5^{th} International Symposium on Nuclear Symmetry Energy

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

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Outline

- Motivation

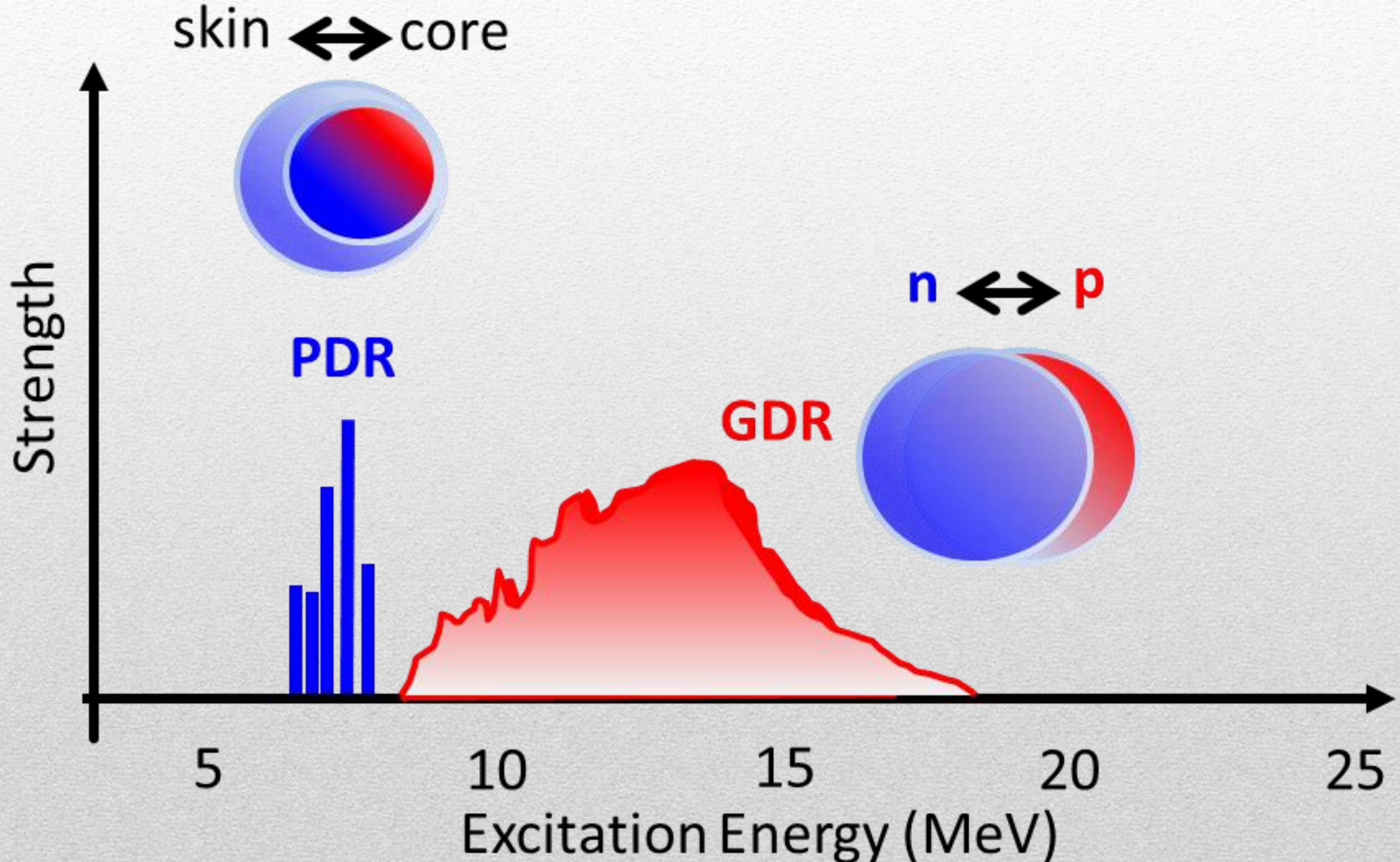
  *E1 strength at particle threshold: the **Pygmy Dipole Resonance (PDR)***

- 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

E1 response in Nuclei

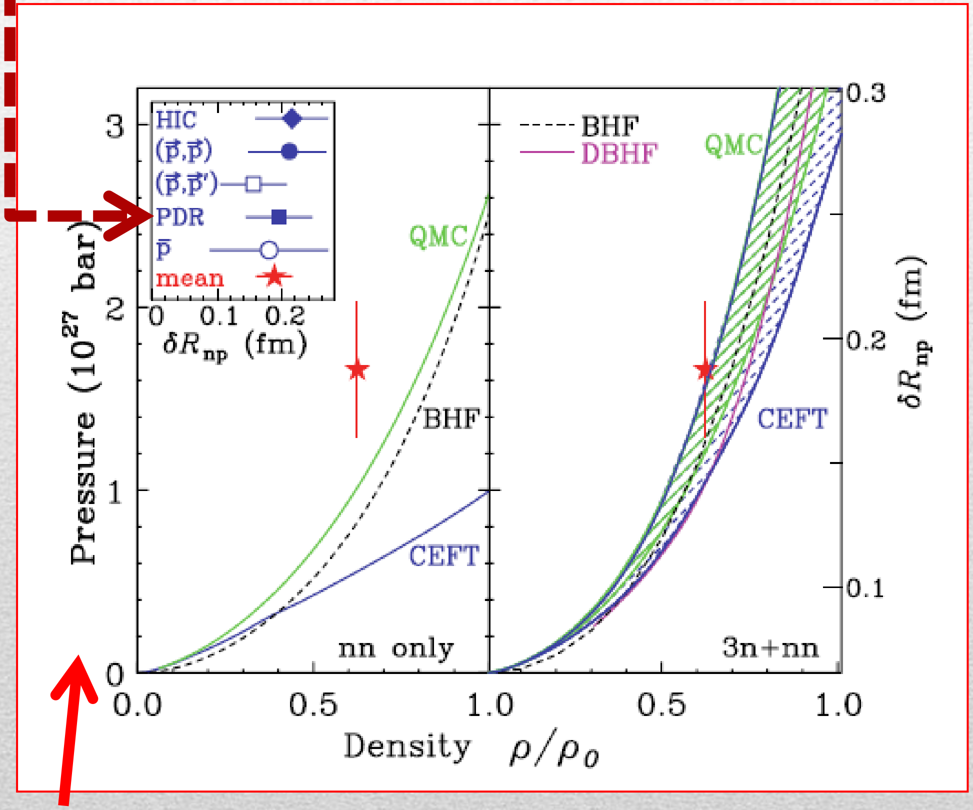


Correlations between the **Nuclear Symmetry Energy**, the **Neutron Skins** and the **PDR Strength****

Experimental data on the neutron skin thickness in ^{208}Pb

The derivative of the symmetry energy at saturation is related to the slope parmeter ***L***

$$S(\rho) = J + \frac{L}{3\rho_0}(\rho - \rho_0) + \frac{K_{sym}}{18\rho_0^2}(\rho - \rho_0)^2 + \ldots$$



