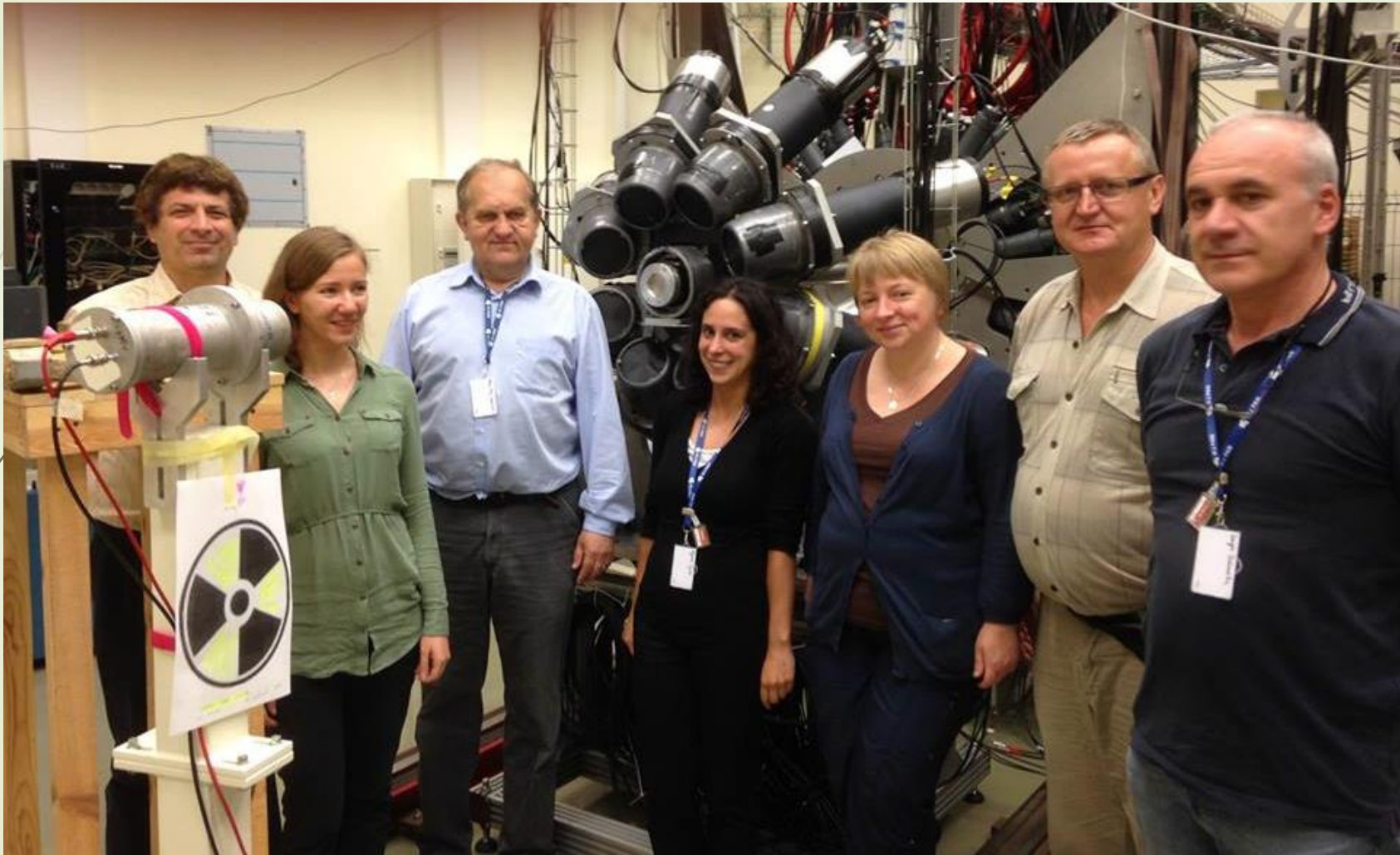




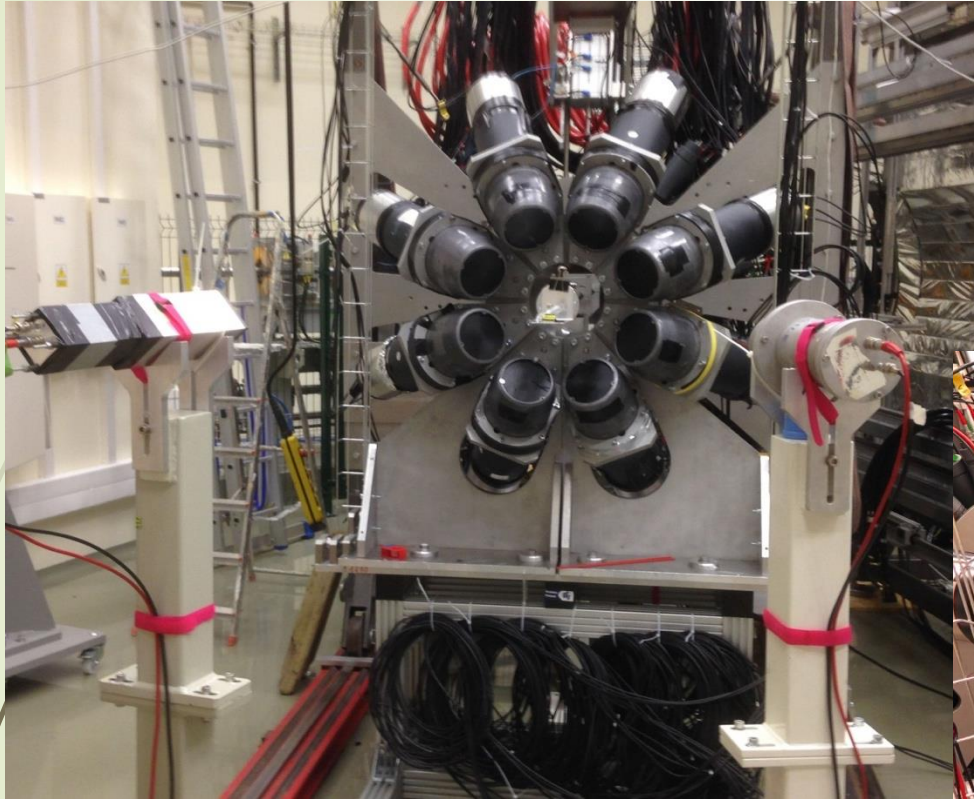
Studying Giant and Pygmy Resonances at CCB IFJ PAN within Milano-Kraków Collaboration

