**NUSPIN 2017 Workshop**

**GSI, June 26 - 29, 2017**

# Gamma decay of pygmy states from inelastic scattering of ions

Fabio Crespi

Università degli Studi di Milano - INFN

# Outline

- Motivation

  *E1 strength at particle threshold: the Pygmy Dipole Resonance*

- Heavy Ion ($^{17}O$) Inelastic scattering

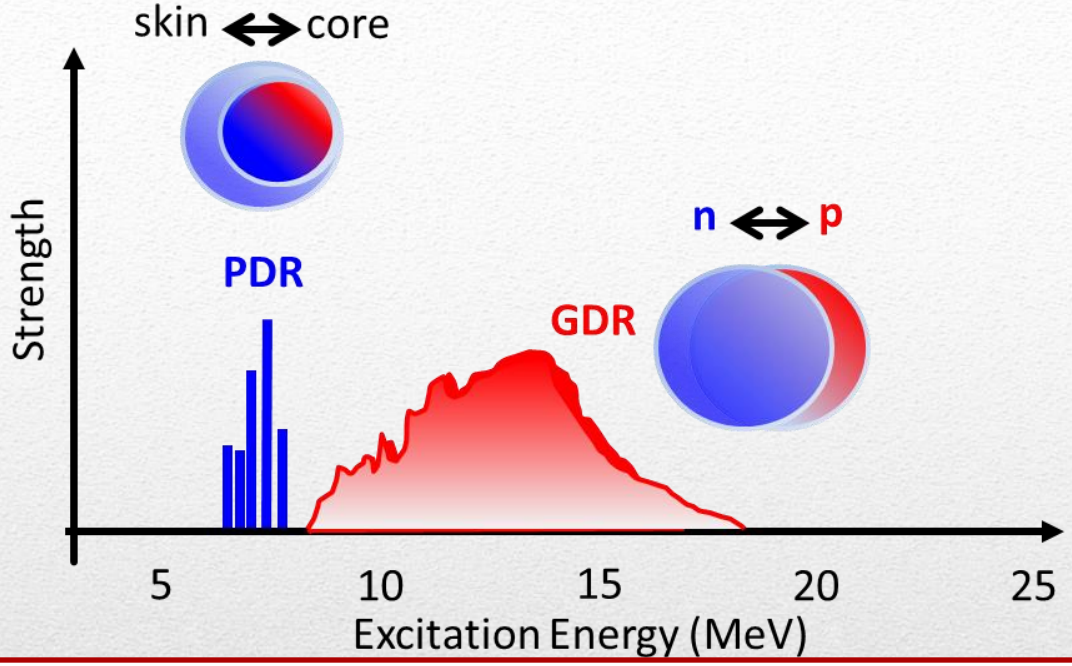
  - *Results of experiments with AGATA at LNL-INFN ($^{90}Zr$, $^{124}Sn$, $^{208}Pb$,$^{140}Ce$)*

- Light Ion ($\alpha$, $p$) Inelastic Scattering

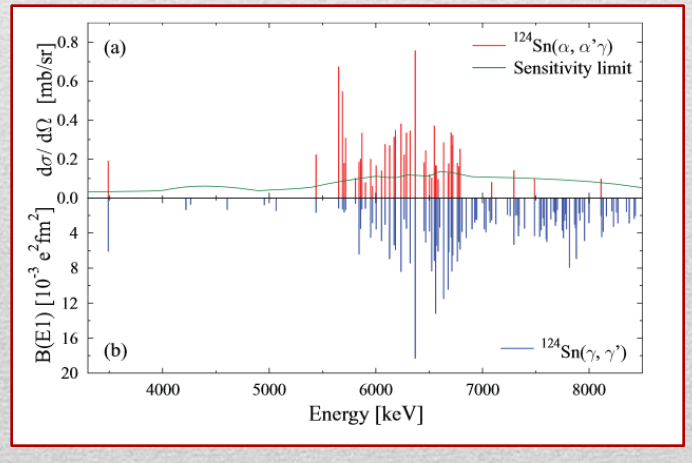
  - *Preliminary results from experiments at RCNP (Osaka) with CAGRA (+LaBr:Ce) and Grand Raiden*

- Conclusions

# Nuclear Structure information from the E1 response in Nuclei




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

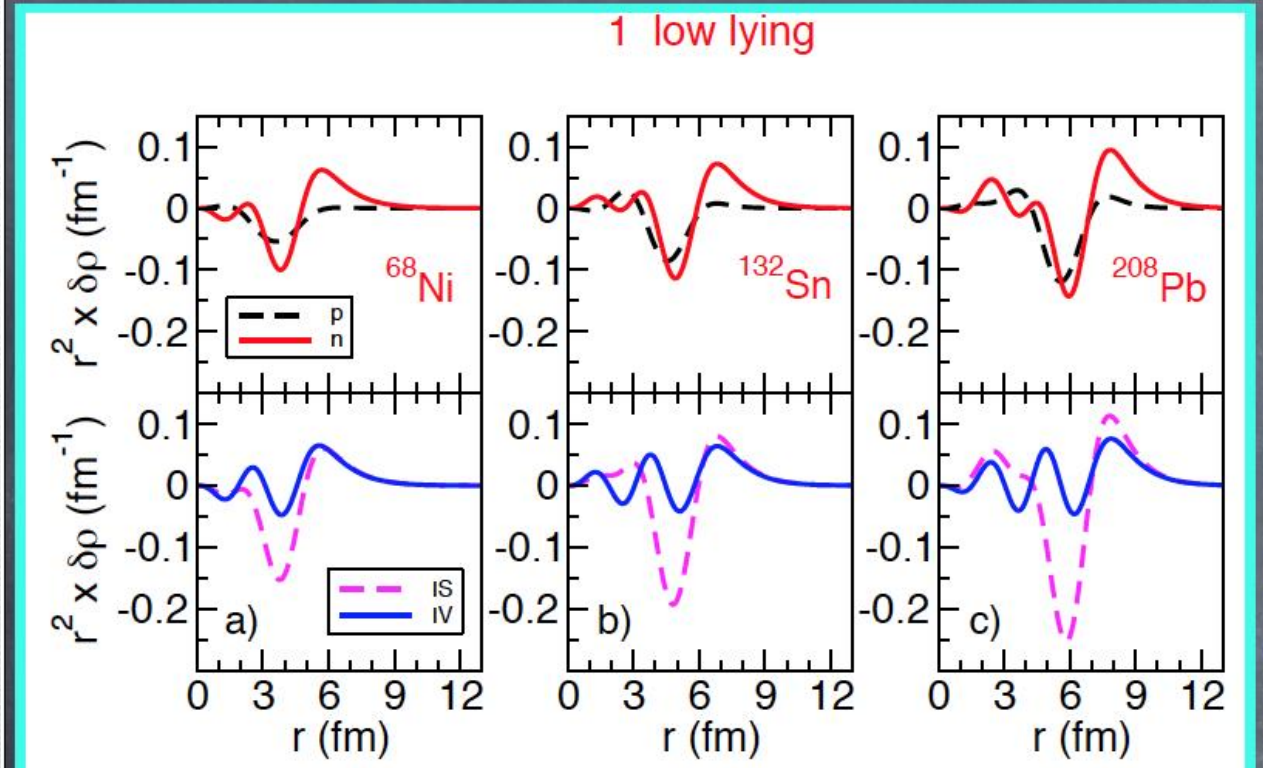



- low energy part → isoscalar character (*neutron-skin oscillations*)
- high-energy states → isovector nature (*transition towards the GDR*)

(*) 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 interesting problem for pygmy states is the cross section sensitivity to transition densities containing the nuclear structure information…**

# 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 !!!**

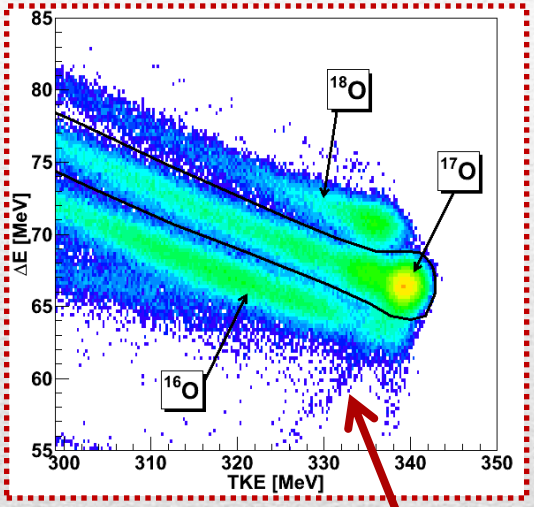

*E. G. Lanza et al., Phys. Rev. C 79 (2009) 054615.

