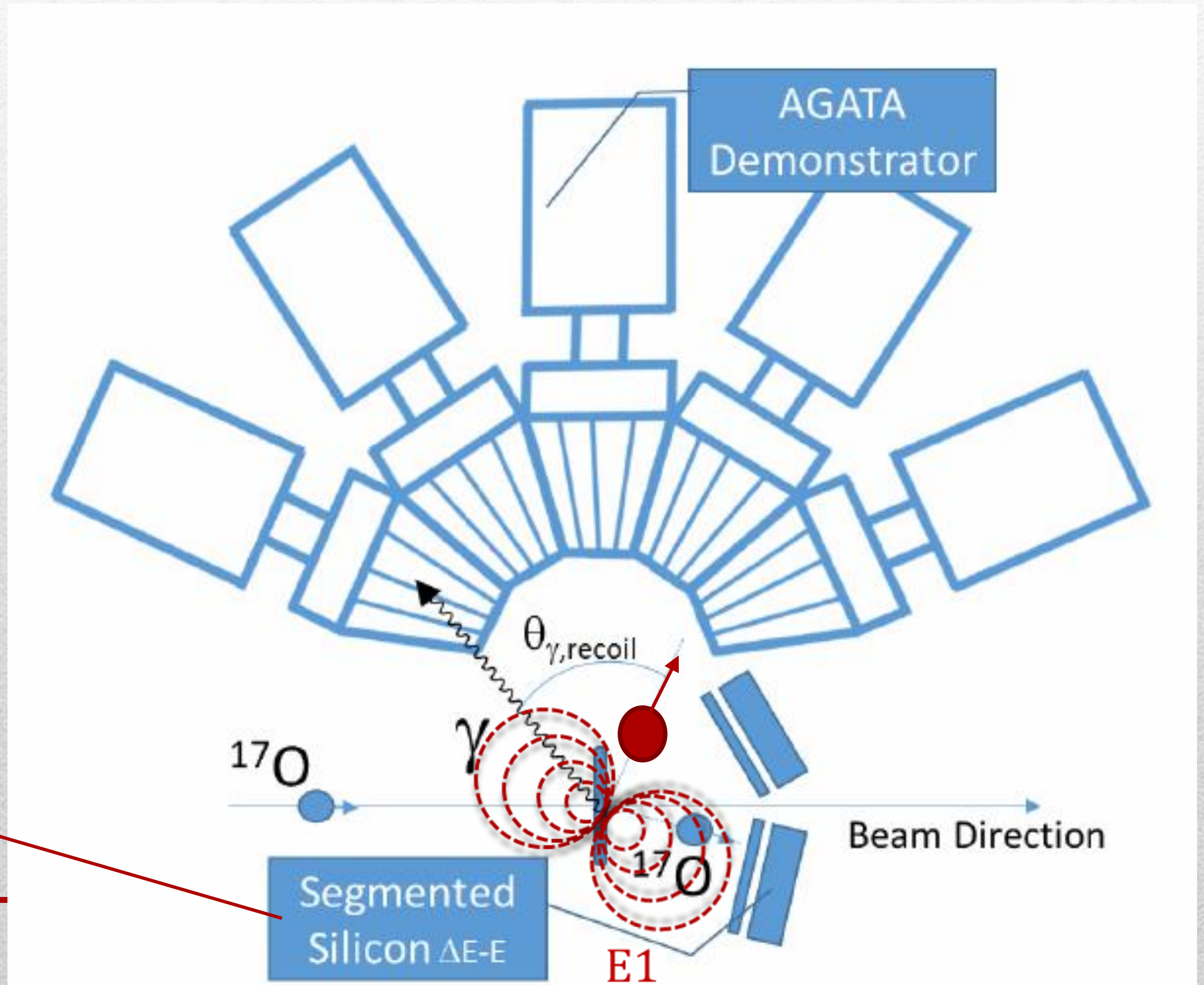


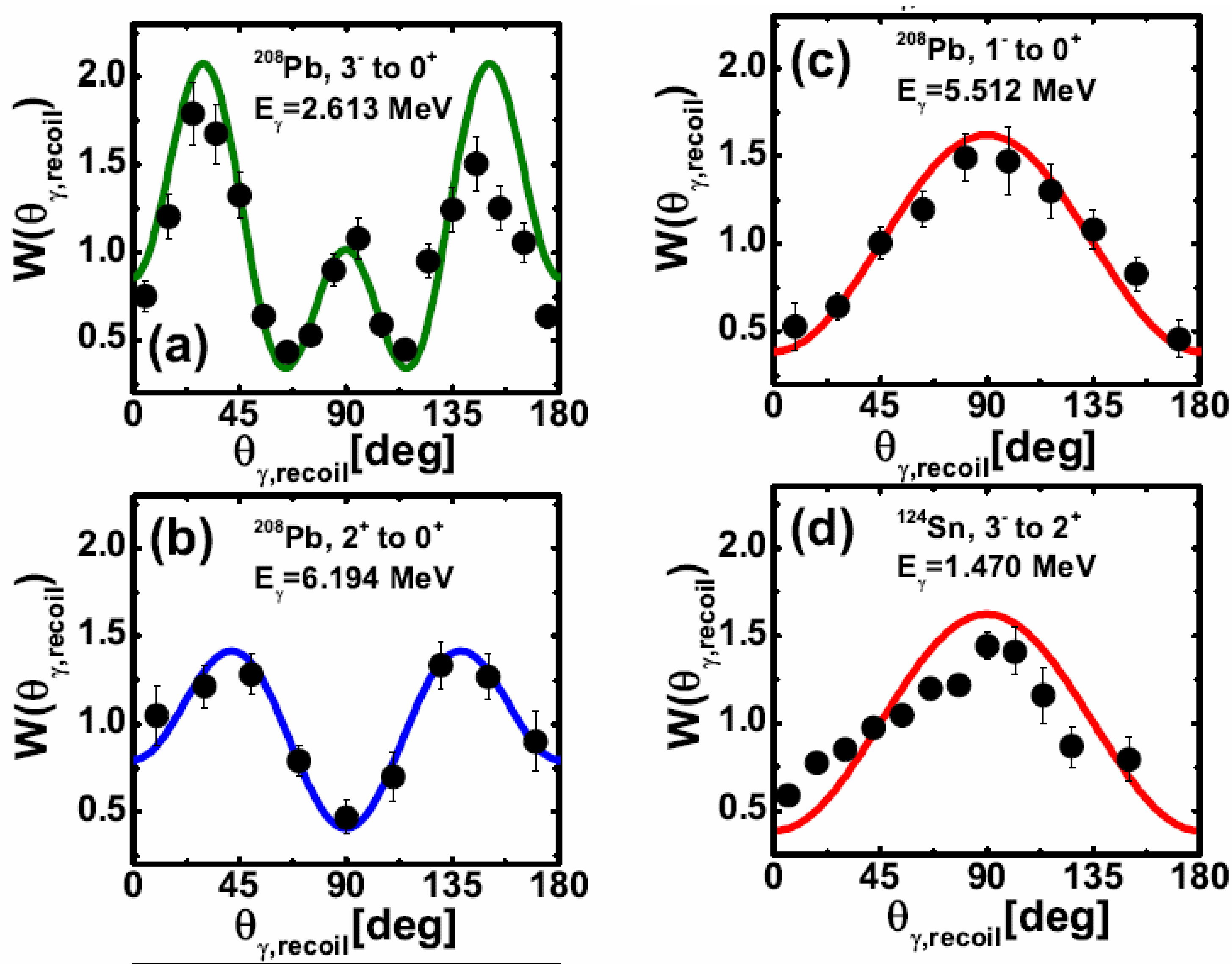




Silicon Detectors, D. Mengoni NIMA 764(2014)241

Angular distribution of γ-rays

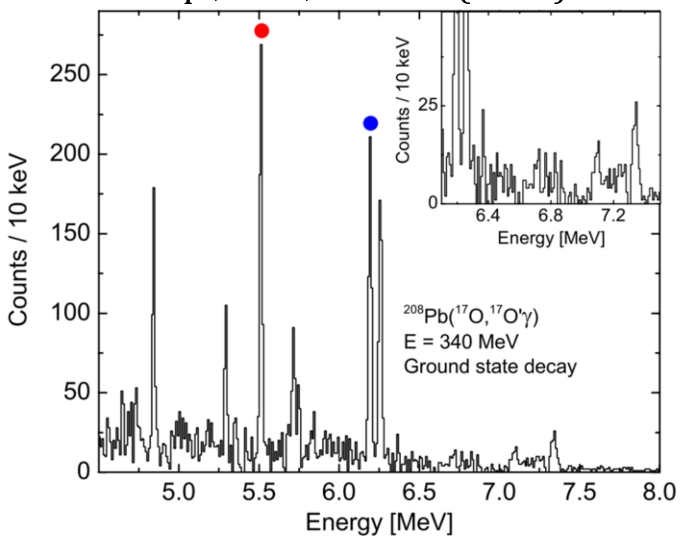
Angular Distribution of γ's obtained exploiting ***position sensitivity*** of **AGATA** and **E-ΔE Si** telescopes (pixel type)