Maria Kmiecik IFJ PAN Kraków

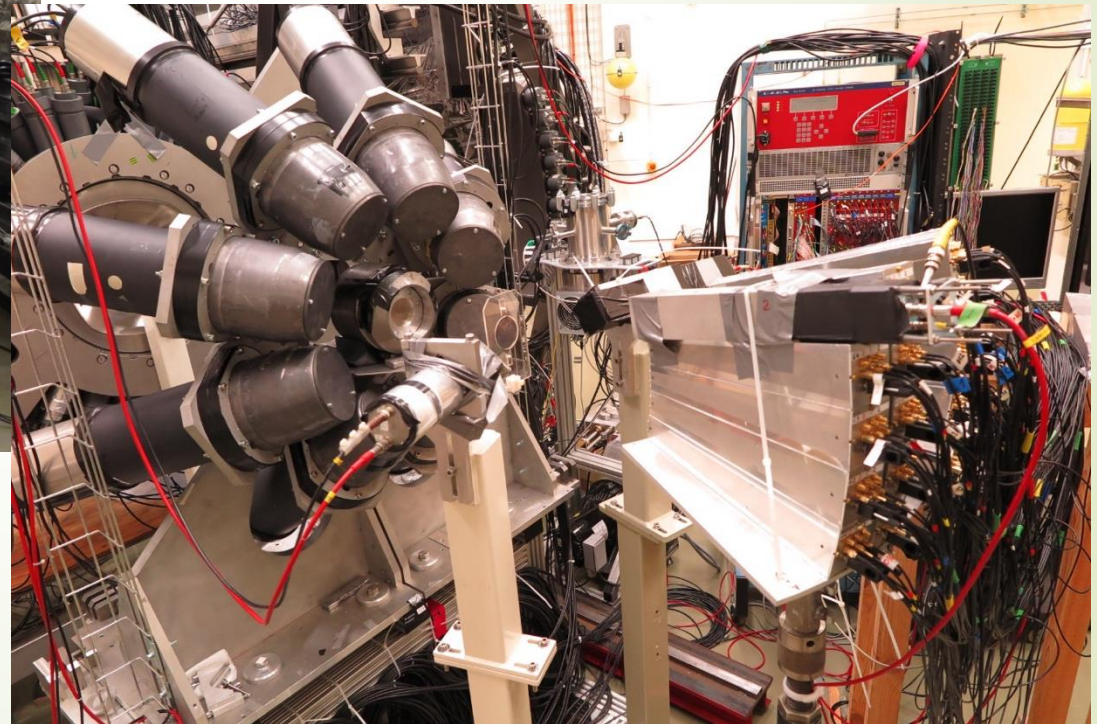
Milano - Kraków collaboration



HECTOR at CCB IFJ PAN



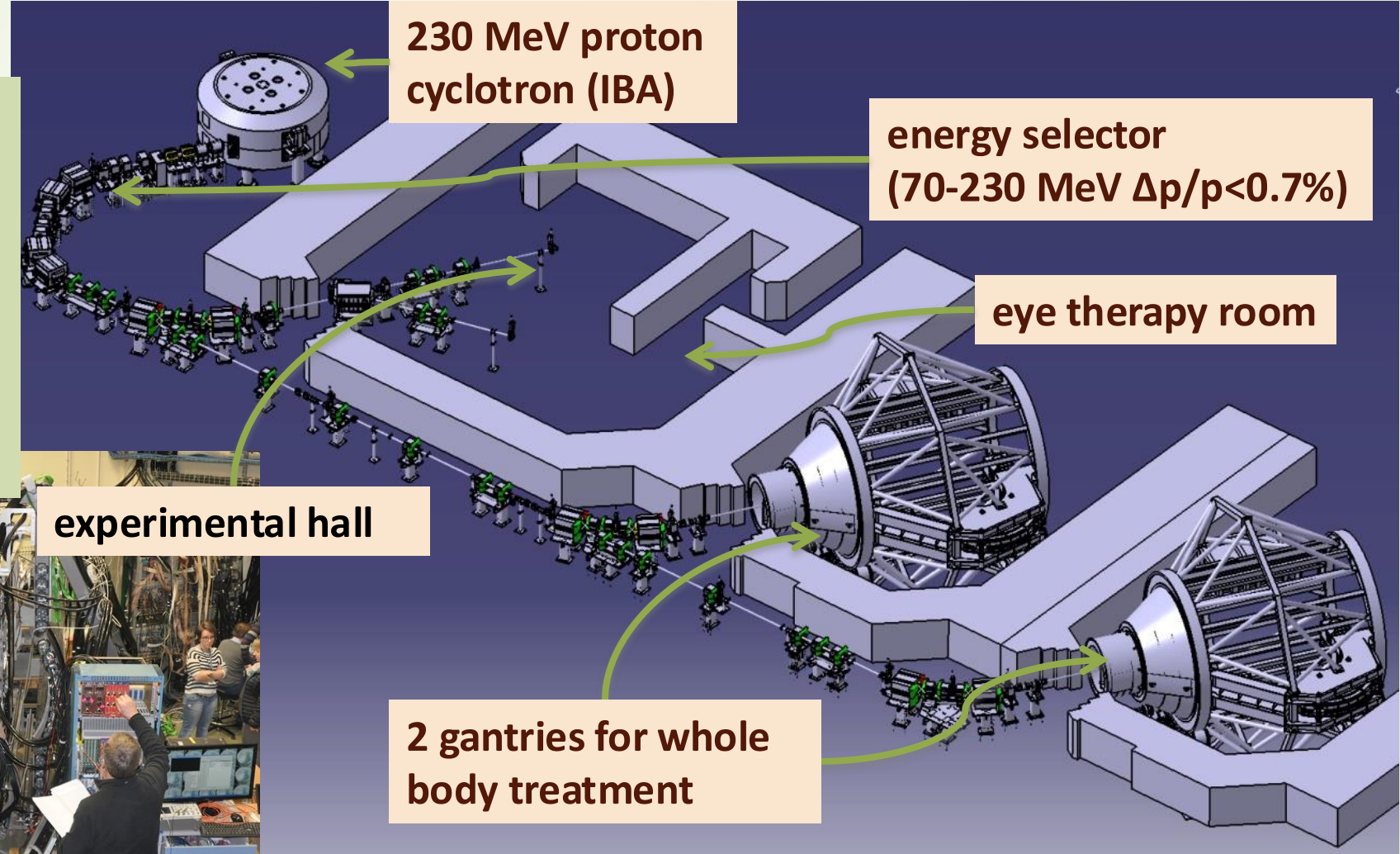
- ▶ HECTOR transported to IFJ and installed in CCB experimental hall - 2014



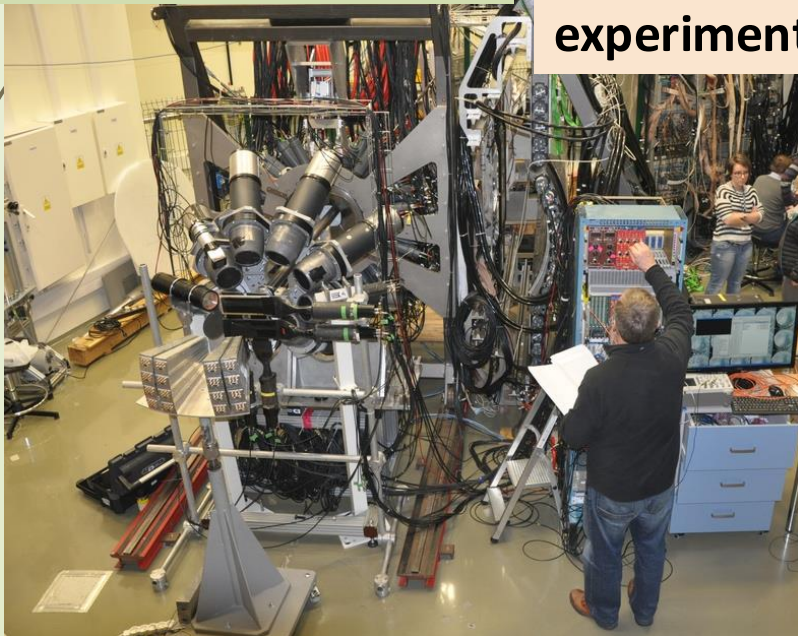
Cyclotron Center Bronowice (CCB) of IFJ PAN

proton cancer therapy and additionally research program on:

- nuclear physics,
- radiobiology
- dosimetry
- medical physics



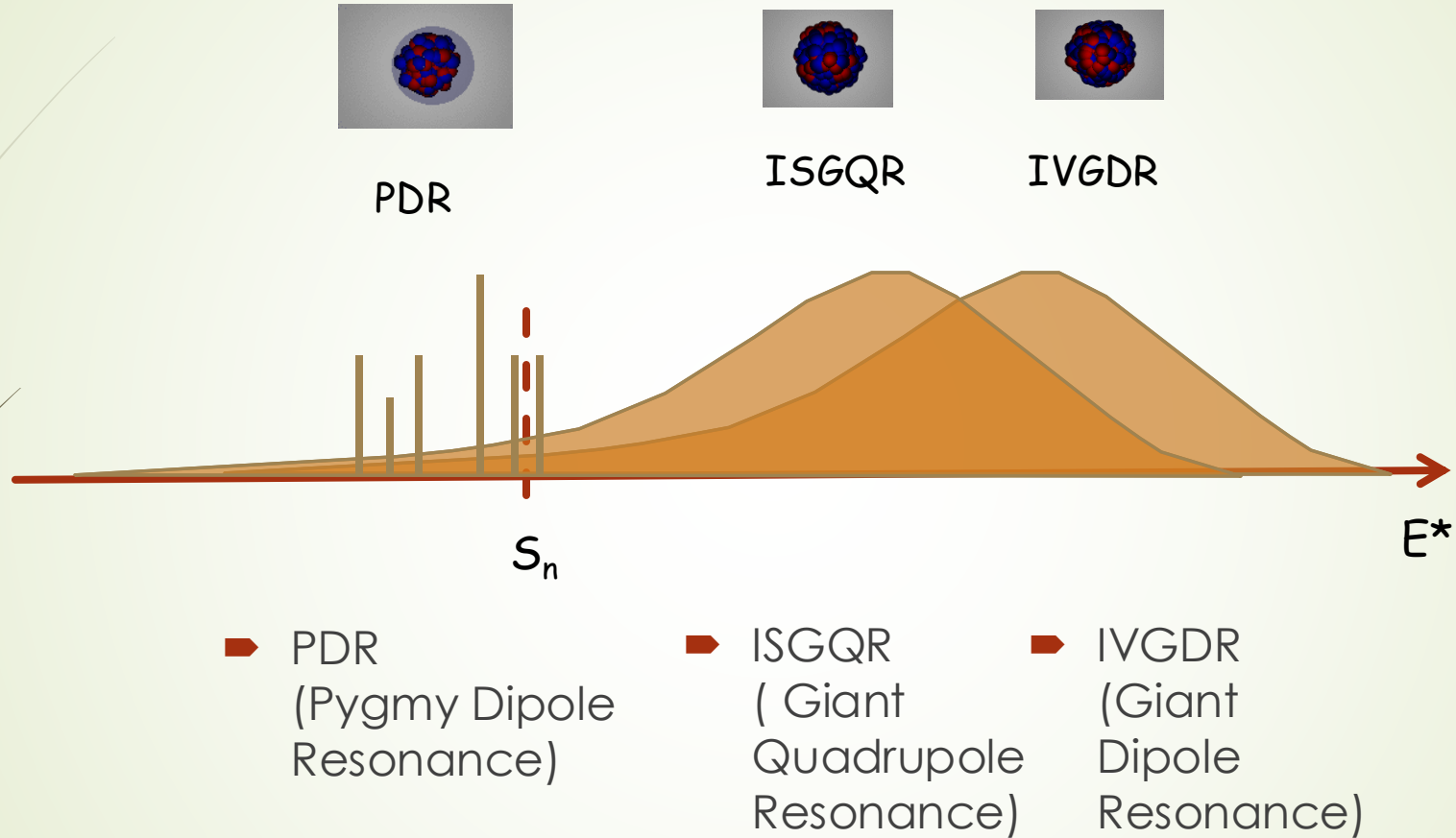
experimental hall



rest after work



Idea of the experiment



main aim of the $(p, p'\gamma)$ measurement at CCB – γ decay of Giant and Pygmy Resonances

First proposal

Proposal for CCB experiments

The gamma decay from high-lying states and giant resonances excited via $(p, p'\gamma)$ at beam 70-200 MeV

F. Crespi¹, M. Kmiecik²,

A. Bracco¹, F. Camera¹, S. Leoni¹, G. Benzoni¹, S. Brambilla¹, A. Giaz¹, L. Pellegrini¹, O. Wieland¹ et al.,

A. Maj², B. Wasilewska², P. Bednarczyk², B. Fornal², M. Krzysiek², N. Cieplicka², K. Mazurek², M. Ziębliński², J. Grębosz², M. Jastrząb², J. Łukasik², P. Pawłowski² et al.

¹University of Milano and INFN

²Institute of Nuclear Physics, Polish Academy of Sciences, Kraków

The gamma decay from high-lying states and giant resonances excited in ²⁰⁸Pb and ⁹⁰Zr via $(p, p'\gamma)$ reaction at 140 MeV bombarding energy

F.C.L. Crespi¹, M. Kmiecik²,

A. Bracco¹, F. Camera¹, S. Leoni¹, G. Benzoni¹, S. Brambilla¹, A. Giaz¹, A. Mentana¹, S. Brambilla¹, O. Wieland¹ et al.,

A. Maj², B. Wasilewska², M. Ciemała², M. Ziębliński², B. Sowicki², J. Łukasik², P. Pawłowski², M. Krzysiek², B. Fornal² et al.
A. Krasznahorkay³, A. Tamii⁴, P. Napiórkowski⁵ et al.

¹Università degli Studi di Milano and INFN, Milano, Italy

²Institute of Nuclear Physics Polish Academy of Sciences, Kraków, Poland

³ATOMKI, Debrecen, Hungary

⁴RCNP, Osaka, Japan

⁵SLCJ Warszawa, Poland

CCB IAC Meeting, Krakow, August 29, 2014

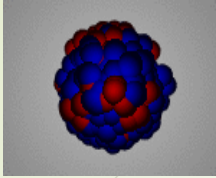
- We propose to continue the study of the gamma decay from high-lying states excited via proton inelastic scattering, using the proton beam at CCB of IFJ PAN in Krakow. The **main goal is to study the gamma decay from excited states and giant resonances (mainly the giant quadrupole resonance, GQR)**

akow, August 26-27, 2016

Fabio Crespi

1/13

GQR γ -decay



GQR γ -decay observed previously only once, in 1980s
difficult to measure – very small probability $\sim 10^{-4}$

J.Beene et al., PRC39(1989)1307

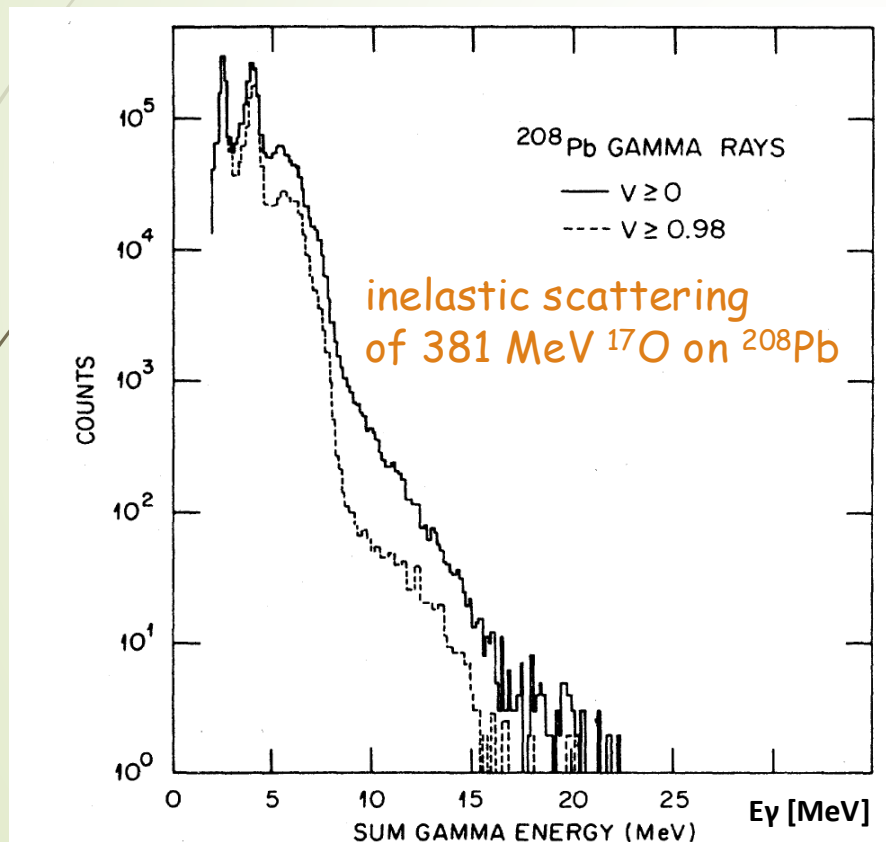


FIG. 5. Gamma-ray spectra from ^{208}Pb for $V \geq 0.98$ (only ground-state gamma rays), and $V \geq 0$ (all gamma rays).