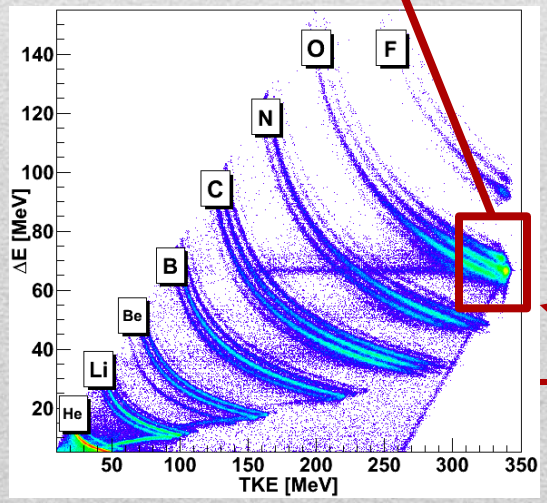
**E. G. Lanza et al., Phys. Rev. C 84 (2011) 064602.

# 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



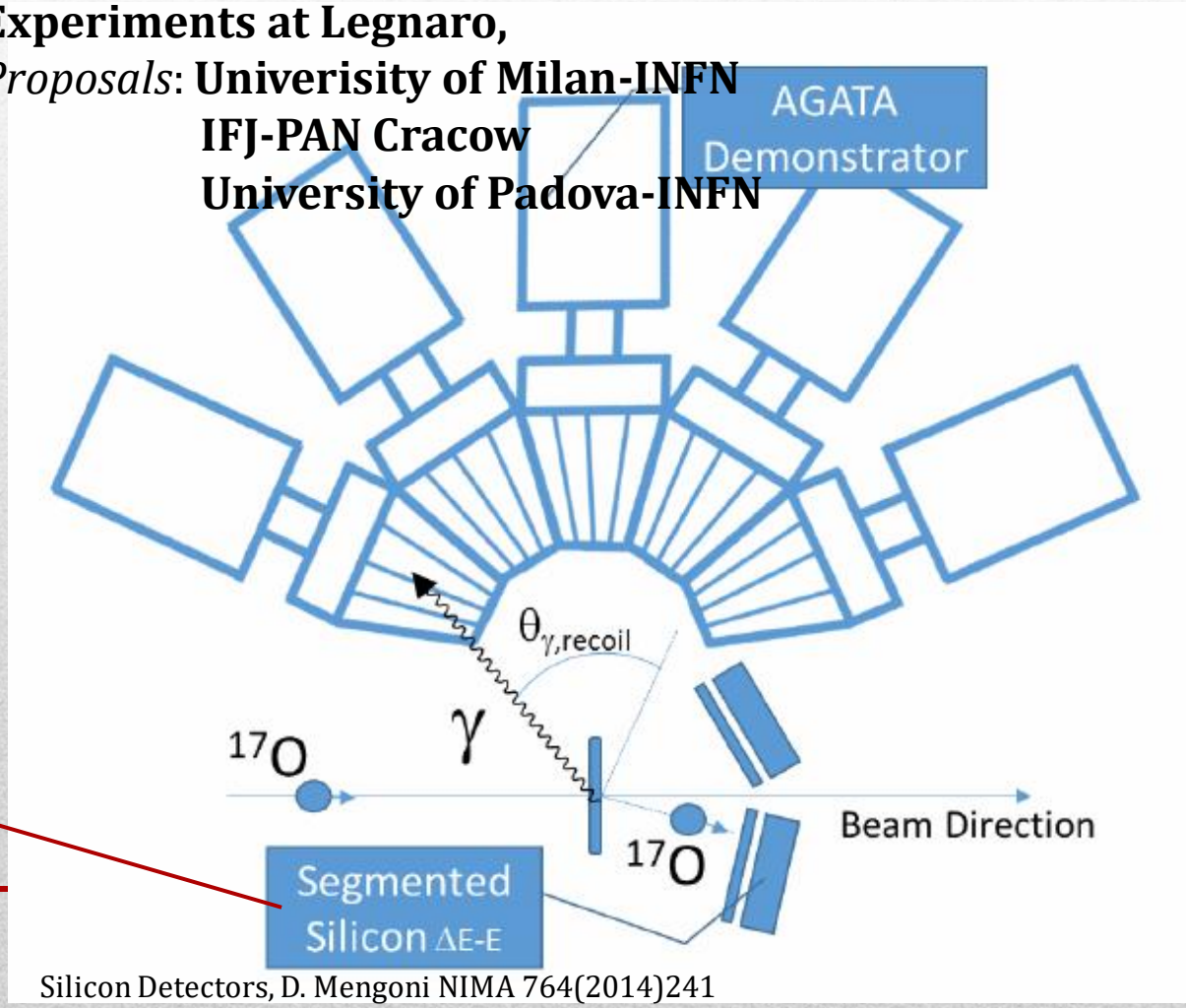




**Experiments at Legnaro,**

*Proposals*: **Univerisity of Milan-INFN**

**IFJ-PAN Cracow**

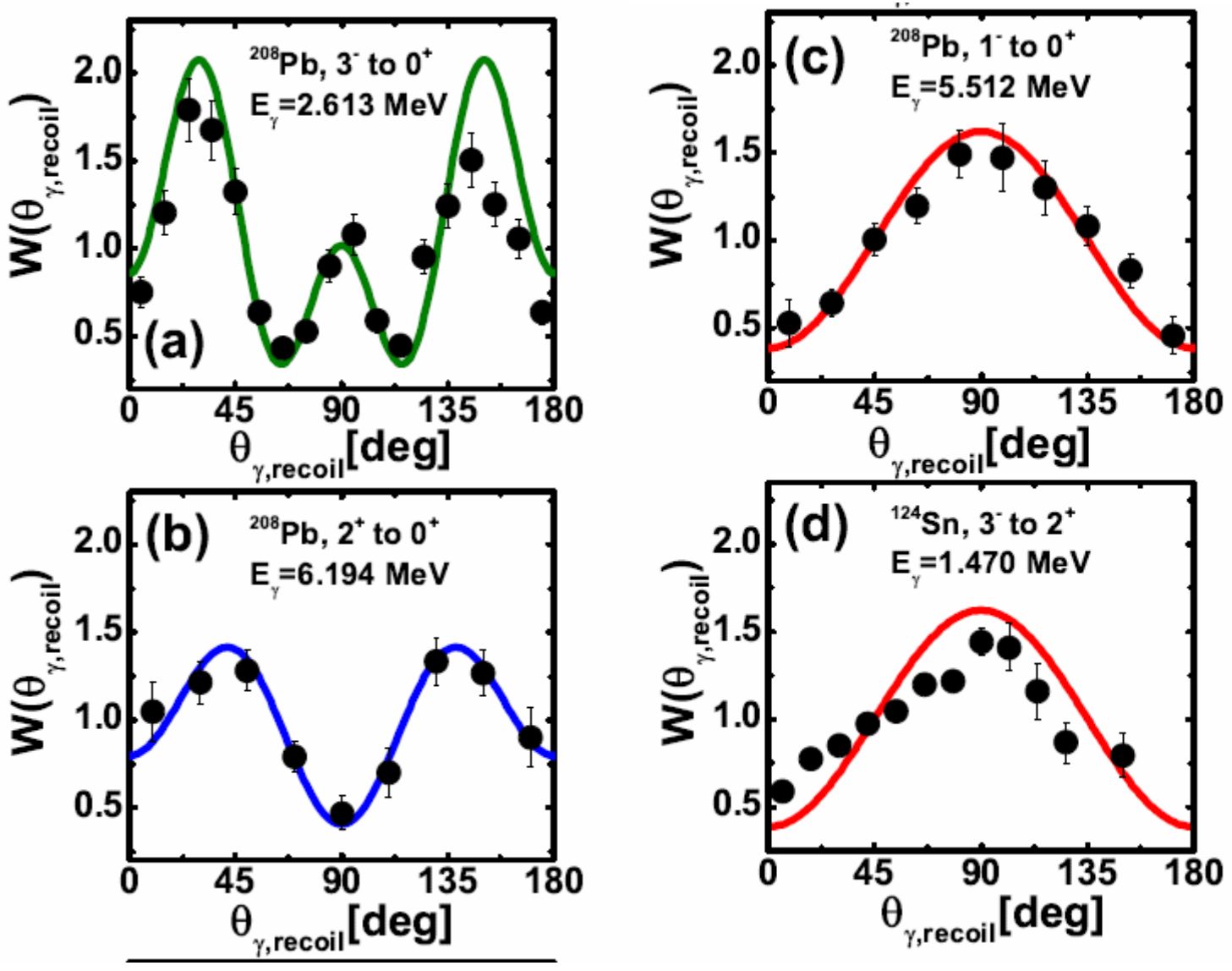
**University of Padova-INFN**




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

# Angular distribution of γ-rays

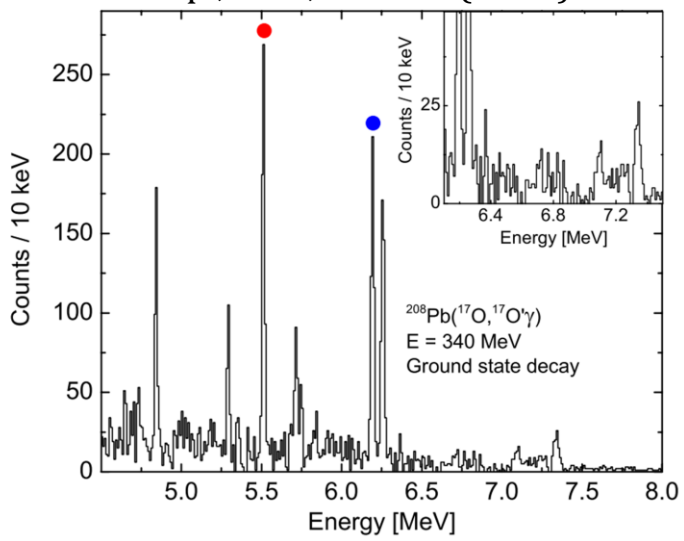