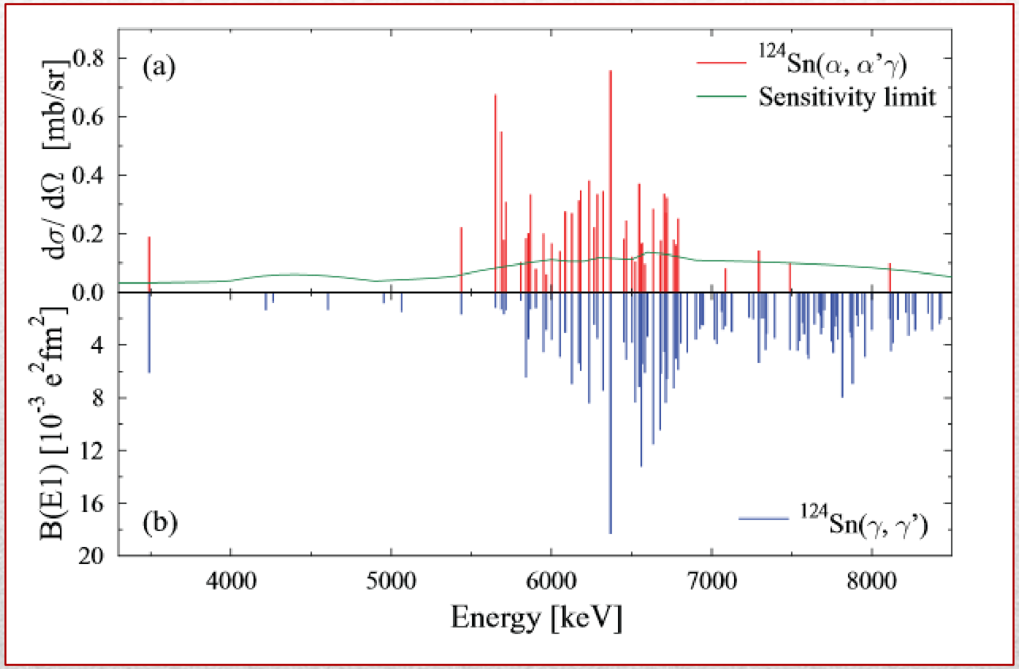
M.B. Tsang et al., Phys. Rev C 86, 015803 (2012)

"*L*" is related to the *Pressure* from the symmetry energy for pure neutron matter in neutron stars

**A. Carbone, G. Colò et al. Phys. Rev. C 81, 041301 (2010)

Nuclear Structure information from the E1 response

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

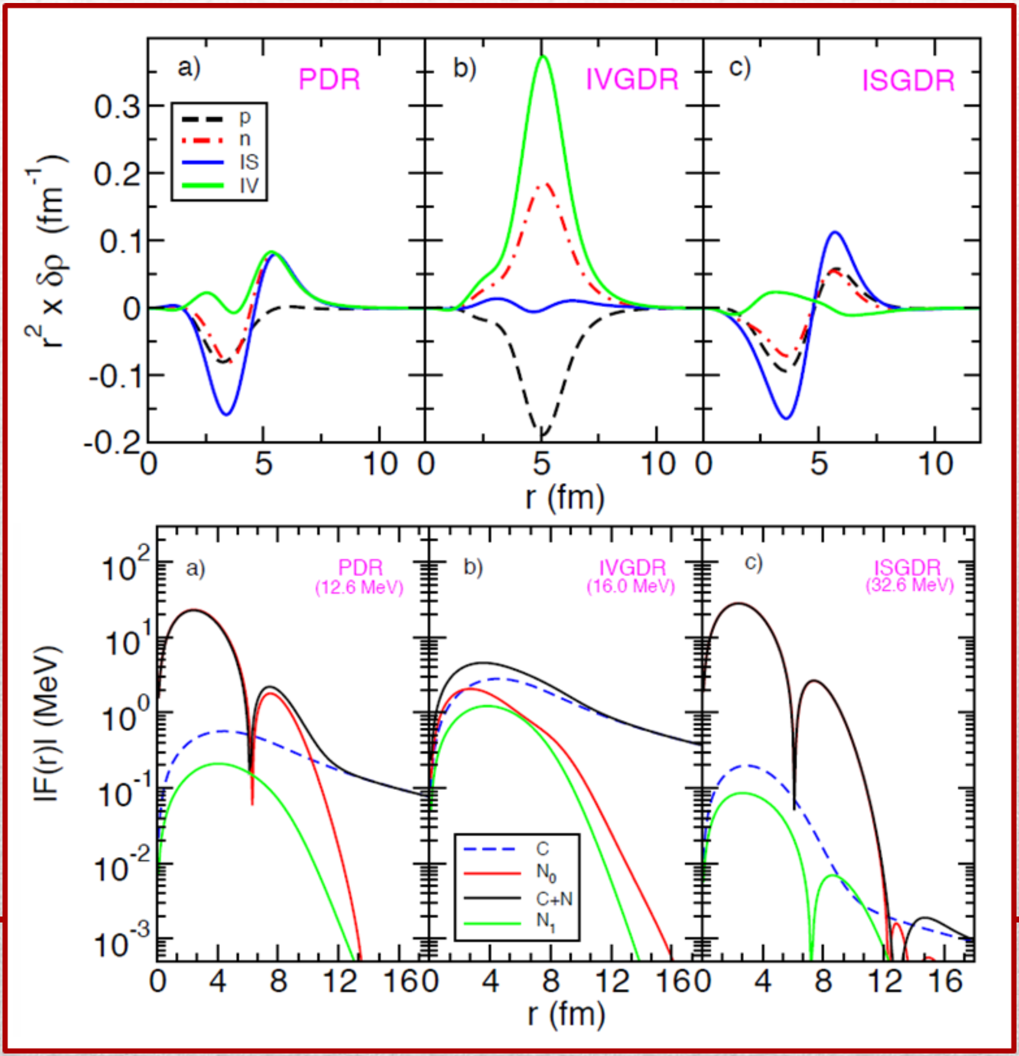
One important open problem for pygmy states is the cross section sensitivity to transition densities containing the nuclear structure information…