**Proposed to study GQR γ -decay using
inelastic scattering of protons @ 85 MeV
on ^{208}Pb target**

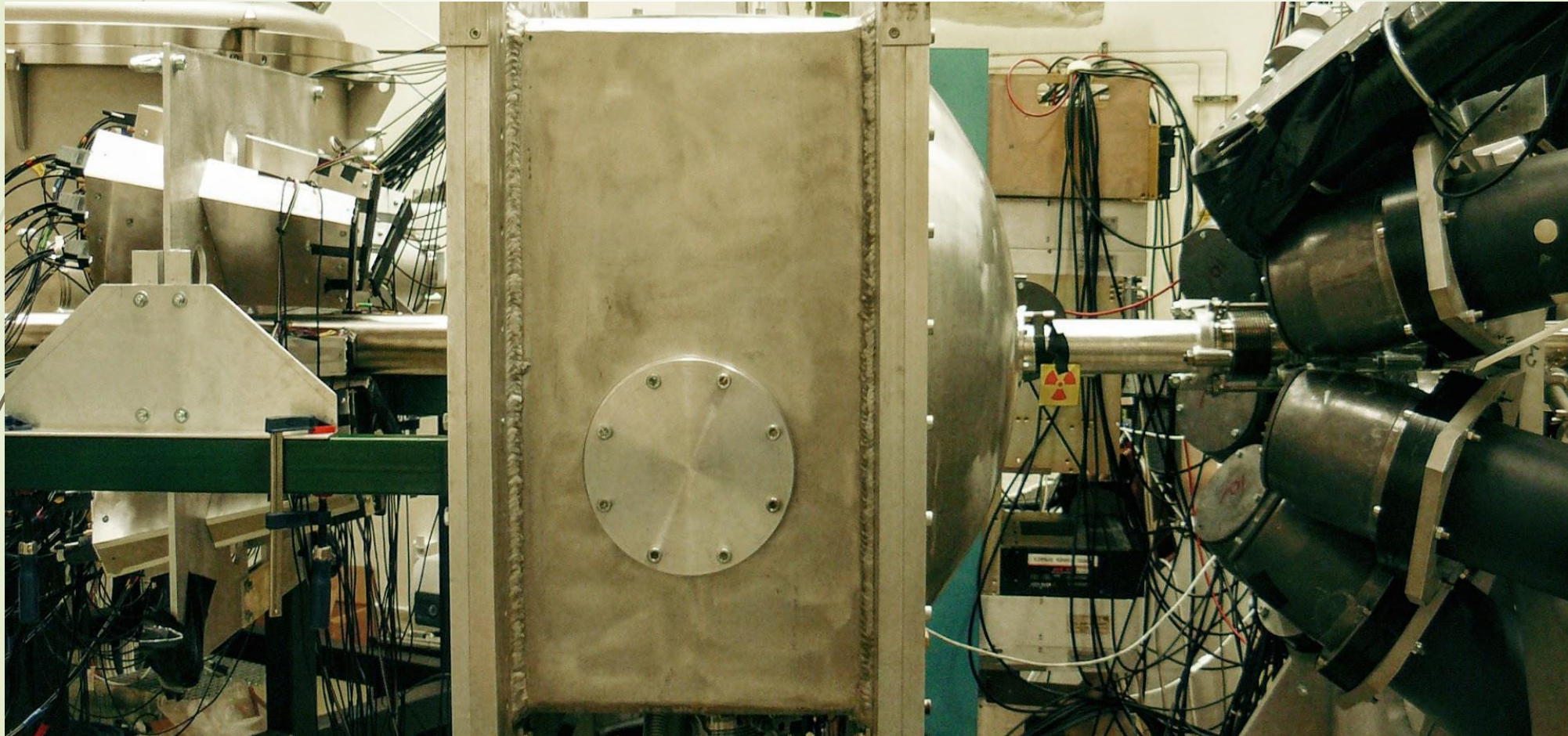
The experimental setup

coincidence measurement of gamma rays and scattered protons

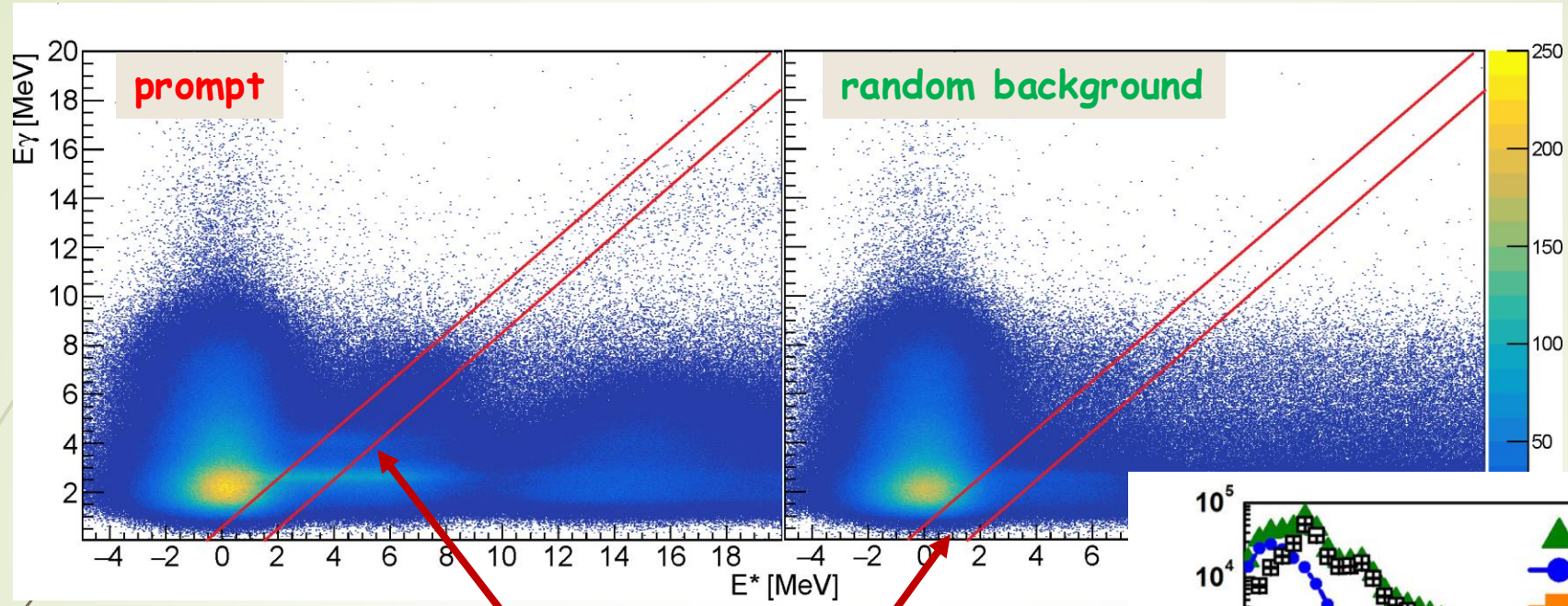
➤ KRATTA
(protons)

vacuum
scattering chamber

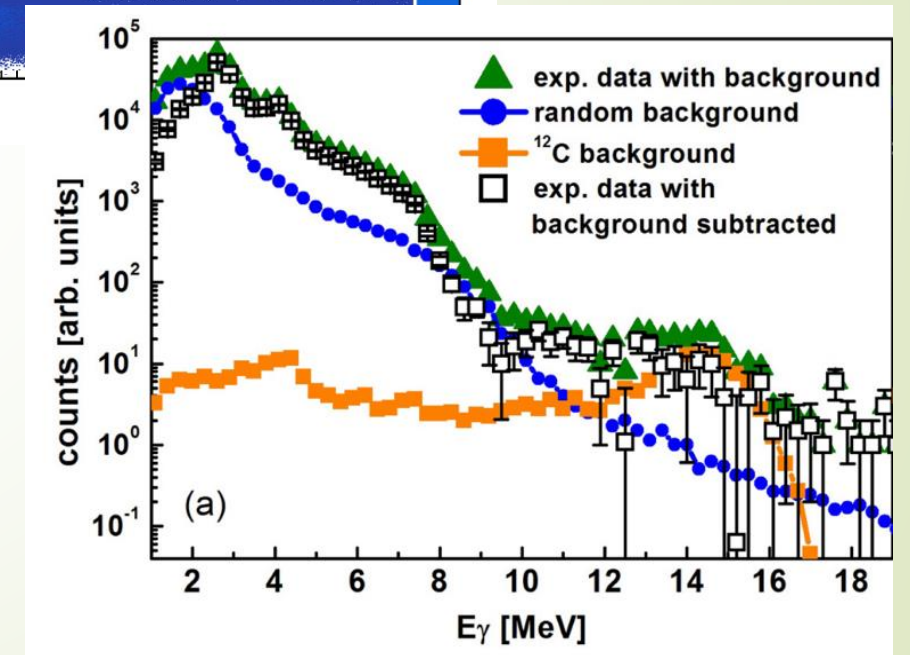
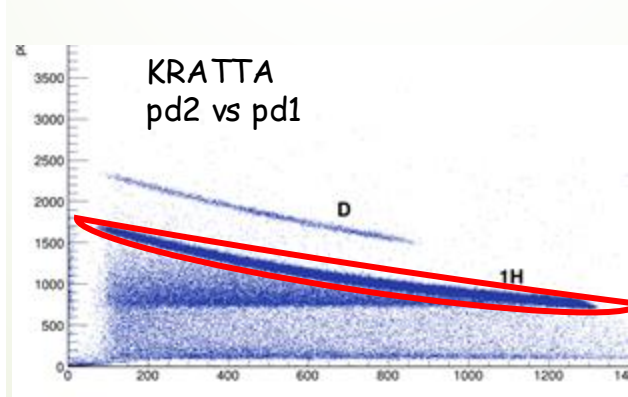
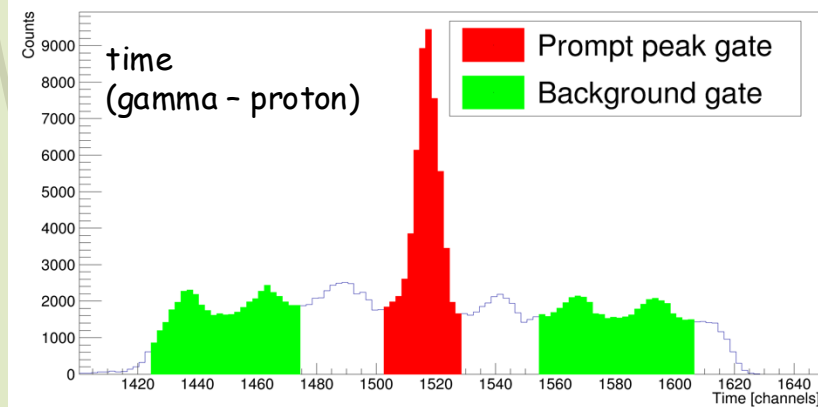
➤ HECTOR + LaBr3 +
PARIS (γ -rays)