***Angular Distribution*** of γ's obtained exploiting ***position sensitivity*** of **AGATA** and **E-ΔE Si** telescopes (pixel type)



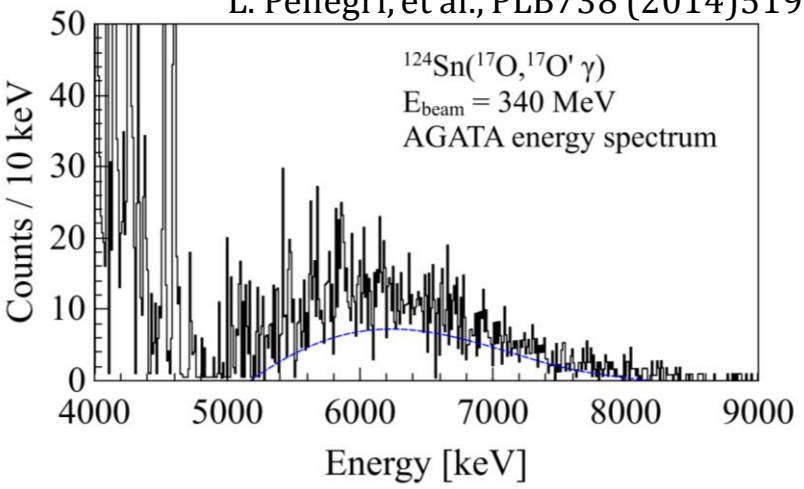
# Identification of the Multipolarity

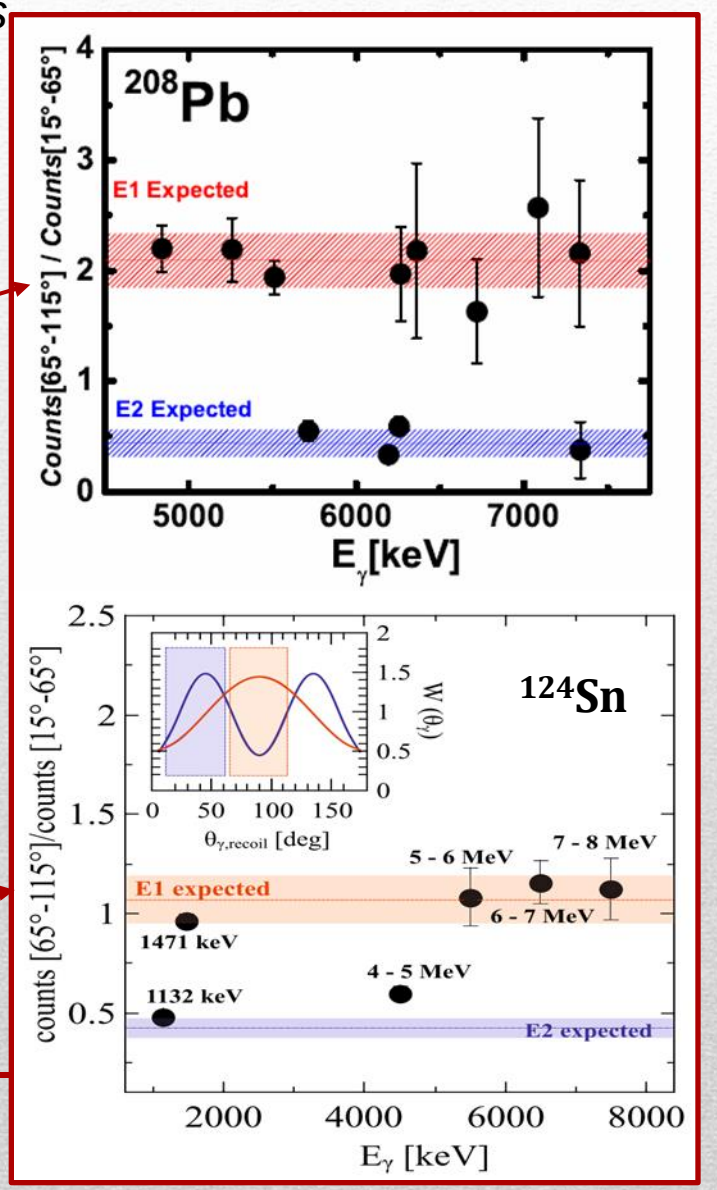
In contrast with light ions, for $^{17}O$ the pattern of the differential cross section for inelastic scattering as a function on angle does not characterize well the multipolarity of the excited states → *angular dist. of gamma-rays*