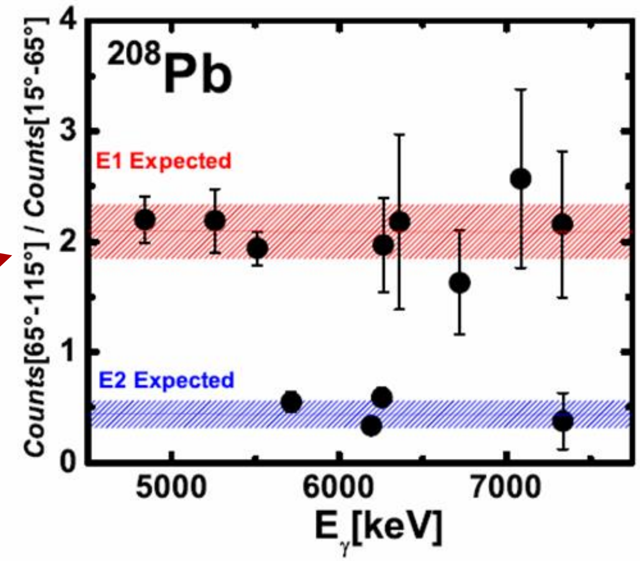


Identification of the Multipolarity

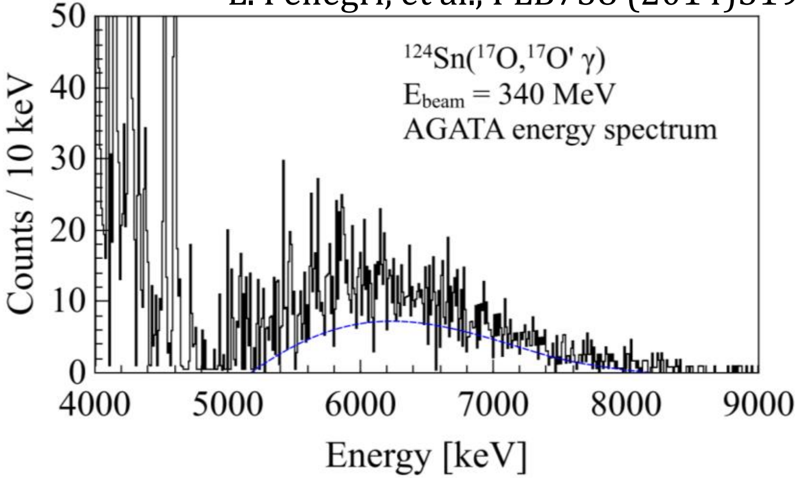
In contrast with light ions, for ^{17}O the pattern of the differential cross section for inelastic scattering as a function on angle does not characterize well the multipolarity of the excited states → *angular dist. of gamma-rays*