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

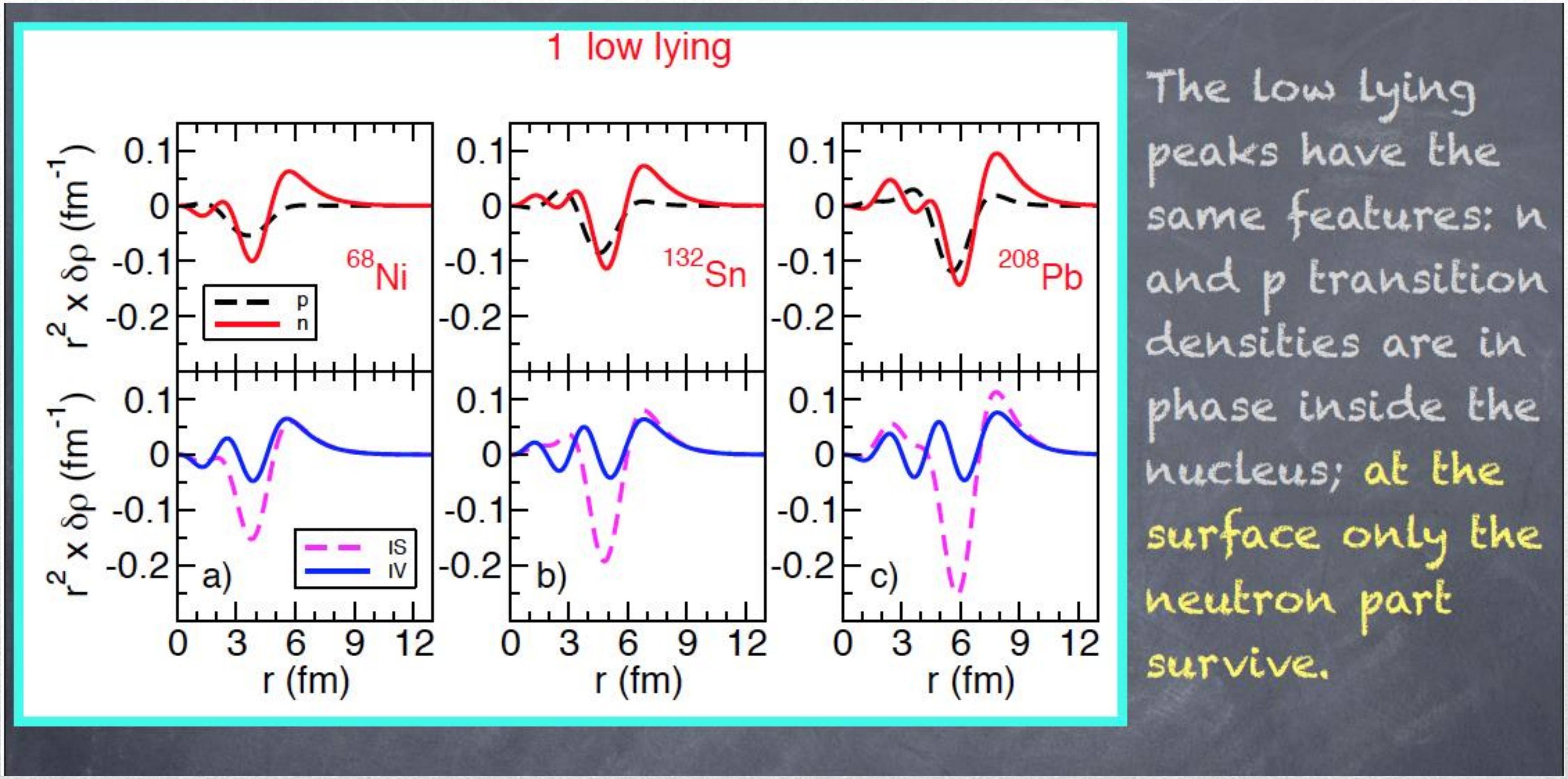
^{90}Zr
Transition Densities

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



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

Transition Densities



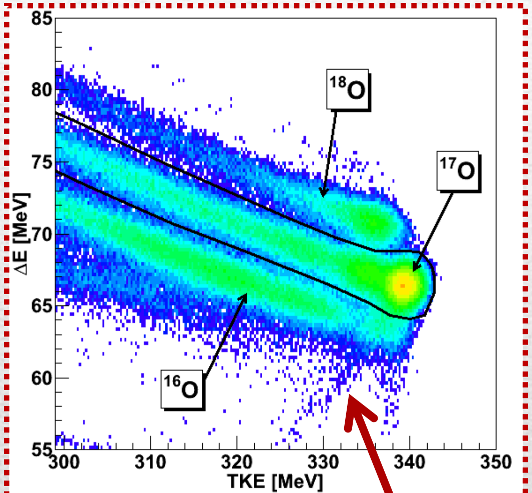
➢ **Interesting to use a probe interacting mainly at the surface !!!**

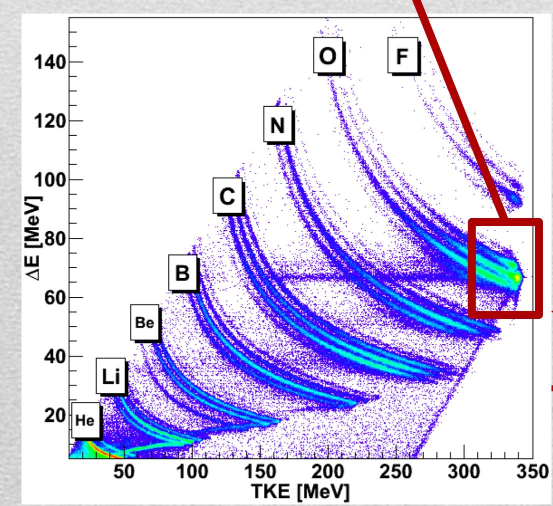
*E. G. Lanza et al., Phys. Rev. C 79 (2009) 054615.
**E. G. Lanza et al., Phys. Rev. C 84 (2011) 064602.

Experimental Technique

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

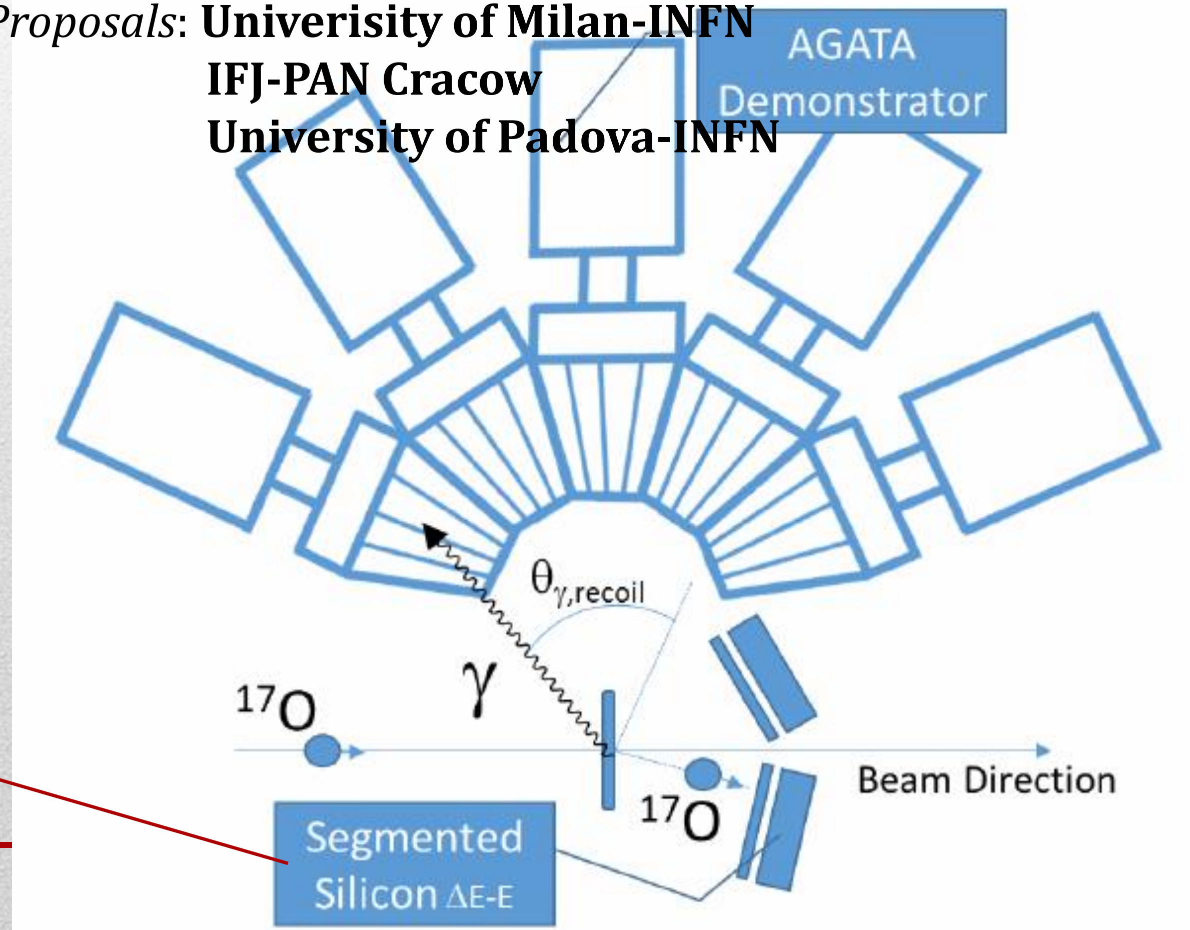
- Large cross-section for the population of the giant resonance region
- ^{17}O is loosely bound (S_n = 4.1 MeV)
- Clean removal of projectile excitation