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




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



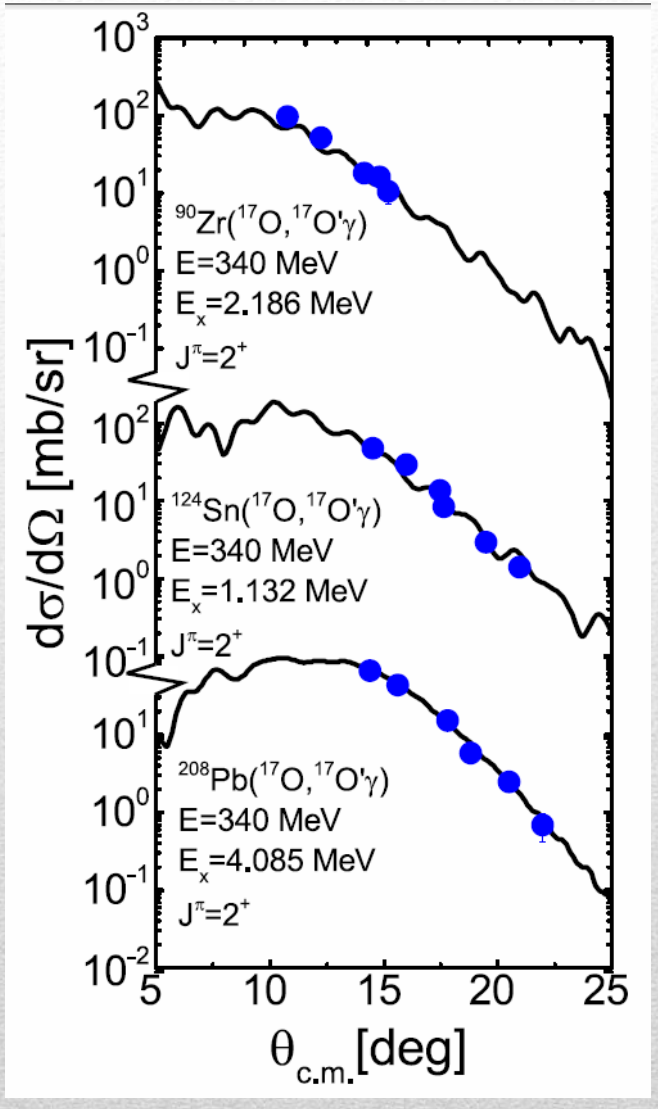
# Angular distributions of the scattered $^{17}O$ ions–INELASTIC SCATTERING

**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/

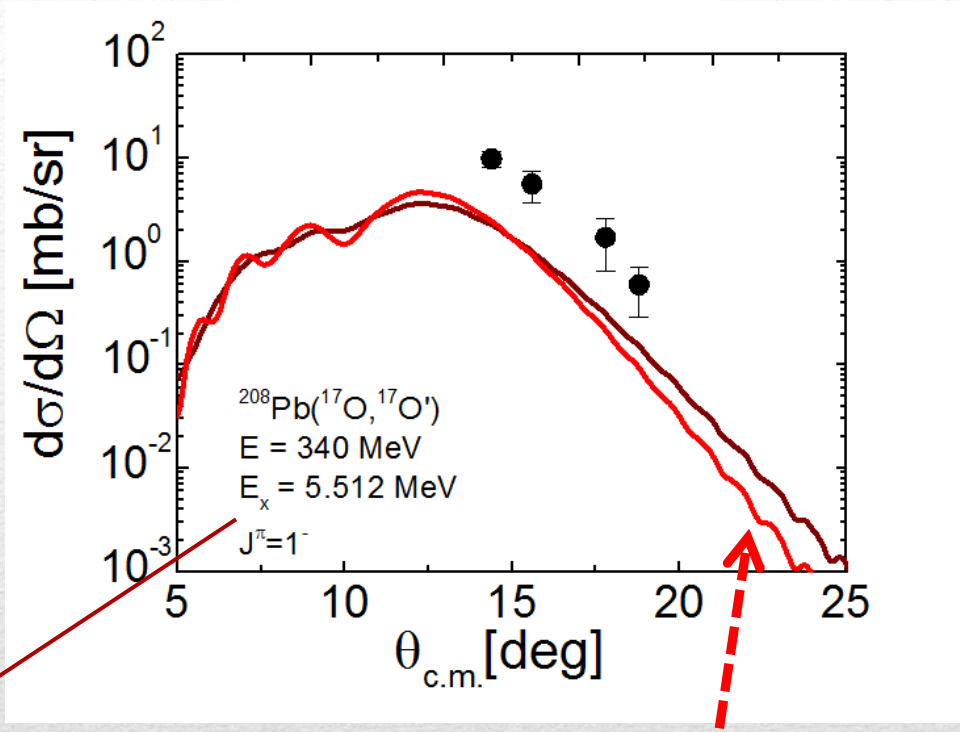
**for the case of $^{208}Pb$: D.J. Horen et al. PRC44(1991)128

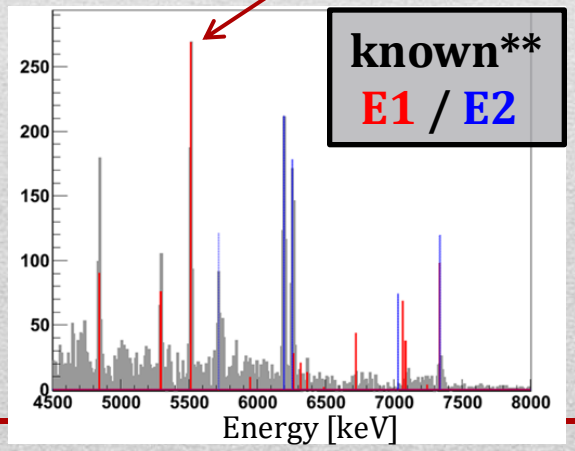
# $1^-$ states in $^{208}Pb$

The calculation accounts only for a fraction of the measured yield

**Why?**

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




**known****
**E1 / E2**

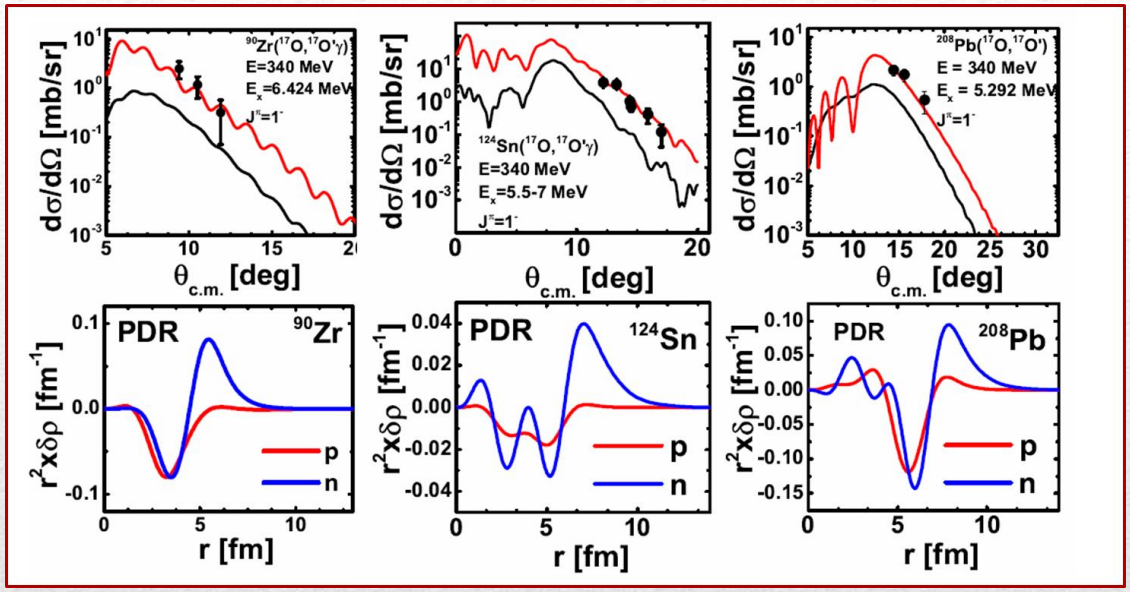
The Coulomb excitation cross section based on the B(E1)↑ values known from (γ,γ)** have been calculated