The experimental method



decay to the ground state ($[E_\gamma + 0.5 - E^*] \leq 1 \text{ MeV}$)

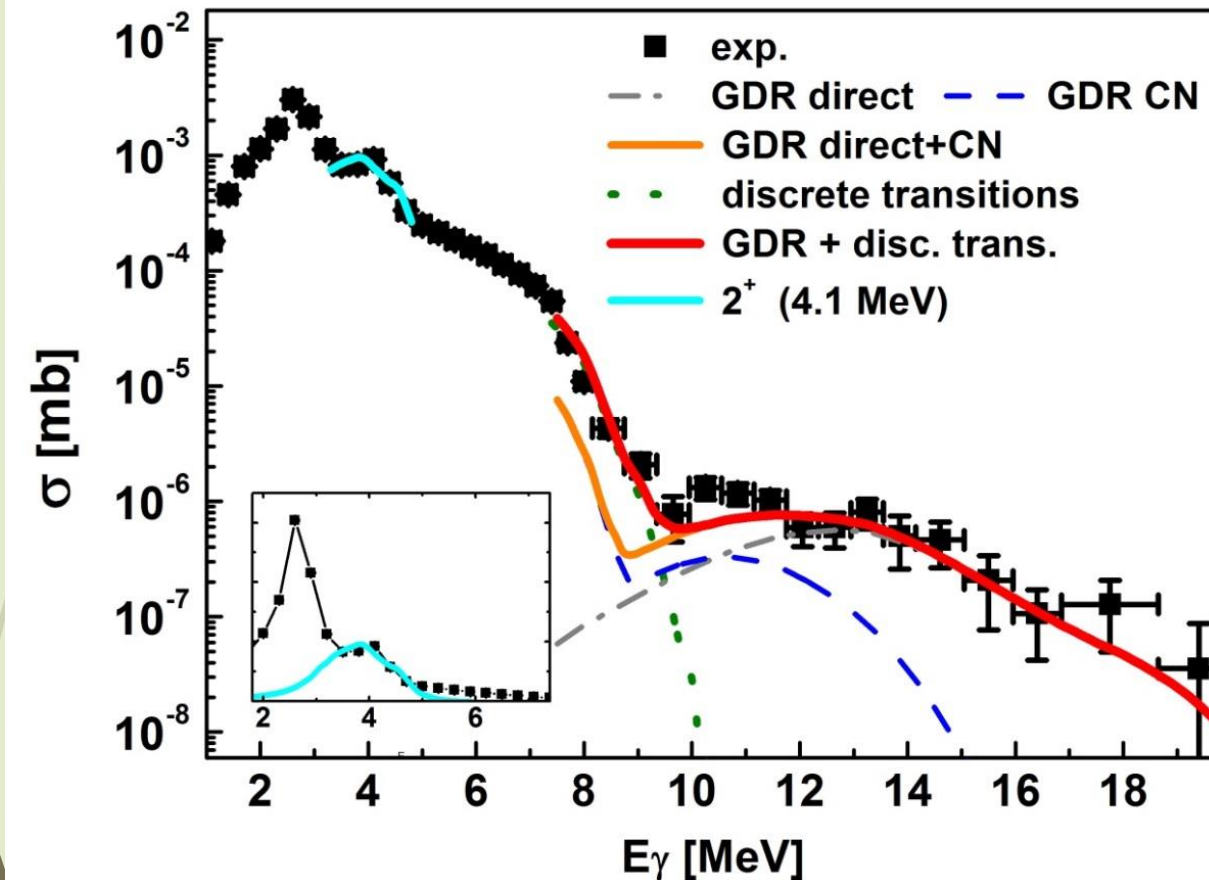


B. Wasilewska et al. PRC 105, 014310 (2022)

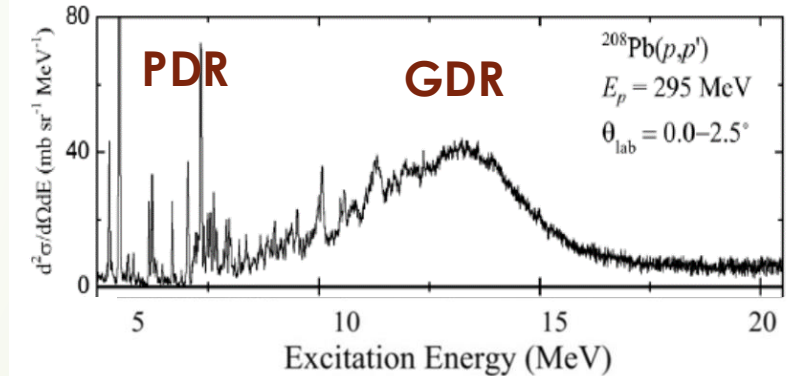
GDR part in ^{208}Pb analysis

$$\sigma_{p,p'\gamma_0}(E) = \sigma_{p,p'}(E; B(E1) = 1) b_{E1}(E) \left[\frac{\Gamma_{\gamma_0}}{\Gamma} + \frac{\Gamma_{\downarrow}}{\Gamma} B_{CN}(E) \right] = \sigma_{\text{direct}} + \sigma_{\text{CN}}$$

direct decay statistical (CN) decay



calculated for:
 $B(E1)$ for 111% EWSR;
 $E_{\text{GDR}} = 13.4 \text{ MeV}$;
 $\Gamma_{\text{GDR}} = 3.9 \text{ MeV}$



A. Tamii et al., Phys. Rev. Lett. 107, 062502 (2011)

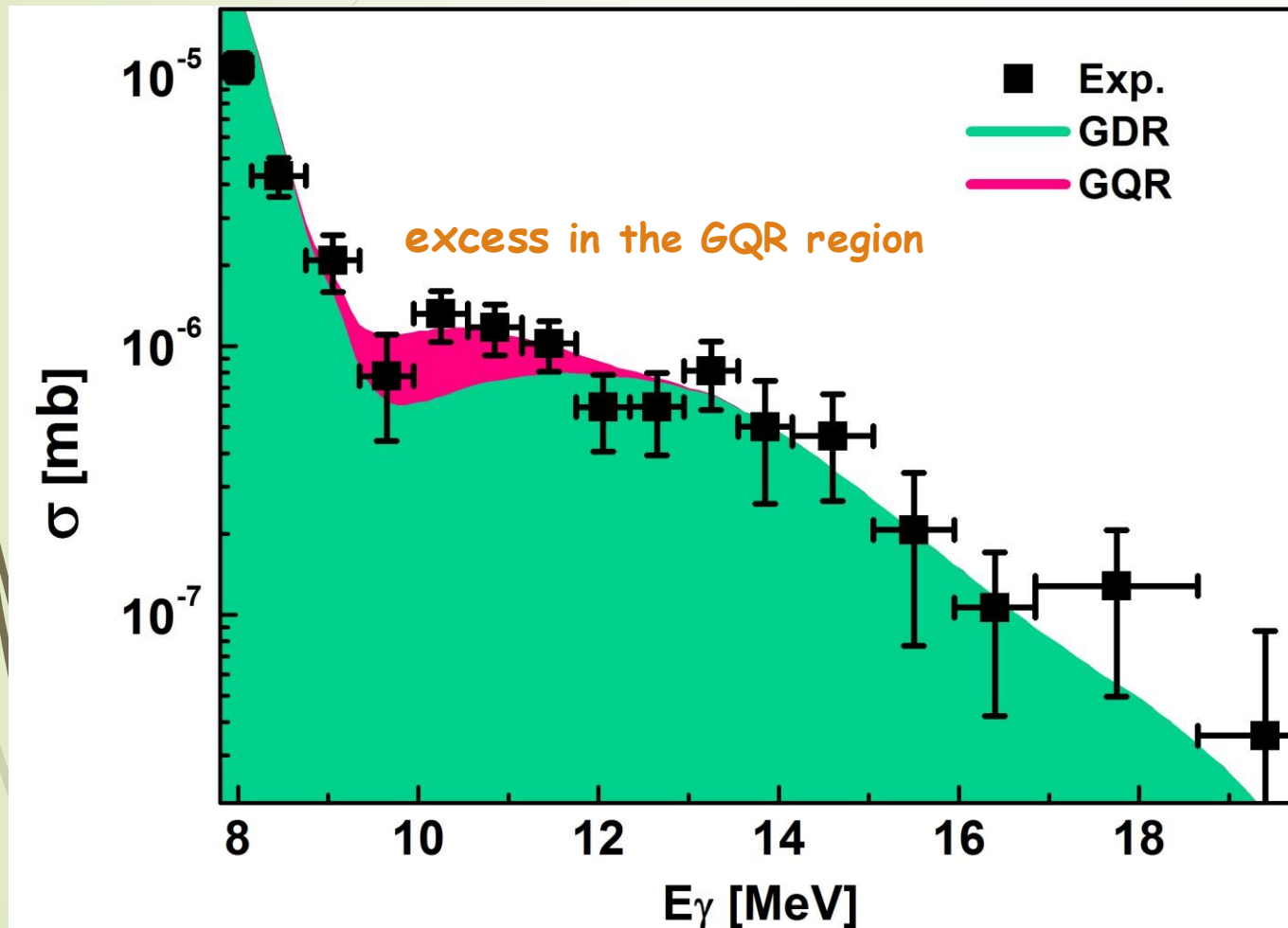
discrete transitions from region 6-9 MeV taken into account

$$\left(\frac{\Gamma_{\gamma_0}}{\Gamma} \right)_{\text{GDR}} = 1.7 \times 10^{-2} \pm 0.5 \times 10^{-2}$$

branching ratio for the GDR gamma decay to the ground state in agreement with published value