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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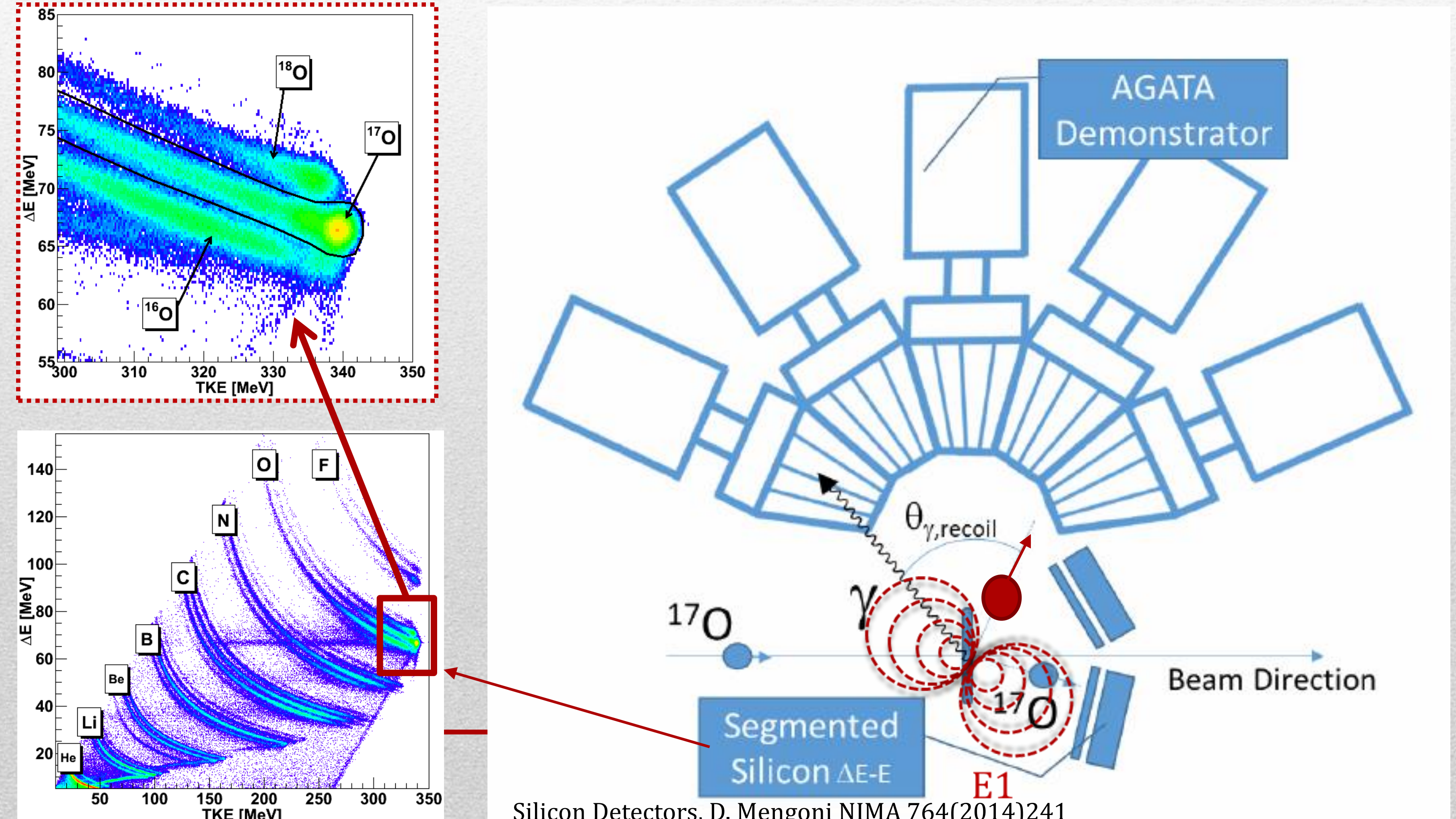
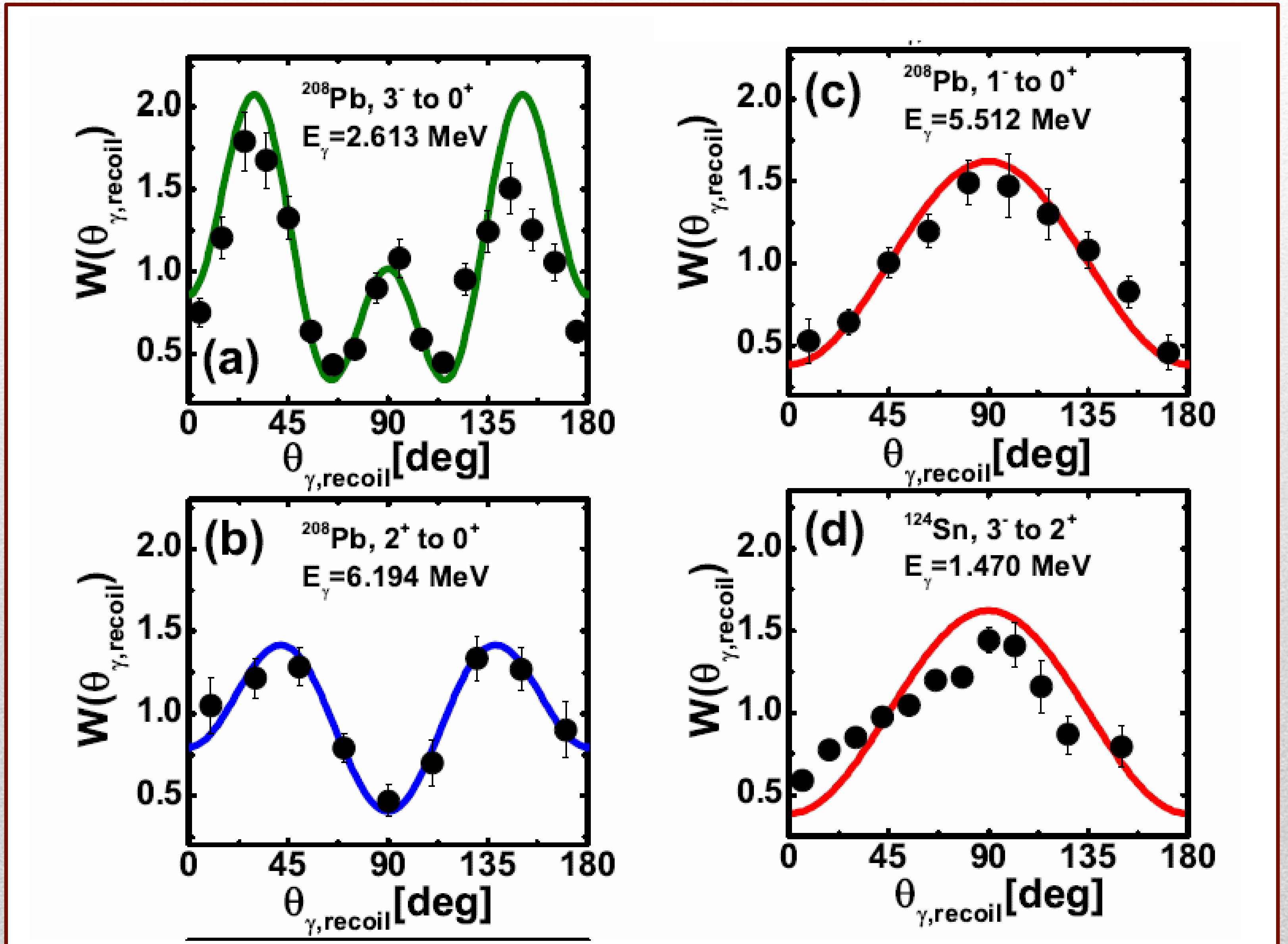