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

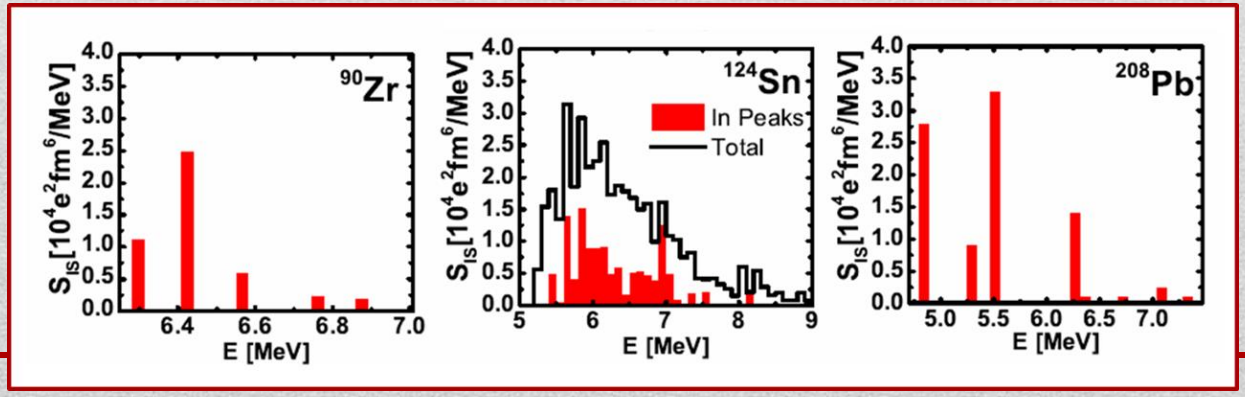
** photon scattering experiments:
N. Ryezayeva
et. al PRL89(2002)272502,
T. Shizuma et al. PRC78(2008)061303

# 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




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

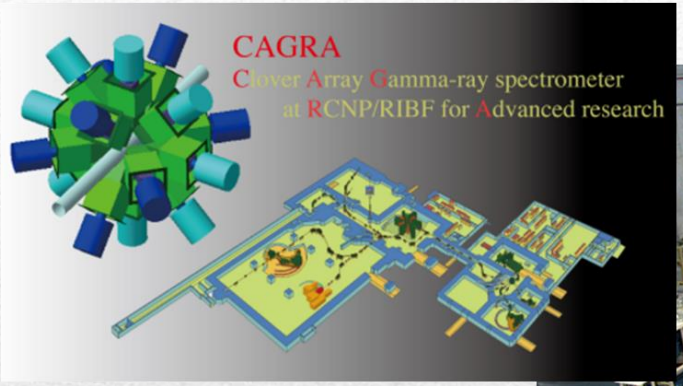



F.C.L. Crespi, et al., PRL113 (2014) 012501
L. Pellegri, et al., PLB738 (2014)519

F.C.L. Crespi et al, PRC 91 (2015) 024323
A. Bracco, F.C.L. Crespi and E.G. Lanza, EPJA(2015)51:99

# Experimental campaign at RCNP Osaka (October-December 2016)

- *Study of the Structure of the Pygmy Dipole Resonance States via the (p, p' γ) and (α,α'γ) Reactions in [in $^{90,94}$**Zr**] $E_{proton}$ = 80 MeV, $E_{alpha}$=130MeV*
- *- Spokespersons A. Bracco, F. Crespi and N. Pietralla*