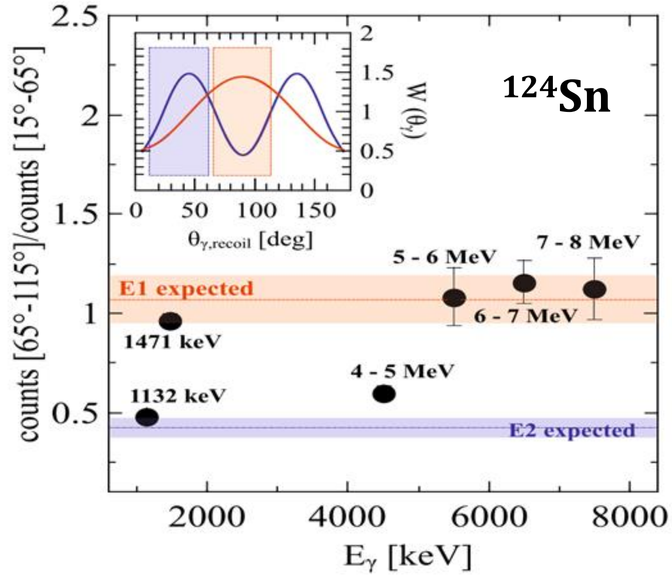
F.C.L. Crespi, et al., PRL113 (2014) 012501





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



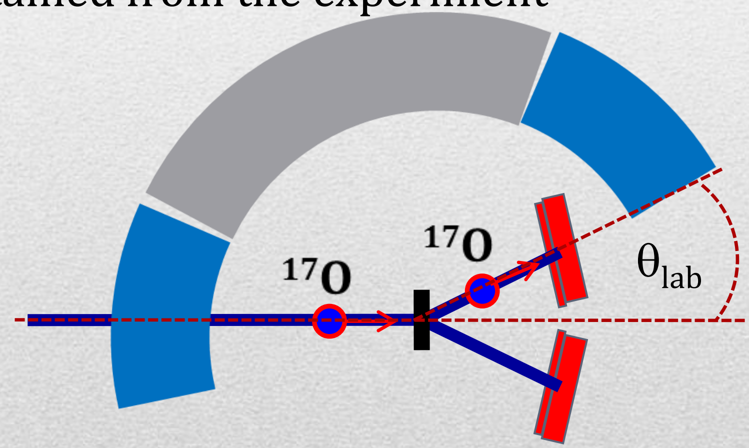


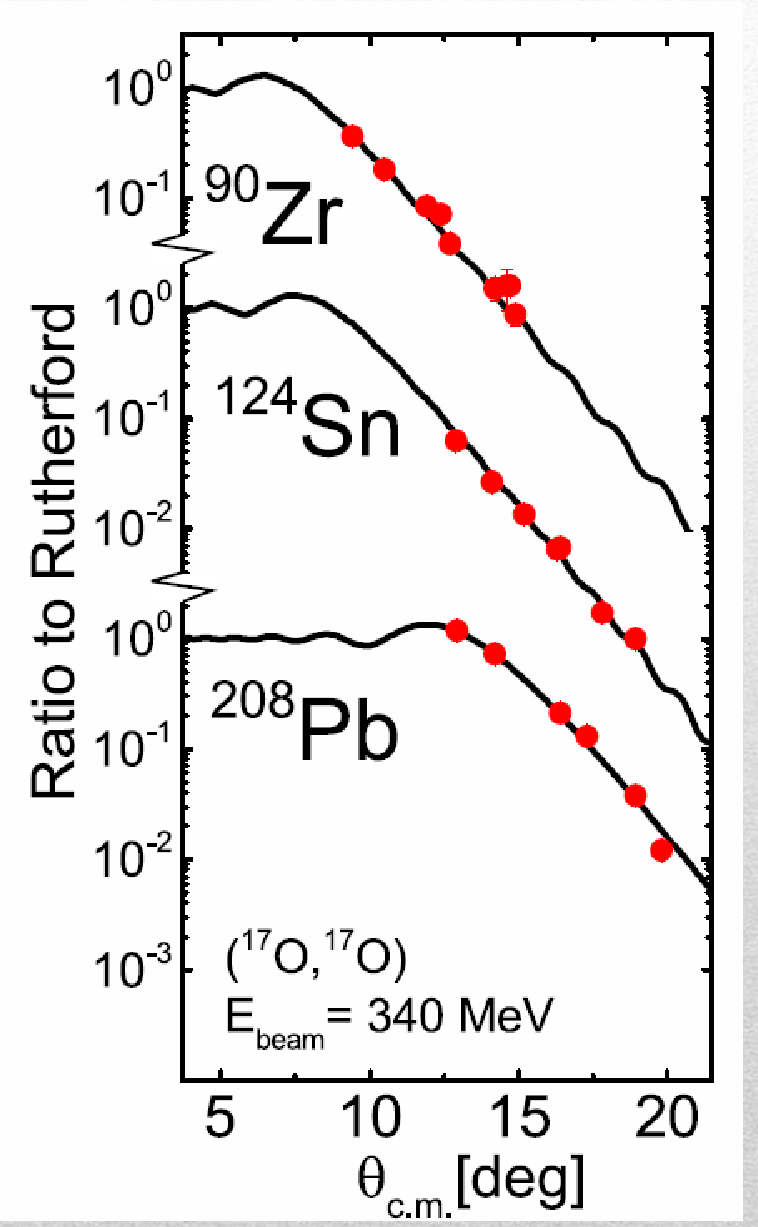
Angular distributions of the scattered ^{17}O ions – ELASTIC SCATTERING

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

→ *the plot shows the ratio to the Rutherford cross section*

The optical model calculation permitted to determine the absolute normalization of the data (elastic and inelastic), which could not be obtained from the experiment