Silicon Detectors, D. Mengoni NIMA 764(2014)241

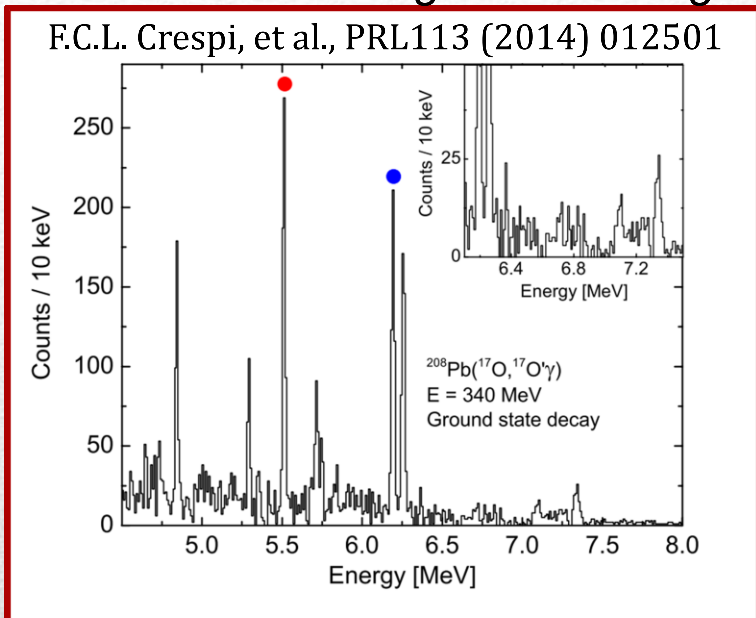
Angular distribution of γ-rays

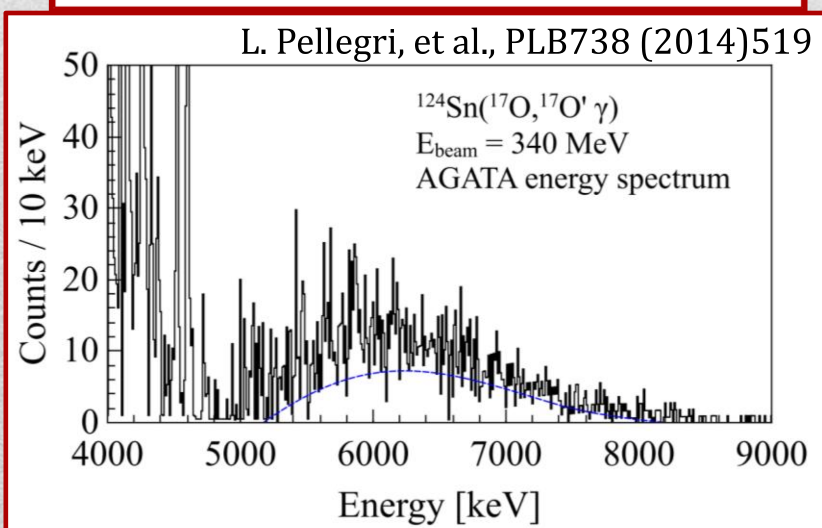
Angular Distribution of γ's obtained exploiting ***position sensitivity*** of **AGATA** and **E-ΔE Si** telescopes (pixel type)