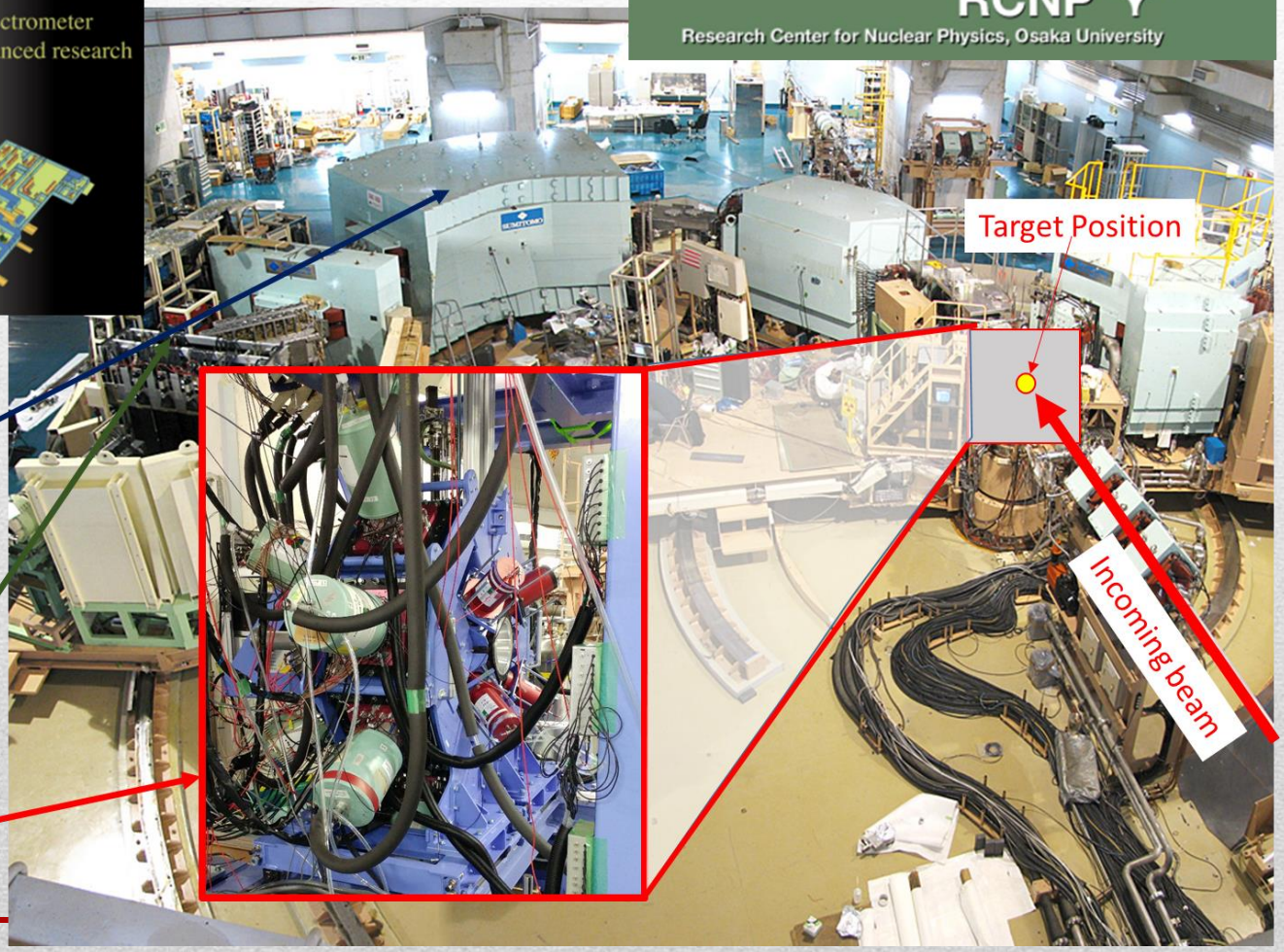



RCNP
Research Center for Nuclear Physics, Osaka University

**Grand Raiden Spectrometer**
**Resolution: 37,000**
**Momentum Byte: 1.05**
**Acceptance: 5.6 msr**

**Focal Plane Detector**
**2 VDC Systems**
**2 Trigger Scintillators**

**Gamma Detection System**
**CAGRA**
- **12 CLOVERS**
- **4 LaBr3:Ce 3,5"x8"**

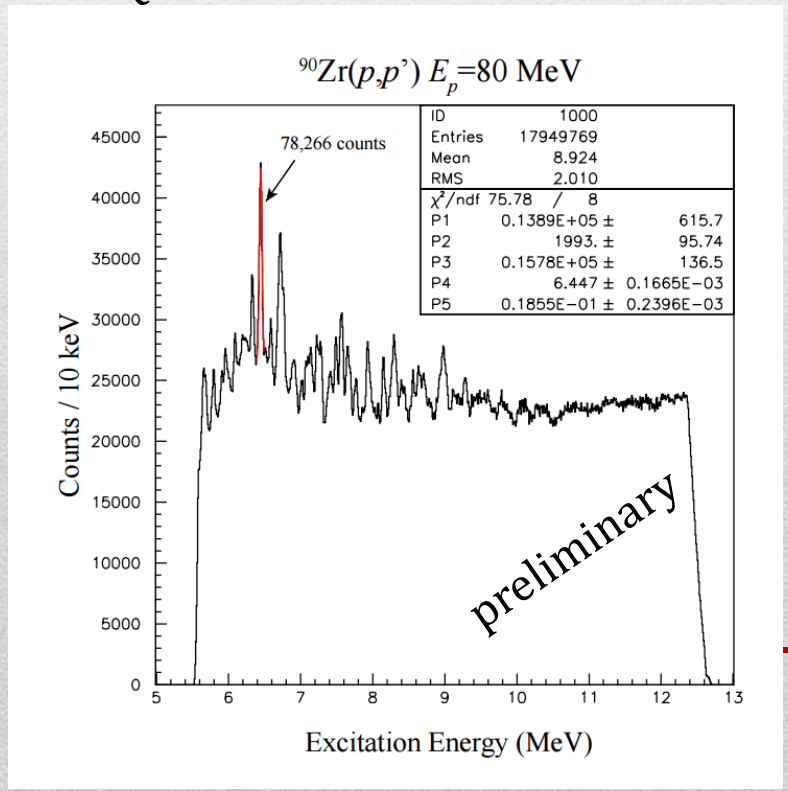


# Experimental campaign at RCNP Osaka (october-December 2016)

- *Study of the Structure of the Pygmy Dipole Resonance States via the (p, p' γ) and (α,α'γ) Reactions in [in $^{90,94}$**Zr**] $E_{proton}$ = 80 MeV, $E_{alpha}$=130MeV*
- *- Spokespersons A. Bracco, F. Crespi and N. Pietralla*

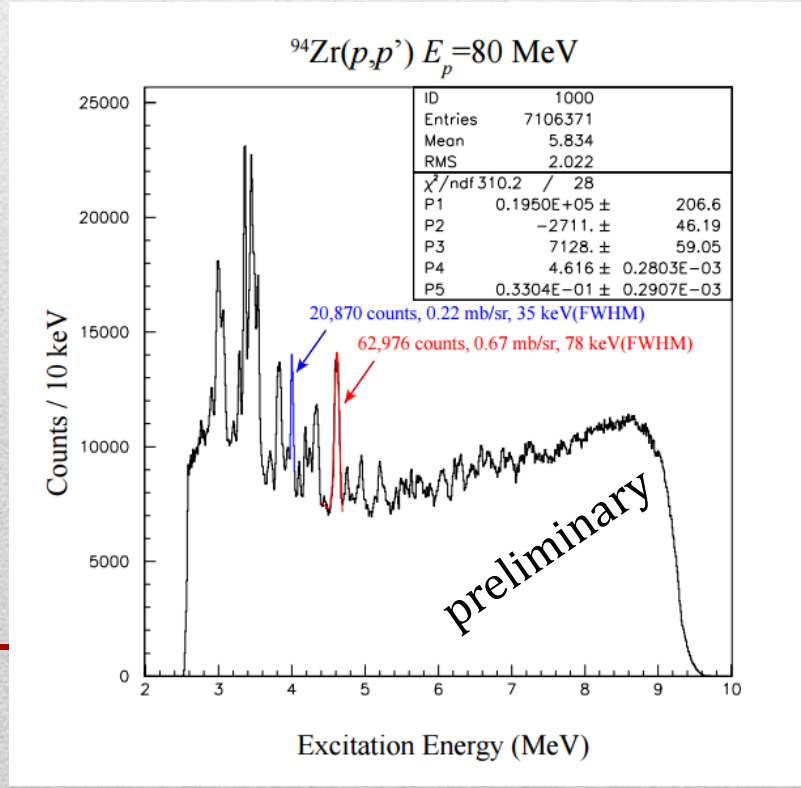
## $^{94}$Zr(p,p')

- Grand Raiden 6.63 deg
- Target thickness: 4.0 mg/cm2
- Solid angle: ~4 msr
- Energy resolution: 44 keV
- DAQ Live: 99%