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

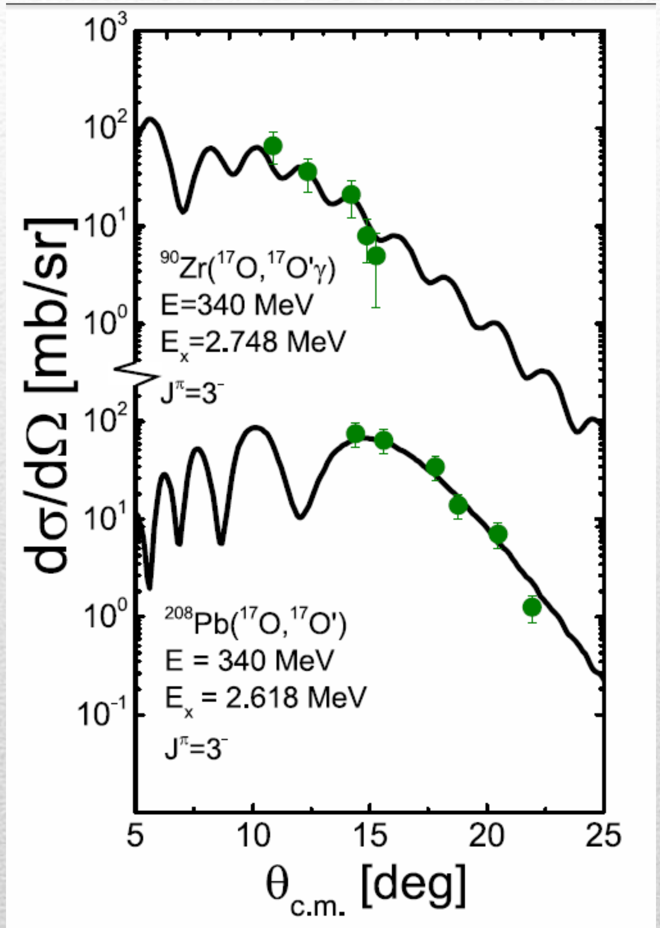
Angular distributions of the scattered ^{17}O ions–INELASTIC SCATTERING

Differential cross sections were determined for excitation of the 3^- states in ^{90}Zr,^{208}Pb

The solid curve results from DWBA calculations using optical model potential parameters determined from the elastic data

In agreement with measurements at similar beam energy**

- The B(E3) is known from other works*
- These calculations were obtained assuming pure isoscalar excitation implying that the ratio of the neutron matrix element and the proton matrix element is given 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

Angular distributions of the scattered ^{17}O ions–INELASTIC SCATTERING

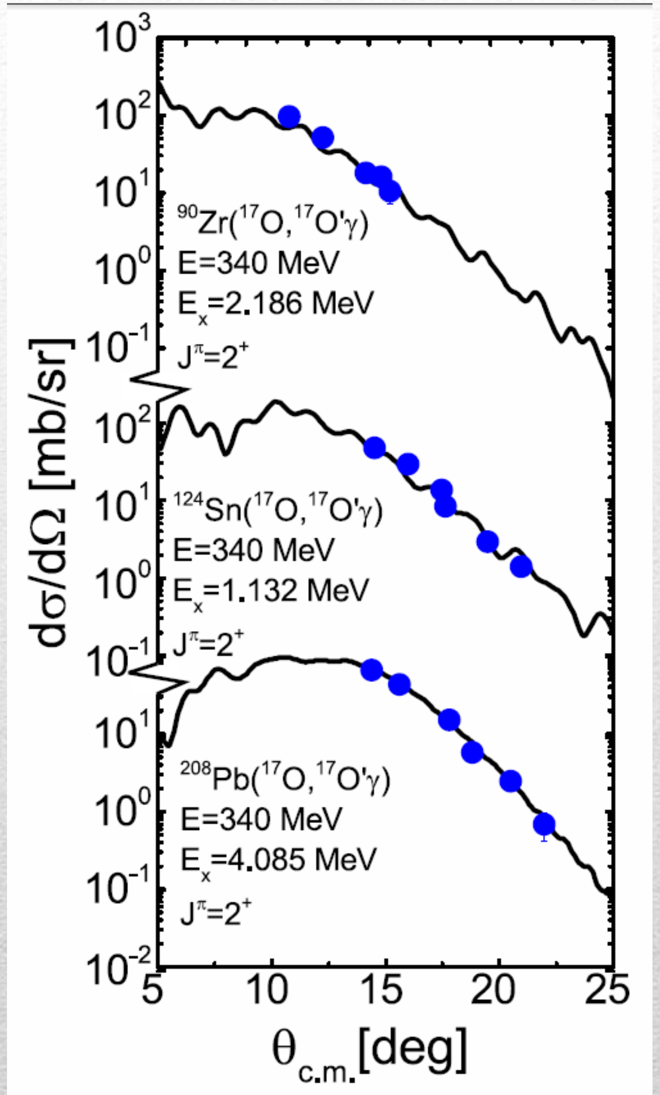
Differential cross sections were determined for excitation of the 2⁺ states in ^{90}Zr,^{124}Sn,^{208}Pb

The solid curve results from DWBA calculations using optical model potential parameters determined from the elastic data

In agreement with measurements at similar beam energy**

- The B(E2) is known from other works*

- These calculations were obtained assuming pure isoscalar excitation implying that the ratio of the neutron matrix element and the proton matrix element is given 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

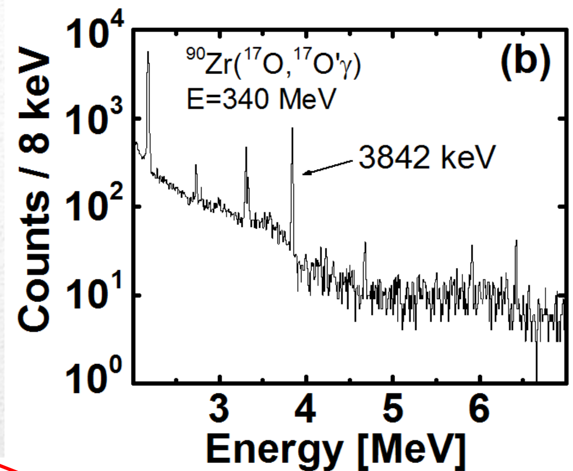
^{90}Zr: 3842 keV 2^+ state, <u>a peculiar behaviour</u>