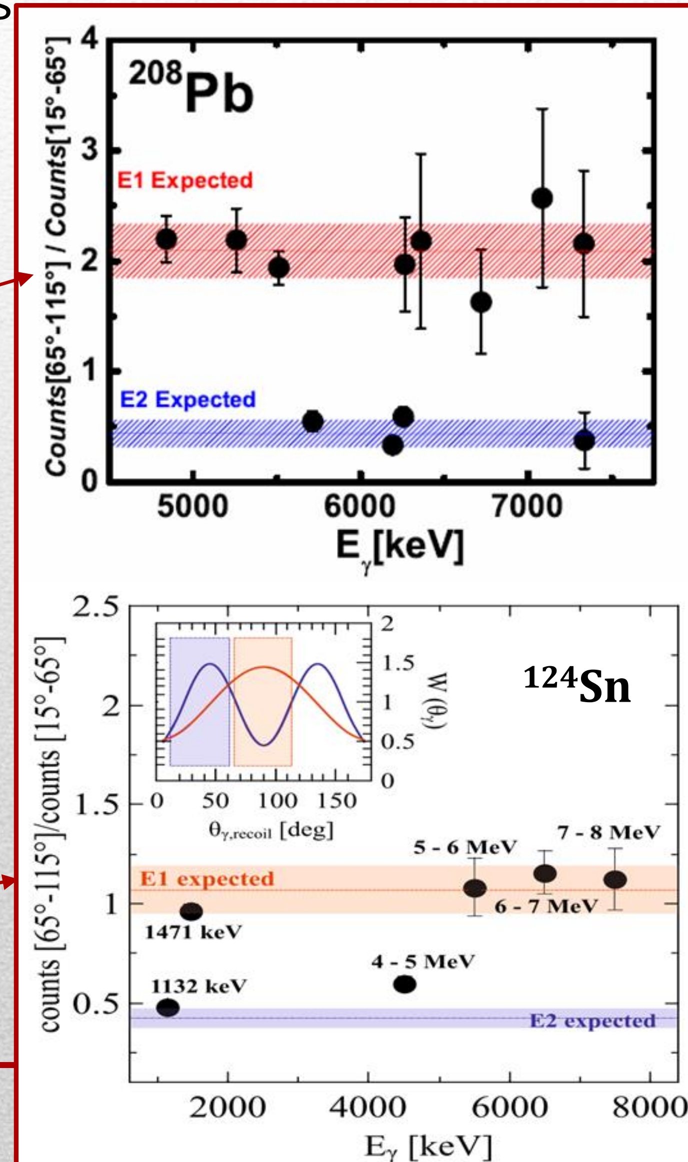


Identification of the Multipolarity

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*





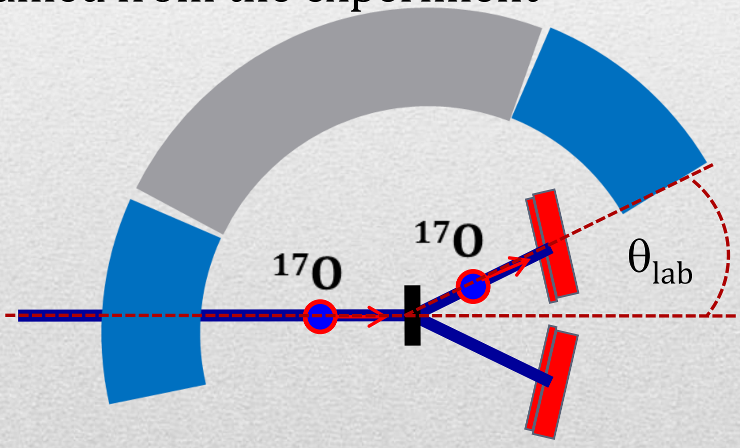


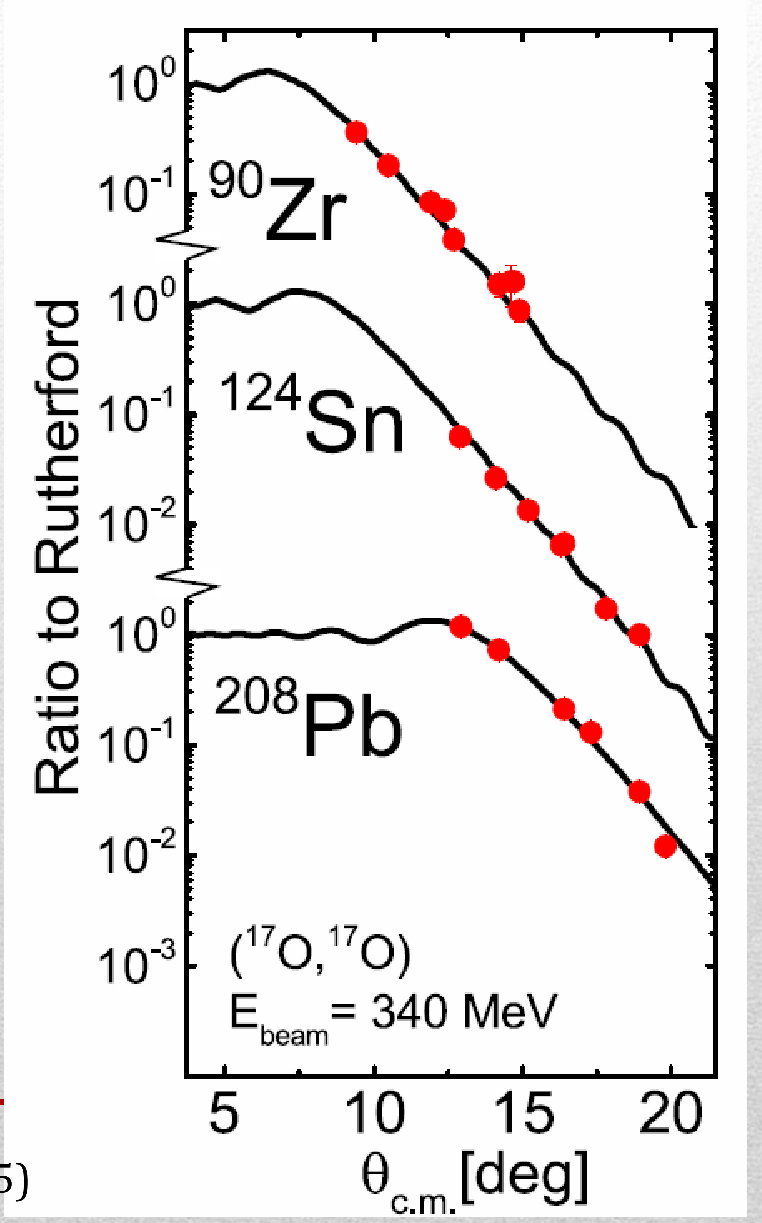
Angular distributions of the scattered ^{17}O ions – ELASTIC SCATTERING

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
A. Bracco, F.C.L. Crespi and E.G. Lanza, submitted to EPJA(2015)

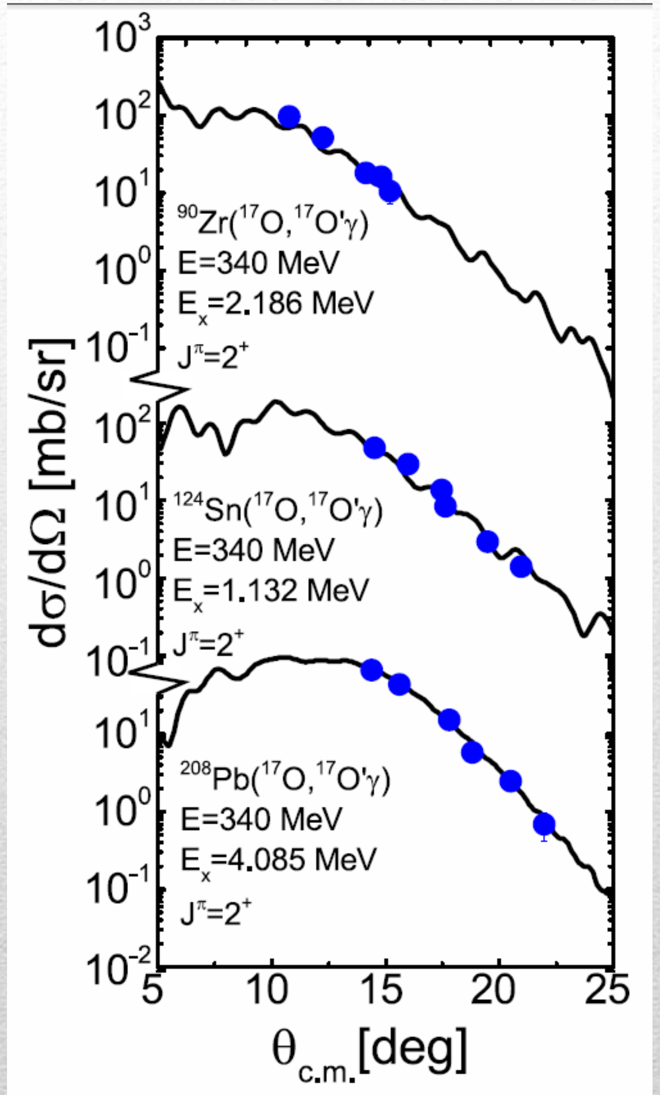
Angular distributions of the scattered ^{17}O ions–INELASTIC SCATTERING