HECTOR γ -ray spectrum from 85MeV (p,p' γ)²⁰⁸Pb reaction

- measured in coincidence with scattered protons
- corresponds to the decay to the ground state

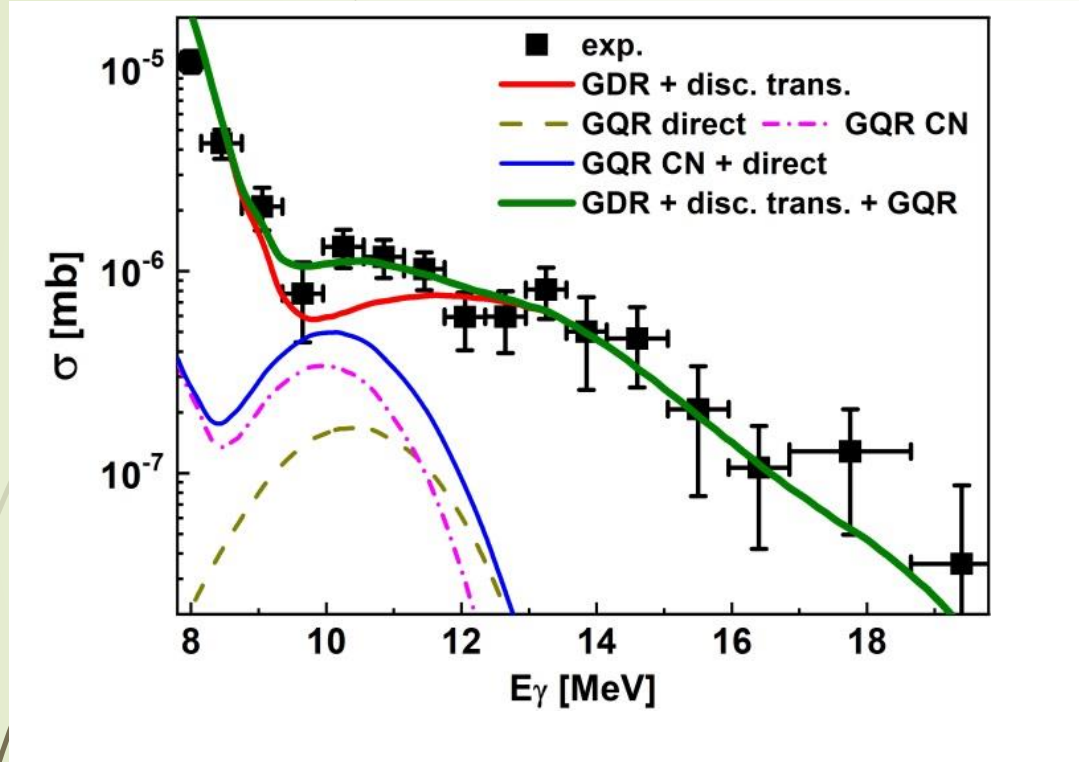


**Observation,
for the 2nd time, after 50 years,
of the gamma decay of the ISGQR**

The GQR γ -decay to g.s. in ^{208}Pb

85 MeV p inelastic scattering

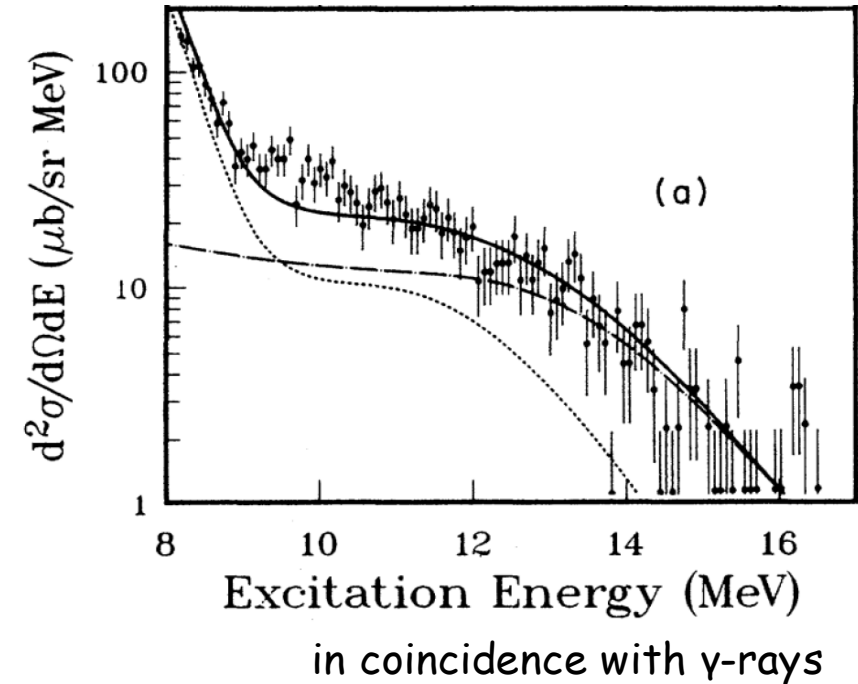
B.Wasilewska et al., PRC105(2022)014310



$$\left(\frac{\Gamma_{\gamma 0}}{\Gamma}\right)_{GQR} = 3 \times 10^{-4} \pm 1 \times 10^{-4}$$