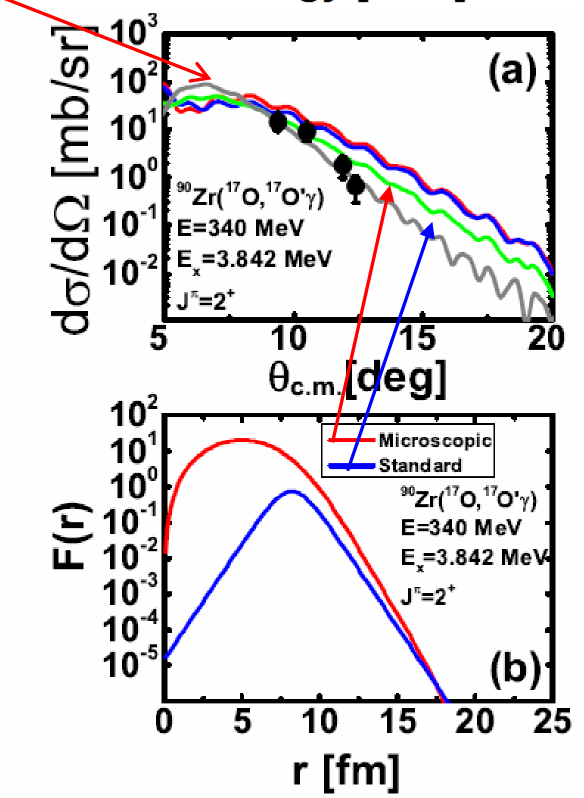
Not possible to reproduce the data with calculations using the standard deformed potential model approach (blue line), the same if adopting a radial form factor is of microscopic type (red line).

lowering the nuclear contribution the associated calculations get closer to the experimental points ($M_n/M_p = 0.1 * N/Z$, **green line**), gray curve considers only the Coulomb excitation contribution

→ as stated in [***], this state has strong four-quasiparticle component and therefore cannot be populated by a one-step process as that assumed within the DWBA approach!

(***the nuclear potential does not play a significant role in the direct excitation process of such a complex excitation mode***)





***J. Heisenberg et al., Phys. Rev. C 29, 97 (1984).

*F.C.L. Crespi et al, PRC 91 (2015) 024323

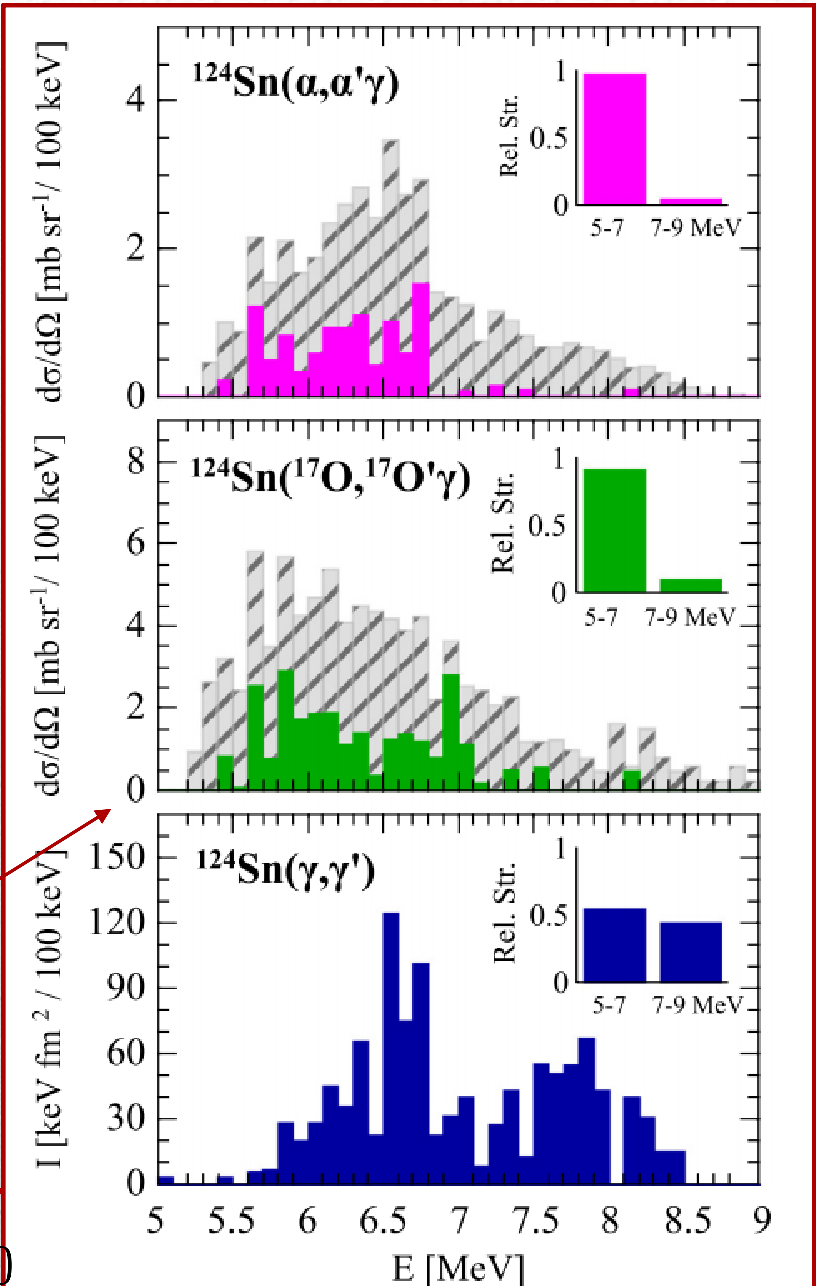
*A.Bracco, F.C.L. Crespi and E.G. Lanza, to be published in EPJA(2015)

Results on the Low-Lying E1 Strength

- Comparison of the presently measured cross sections with (γ,γ′) and (α,α′γ) results (**).
  - *discrete peaks*
  - *total measured counts* (unresolved strength dashed grey bars)

- Splitting of the PDR states in two regions also in (17O,17O’γ)
  - isoscalar transition densities (*peaked on the surface, enhanced in the isoscalar E1 response*)
  - higher-lying states (*GDR type, suppressed in the isoscalar channel*)