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/

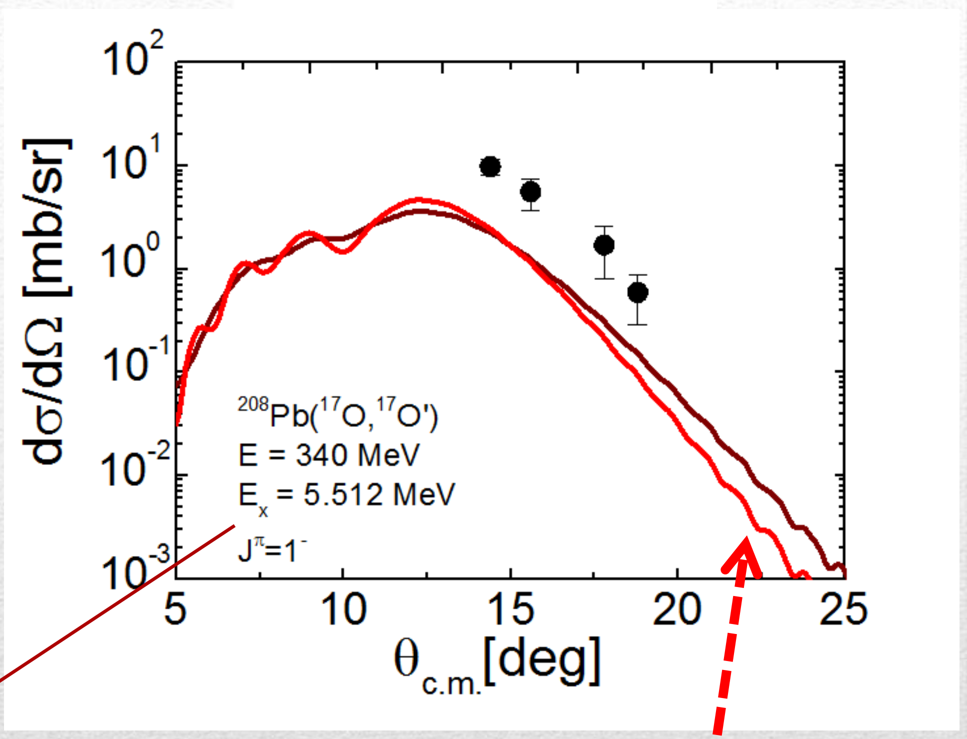
**for the case of ^{208}Pb: D.J. Horen et al. PRC 44(1991)128

1^- states in ^{208}Pb

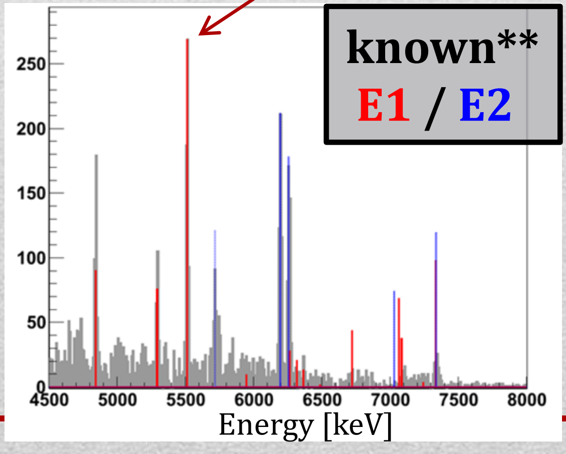
The calculation accounts only for a fraction of the measured yield

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



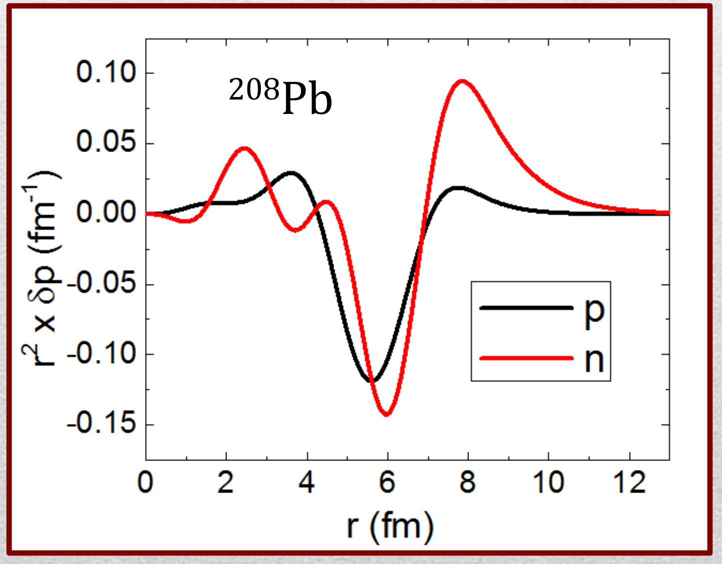
known**
E1 / E2

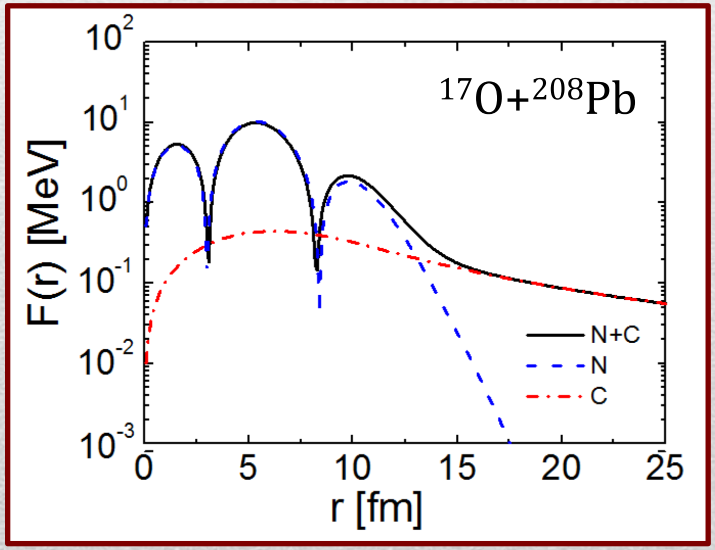
The Coulomb excitation cross section based on the B(E1)↑ values known from (γ,γ)** have been calculated