381 MeV ^{17}O inelastic scattering

J.Beene et al., PRC39(1989)1307

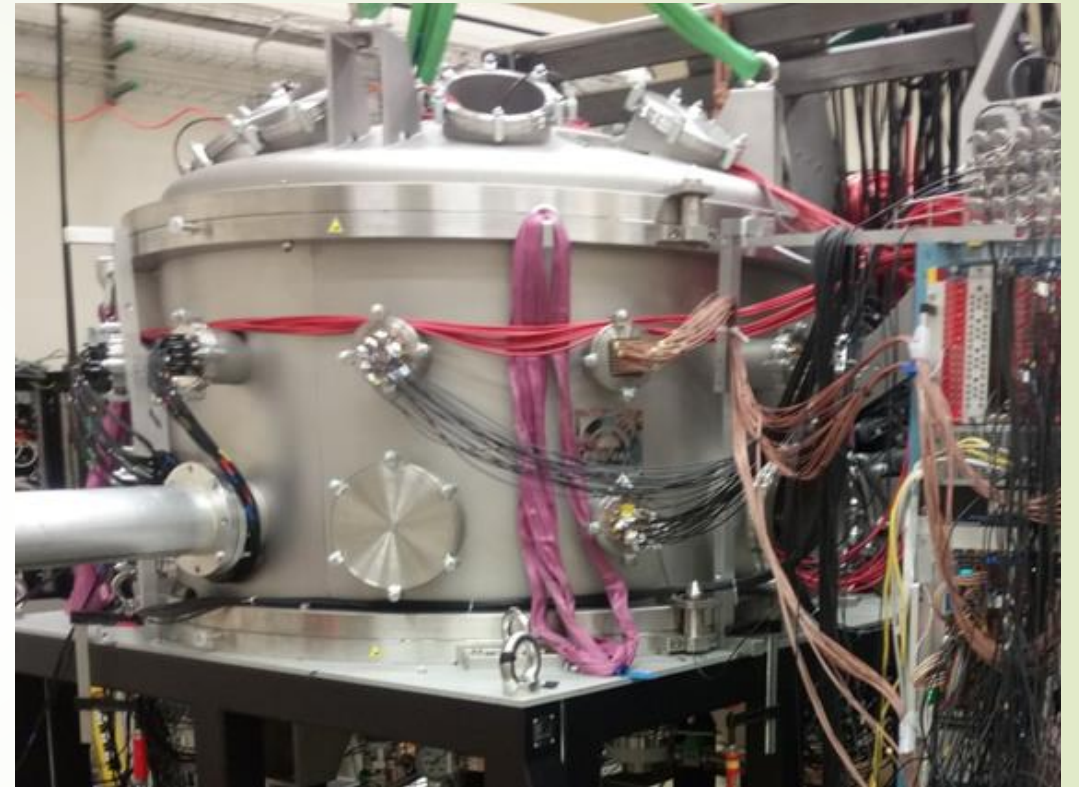
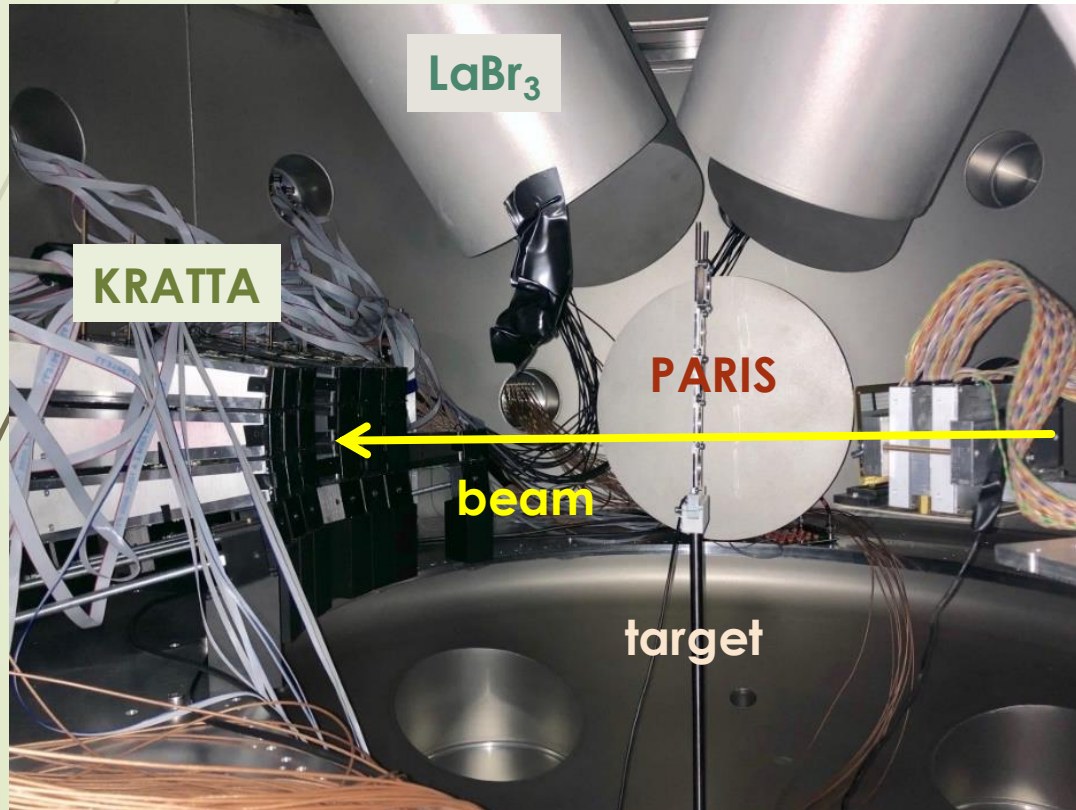


$$\left(\frac{\Gamma_{\gamma 0}}{\Gamma}\right)_{GQR} = 4 \times 10^{-4} \pm 1 \times 10^{-4}$$

Obtained branching ratio for the GQR gamma decay to the ground state - in agreement to previous value measured with heavy ions

New experimental setup based on big scattering chamber

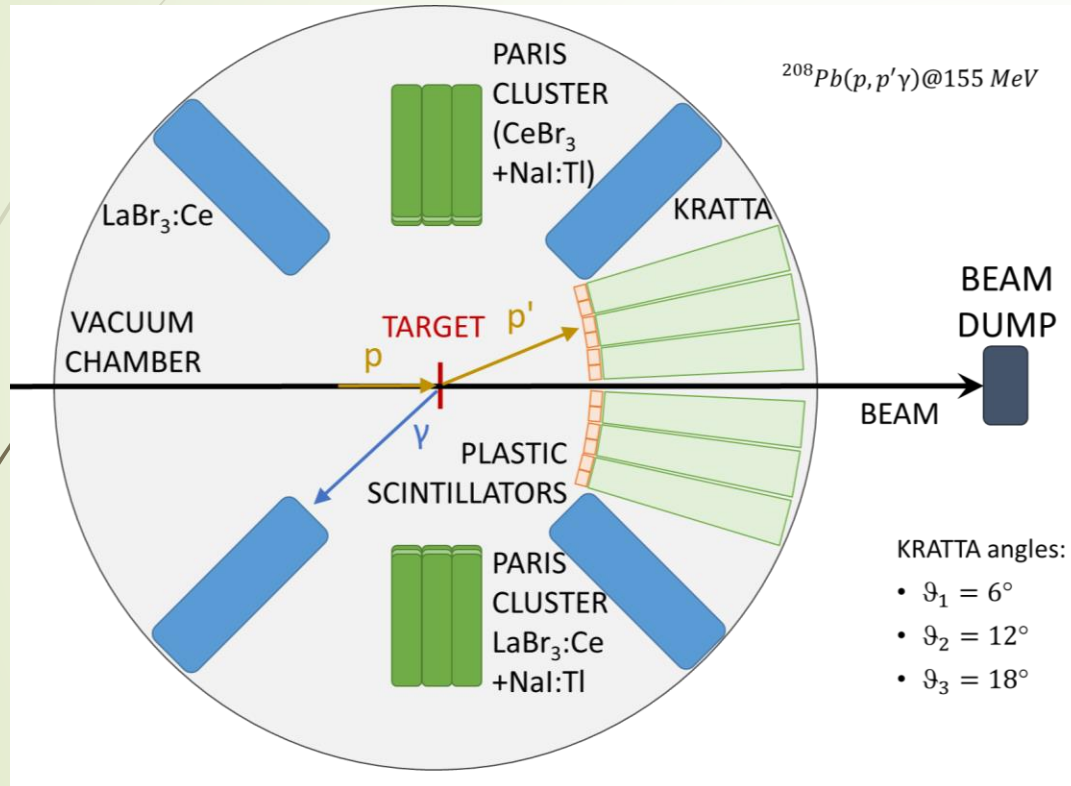
KRATTA inside the chamber – in the vacuum gamma detectors outside mounted using holders / cylindrical pockets



Next experiments with new setup

(p,p'γ) on ^{208}Pb @ ~155 MeV

(p,p'γ) on ^{120}Sn @ ~200 MeV

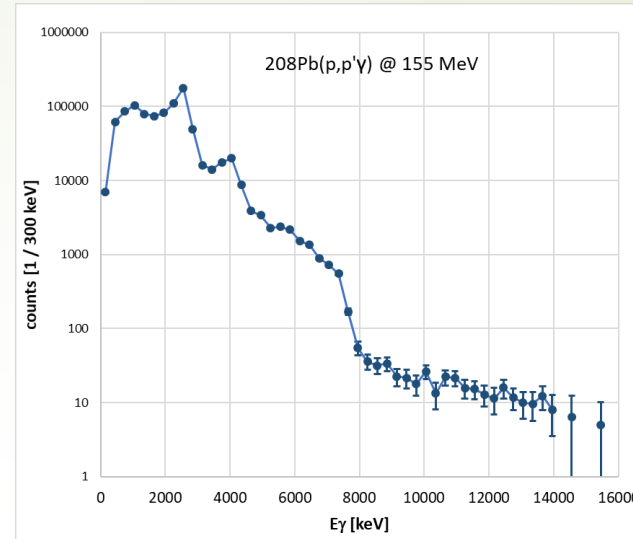
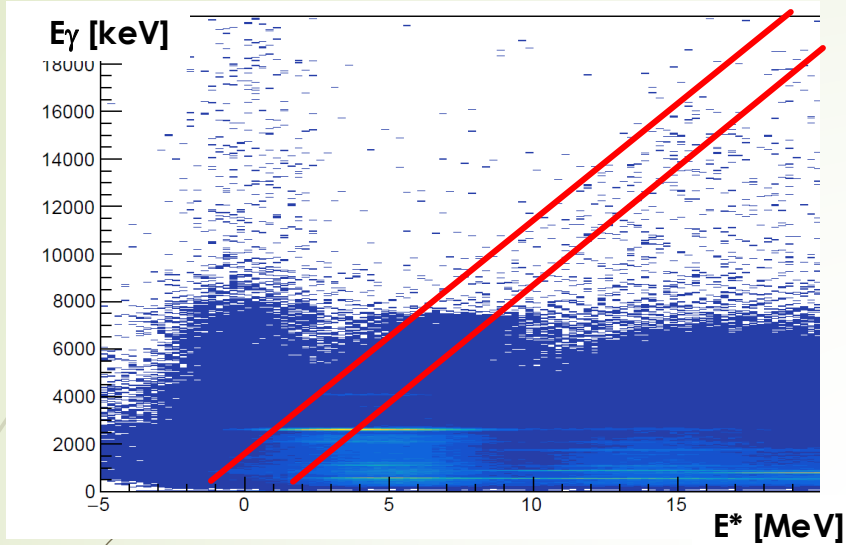