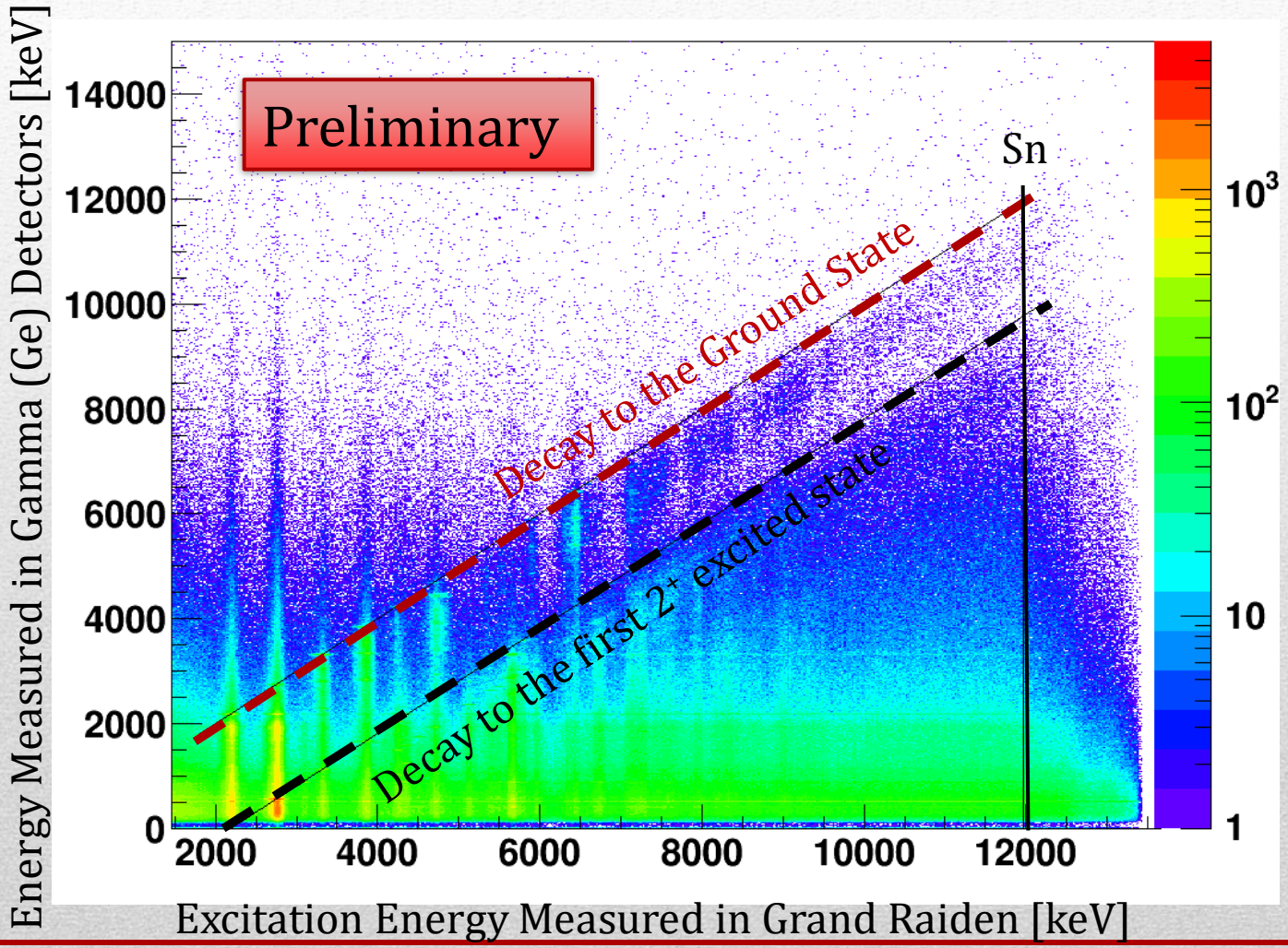

## $^{90}$Zr(p,p')

- Grand Raiden 6.63 deg
- Target thickness: 1.95 mg/cm2
- Solid angle: ~4 msr
- Energy resolution: 44 keV
- DAQ Live: 98%

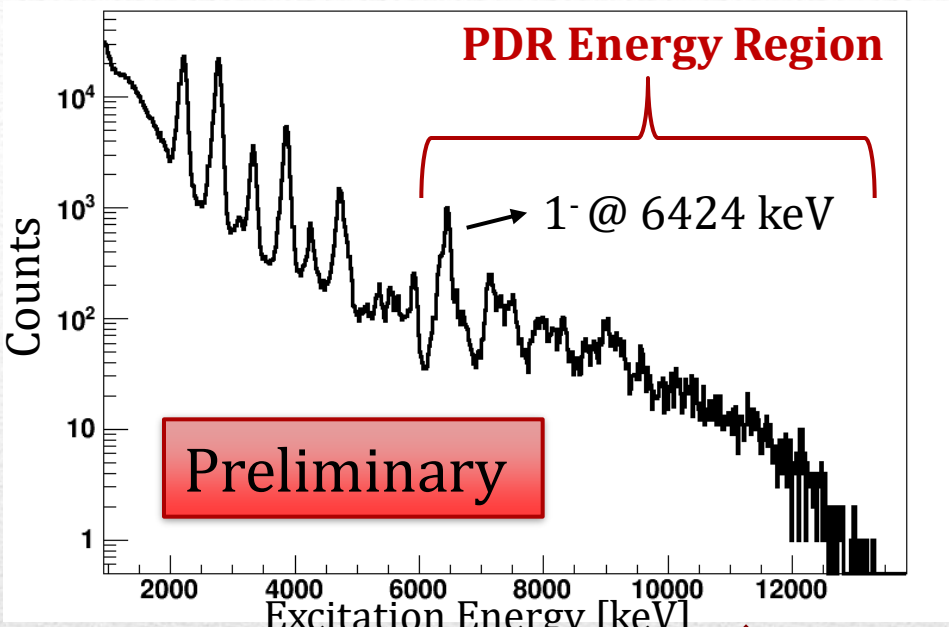


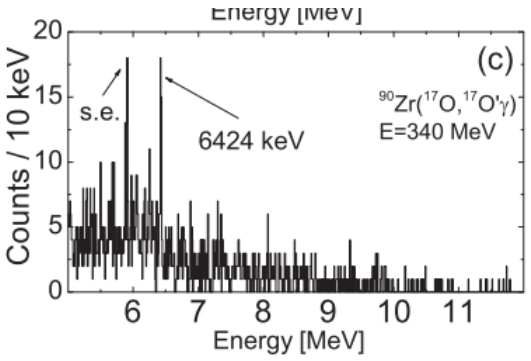
# $(\alpha,\alpha'\gamma)$ Reaction in $^{90}$Zr, $E_{alpha}$=130MeV

- light-ion inelastic scattering with the high-resolution spectrometer Grand-Raiden in coincidence with gamma-ray detection