** 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.





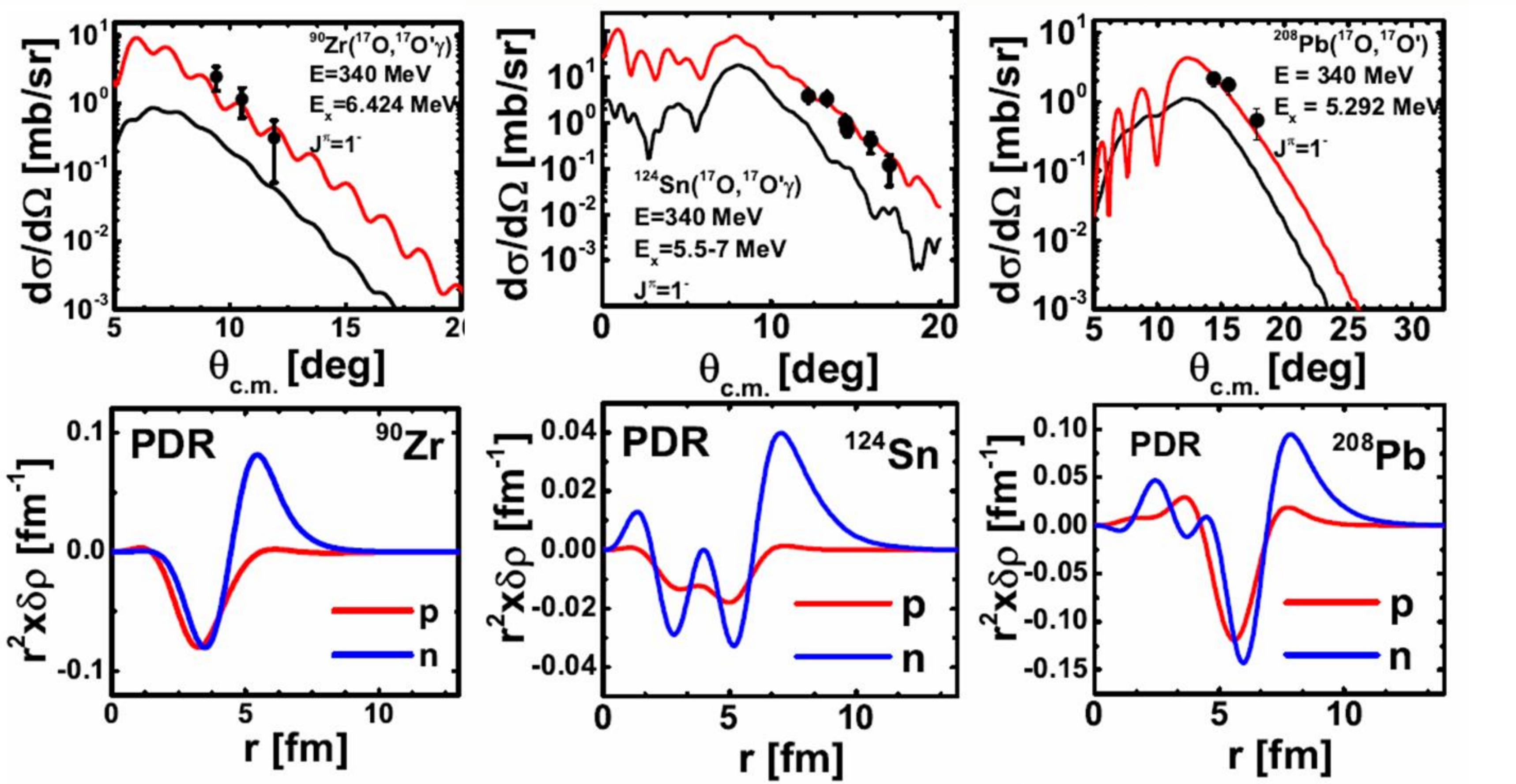
*E. G. Lanza et al., Phys. Rev. C 79 (2009) 054615

**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*

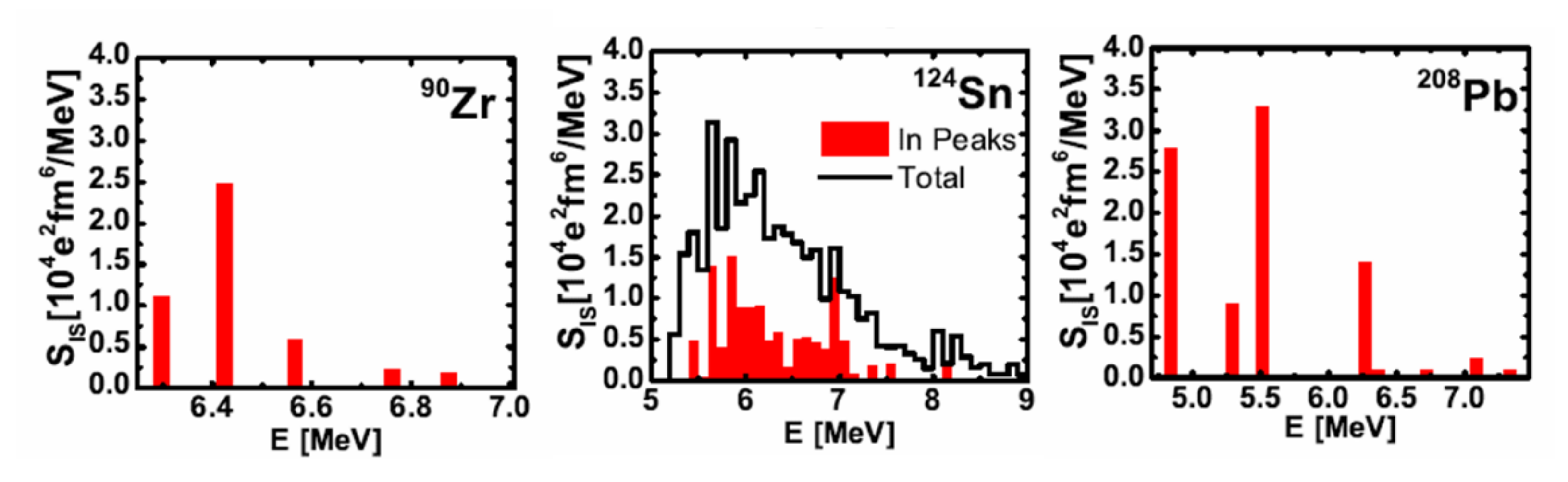


Calculated transition densities:
*(for 124Sn)E. Litvinova, et al., PRC 78 (2008)014312, **E.G. Lanza, et al.,PRC 89 (2014) 041601

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.



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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** (Mateusz Krzysiek → NEXT TALK !!!)
- **Experiments at RCNP Osaka (PDR in ^{90}Zr,^{96}Zr) and CCB Cracow (GQR)**

Collaboration

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