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)

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

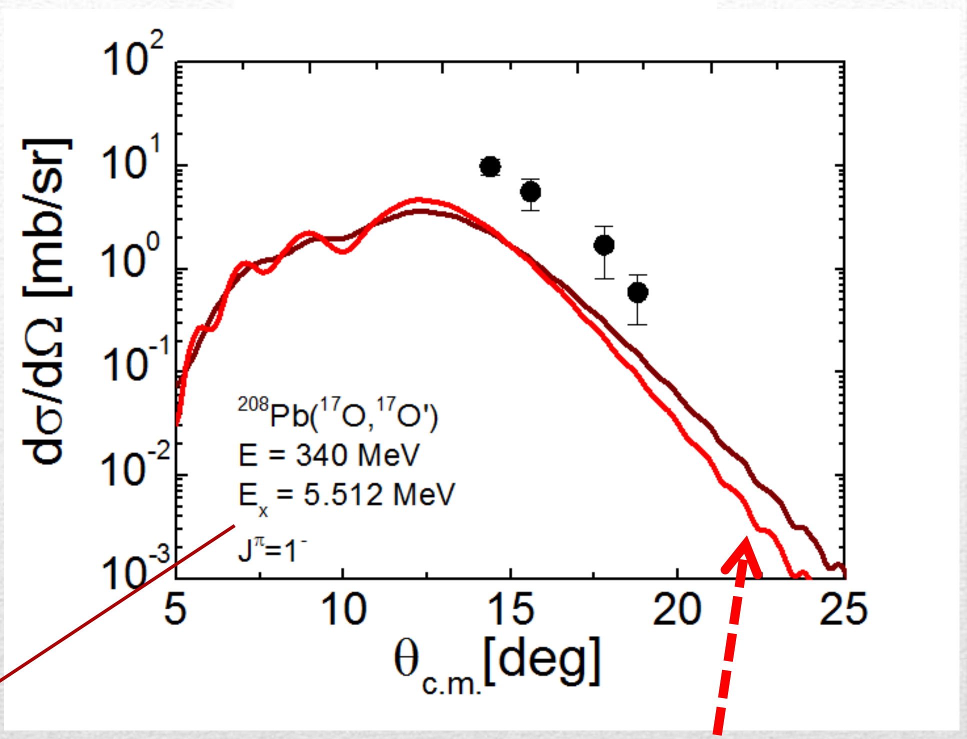
Results on the Low-Lying E1 Strength

1⁻ states in ^{208}Pb

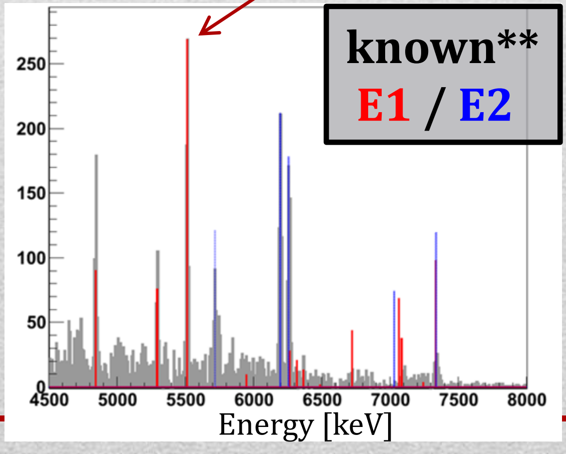
The calculation accounts only for a fraction of the measured yield

Why?

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



To understand the measured E1 cross sections, we have to perform DWBA calculations with a different type of nuclear form factor



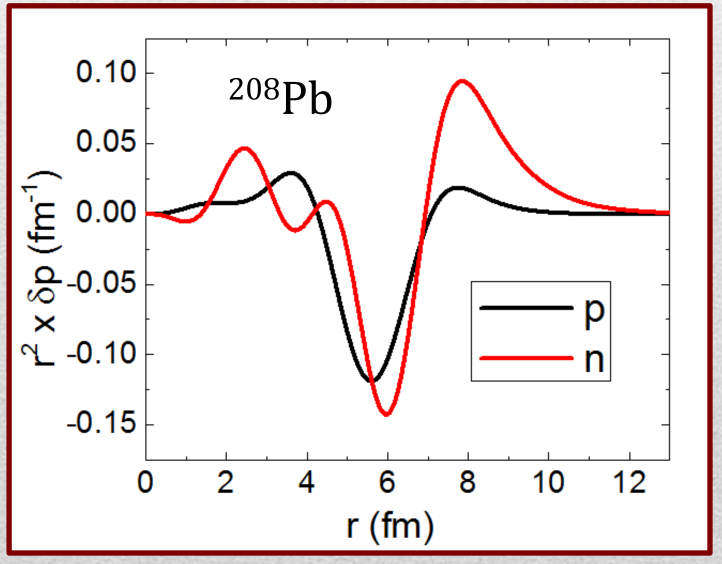
known**
E1 / E2

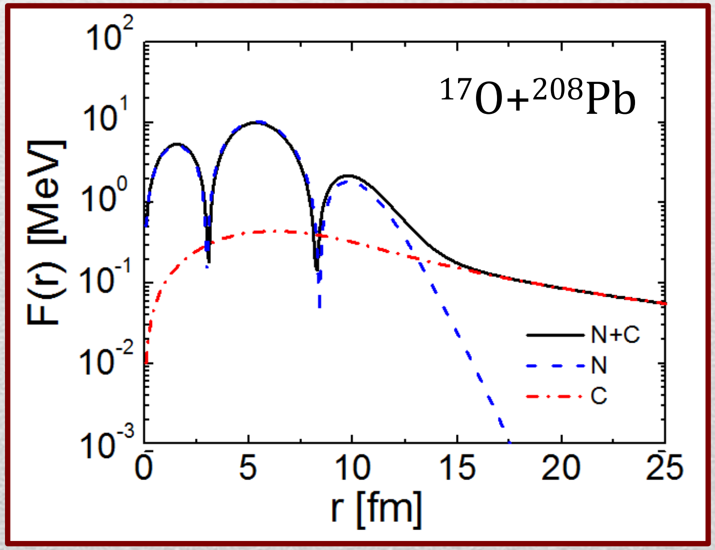
The Coulomb excitation cross section based on the B(E1)↑ values known from (γ,γ)** have been calculated

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

Microscopic Form Factor

- A **microscopic form factor** was calculated for $^{17}O+^{A}X$, by using a double folding procedure (*)
- This is shown with the contributions [Coulomb (red dotted-dashed line), nuclear (blue dashed line)]. In the region physically more significant (between 10 and 14 fm), the most important contribution for the form factor comes from the nuclear part.
- The used **transition density** shows the strong isoscalar characteristics of the pygmy dipole state: neutron and proton transition densities are in phase in the interior and a strong surface contribution due only to neutrons.