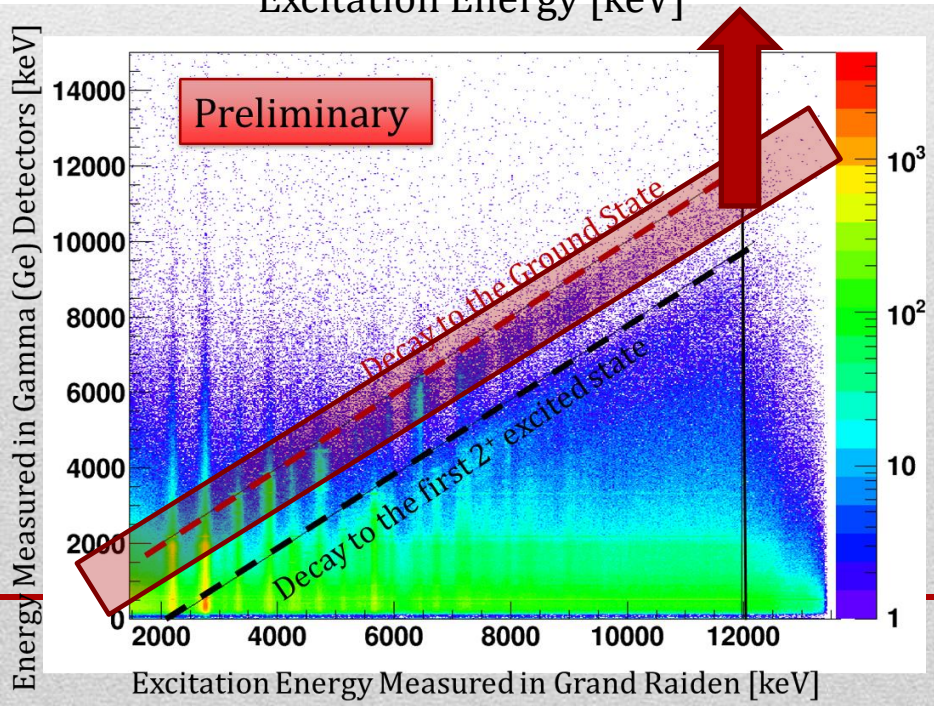


# $(\alpha,\alpha'\gamma)$ Reaction in $^{90}$Zr, $E_{alpha}$=130MeV



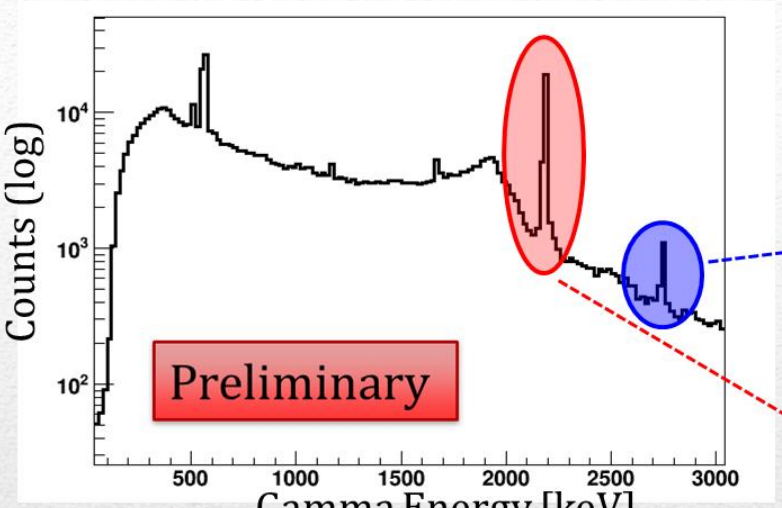



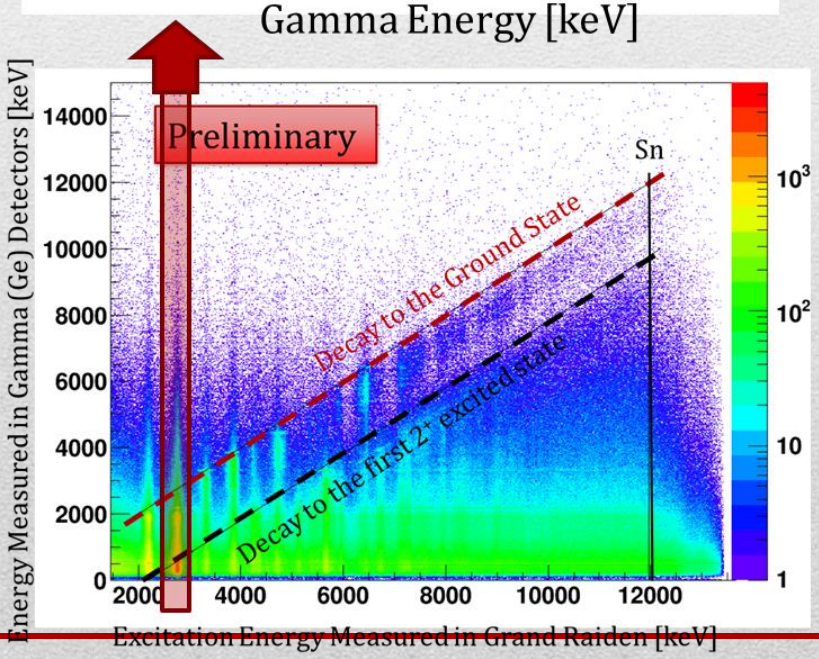

F.C.L. Crespi et al.
Phys. Rev. C 91, 024323 (2015)

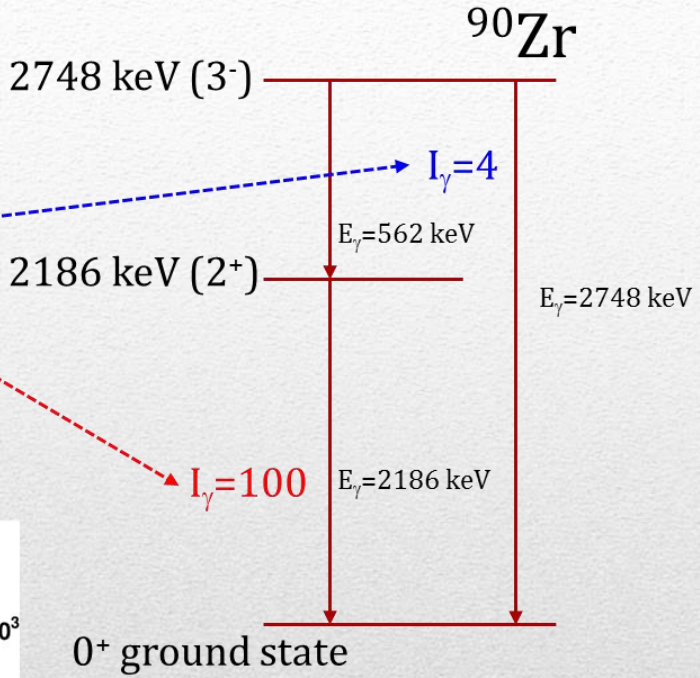


# $(\alpha,\alpha'\gamma)$ Reaction in $^{90}$Zr, $E_{alpha}$=130MeV

- Branching Ratio




*$E_\gamma$ and $I_\gamma$ values from: https://www.nndc.bnl.gov

# Conclusions and Future Work

- **Isospin Properties of pygmy dipole states investigated using the ($^{17}O$, $^{17}O'\gamma$) reaction at 340 MeV**

For $1^-$ transitions a form factor obtained by folding a microscopically calculated transition density (PDR) allowed to reproduce the data remarkably well

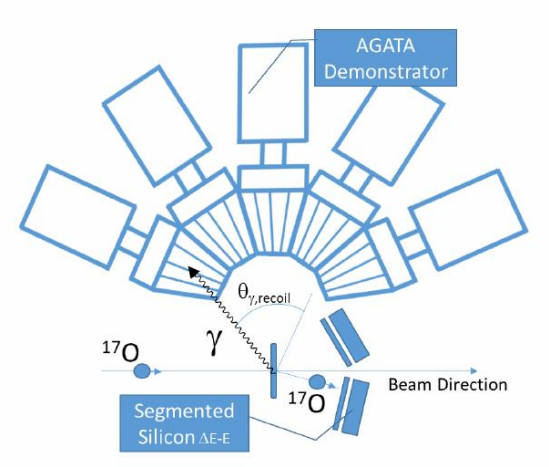
  - *Extracted the isoscalar component of the $1^-$ excited states*

- **Preliminary results from light-ion inelastic scattering experiments at RCNP**
  - Population of the PDR states
  - Analysis still in preliminary phase (Ge and LaBr data for all the runs, background subtraction, add-back for Ge,…)

# Collaborations

**Experiments performed with AGATA at LNL-INFN**

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





**F.C.L. Crespi, A. Bracco,** G. Benzoni, N. Blasi, C. Boiano, S. Brambilla, F. Camera, A. Giaz, S. Leoni, B. Million, A. Morales, R. Nicolini, **L. Pellegri**, S. Riboldi, V. Vandone, O. Wieland
*Università degli Studi e INFN Sezione di Milano, Via Celoria 16, 20133, Milano*

M. Kmiecik, A. Maj, P. Bednarczyk, M. Ciemala, B. Fornal, J. Grębosz, **M. Krzysiek**, K. Mazurek, W. Męczyński, M. Zięblińśki
*The Niewodniczanski Institute of Nuclear Physics, Polish Academy of Sciences, Krakow, Poland*

**E.G. Lanza**
*INFN Sezione di Catania*

G. De Angelis, D. R. Napoli, J.J. Valiente-Dobon
*INFN, Laboratori Nazionali di Legnaro, Legnaro, Italy*

D. Bazzacco, E. Farnea, A. Gottardo, S. Lenzi, S. Lunardi, D. Mengoni, C. Michelagnoli, F. Recchia, C. Ur
*Università di Padova e INFN, sezione di Padova, Padova, Italy*

A. Gadea, T. Huyuk, D. Barrientos
*IFIC, Valencia, Spain*

B. Birkenbach, K. Geibel, H. Hess, P. Reiter , T. Steinbach, A. Wiens
*Institut fur Kernphysik der Universitat zu Koln, Germany*

A.Bürger, A. Görgen, M. Guttormsen, A.C. Larsen, S. Siem
*Department of Physics, University of Oslo, Norway*


## Experiments at RCNP (Osaka) – CAGRA Collaboration