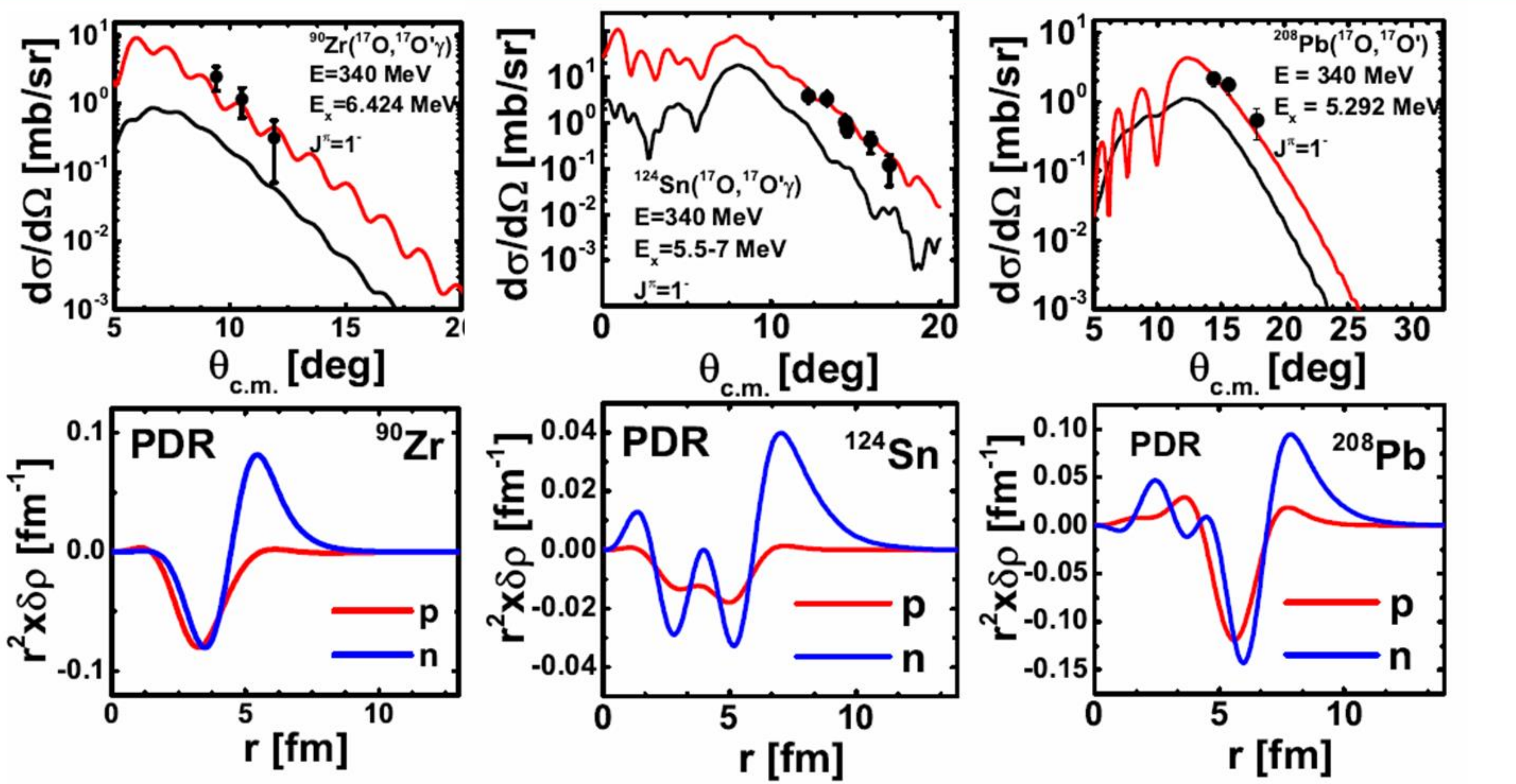




*E. G. Lanza et al., Phys. Rev. C 79 (2009) 054615
**E. G. Lanza et al., Phys. Rev. C 84 (2011) 064602
***E. G. Lanza et al., PRC 89 (2014) 041601

Results on the Low-Lying E1 Strength

- DWBA calculation were performed (red solid lines) using microscopic form factors based on the transition density associated to the E1 PDR states*

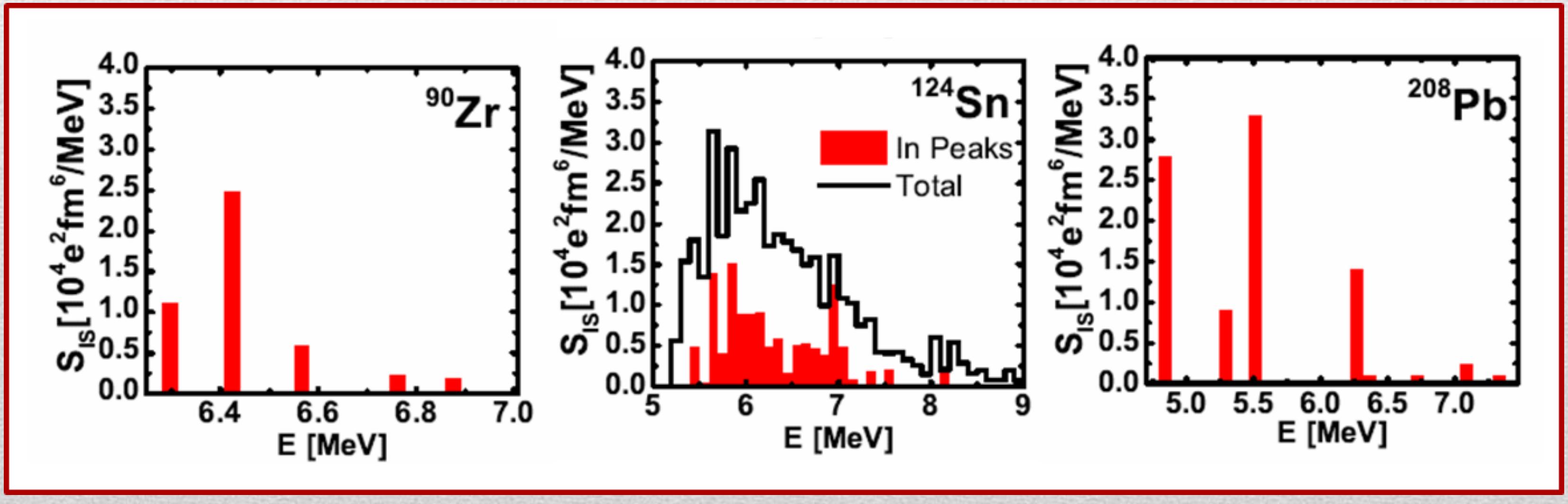


Calculated transition densities:
*(for 124Sn)E. Litvinova, et al., PRC 78 (2008)014312, **E.G. Lanza, et al.,PRC 89 (2014) 041601

The isoscalar strength in the pygmy region

The main objective of the data analysis was the extraction of the values of the isoscalar strength from the measured cross section

- The cross section has **two contributions**: one being the
Coulomb and the other the **Nuclear** - *Isoscalar* –
- For the Coulomb contribution we fixed the value corresponding to the known B(E1)
- For the Nuclear contribution the reference value used was that associated to the microscopic form factor used, corresponding to a specific value of the isoscalar strength.



F.C.L. Crespi, et al., PRL113 (2014) 012501
L. Pellegri, et al., PLB738 (2014)519
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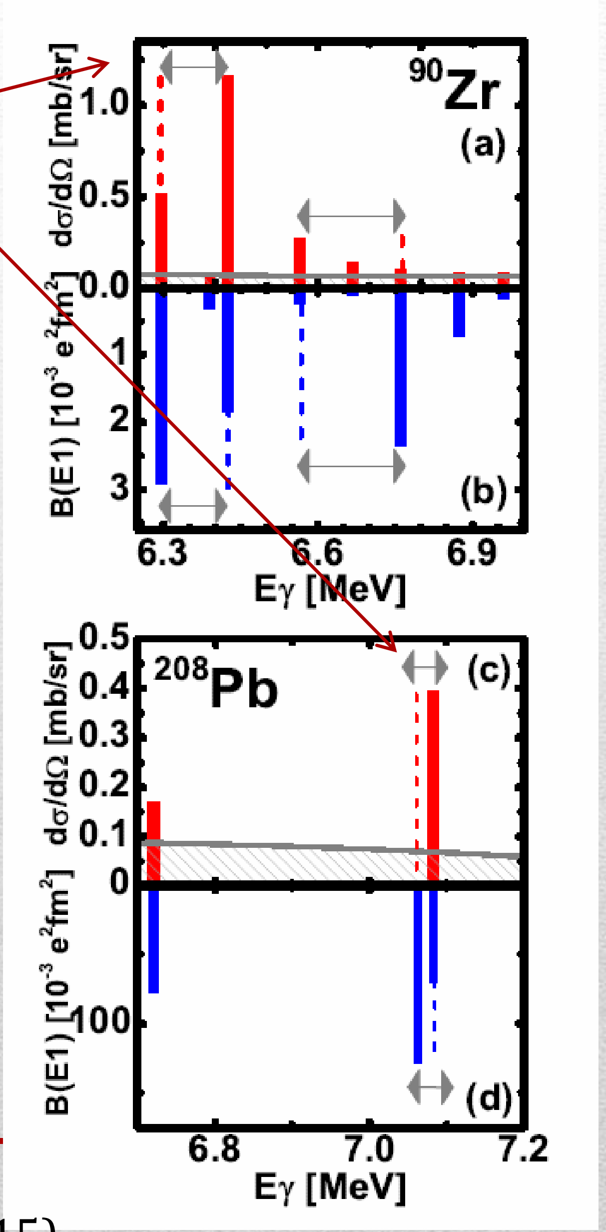
Isospin Mixing

When an isoscalar 1⁻ state is excited by a probe with dominant isoscalar character, the E1 gamma decay, which must proceed through the isovector part of the E1 transition operator, 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)

Conclusions and Future Work

- **Isospin Properties of pygmy dipole states investigated using the (17O, 17O'γ) reaction at 340 MeV**
- Angular distributions measured both for the γ rays and the scattered ^{17}O ions
- The data analysis with the DWBA approach gives a good description of the elastic scattering and of the inelastic excitation of the low lying 2^+ and 3^- states
- For 1^- transitions a form factor obtained by folding a microscopically calculated transition density (PDR) allowed to reproduce the data remarkably well
    - *Extracted the isoscalar component of the 1^- excited states*

- **Analysis on ^{140}Ce in final stage** (M. Krzysiek et al. Phys. Scr. 89 (2014) 054016.)
- **Experiments at RCNP Osaka (PDR in ^{90}Zr,^{96}Zr) and CCB Cracow (GQR)**
- **An interesting perspective: loosely bound ^{13}C could be used as a target with intense radioactive beams in inverse kinematics**

Collaboration

<u>F.C.L. Crespi</u>, A. Bracco, G. Benzoni, N. Blasi, C. Boiano, S. Brambilla, F. Camera, A. Giaz,
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