- better energy resolution
- higher beam energy – enhancement of GQR



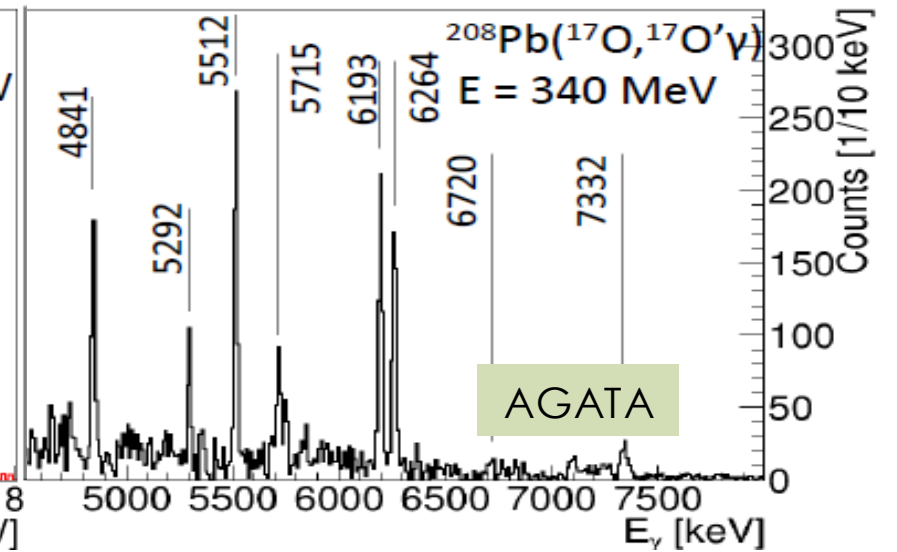
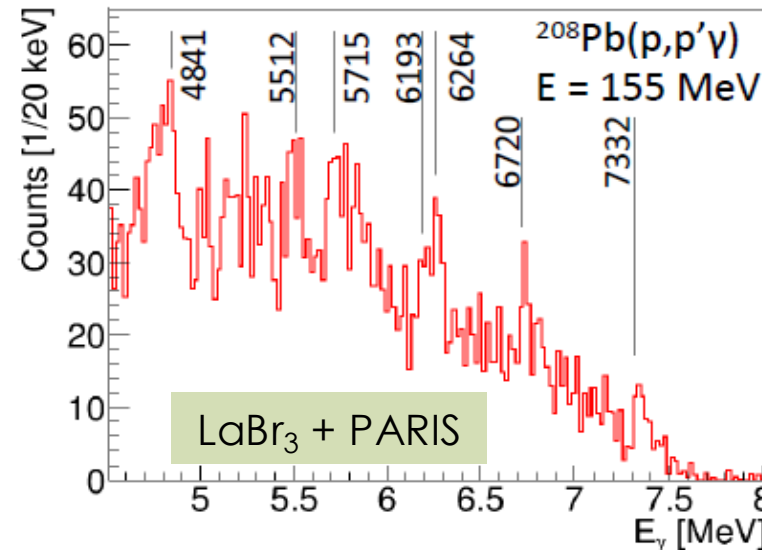
- 4 large volume LaBr₃ (3.5''x8'') at top
- 2 PARIS clusters: (9 LaBr₃+NaI and 9 CeBr₃+NaI) at 90°
- KRATTA angles from ~8° to ~24°

(p,p'γ) on ^{208}Pb @ ~155 MeV - first results



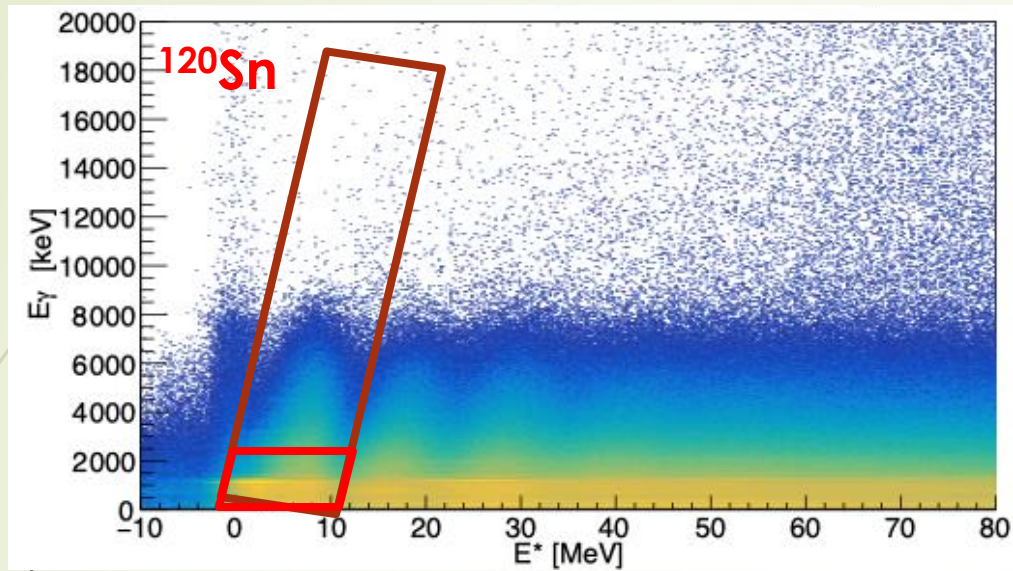
B. Wasilewska et al., Acta Phys. Pol. B (2020) 677

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

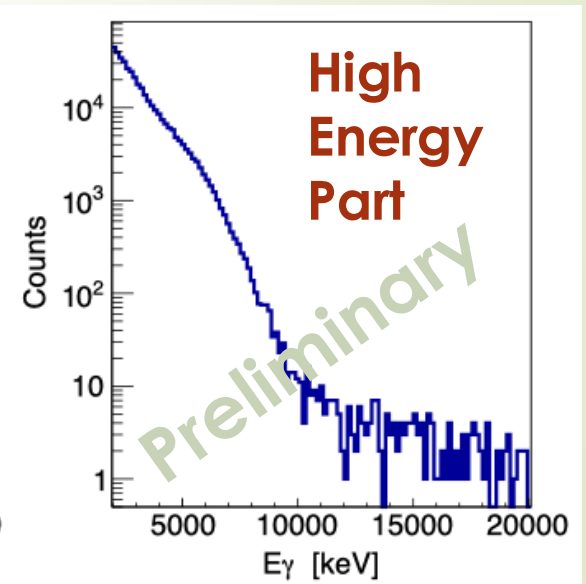
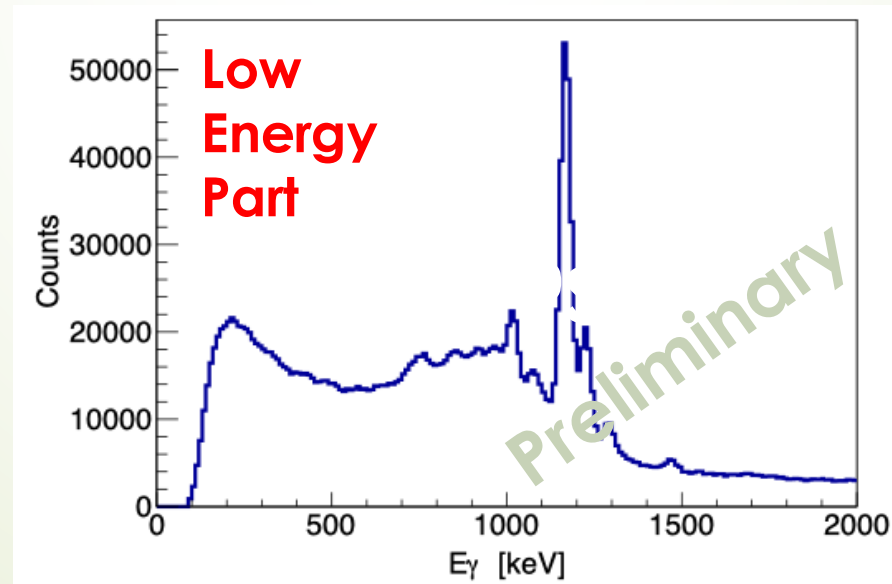


Thanks to better energy resolution more detailed study of pygmy region possible

(p,p'γ) on ^{120}Sn @ ~200 MeV

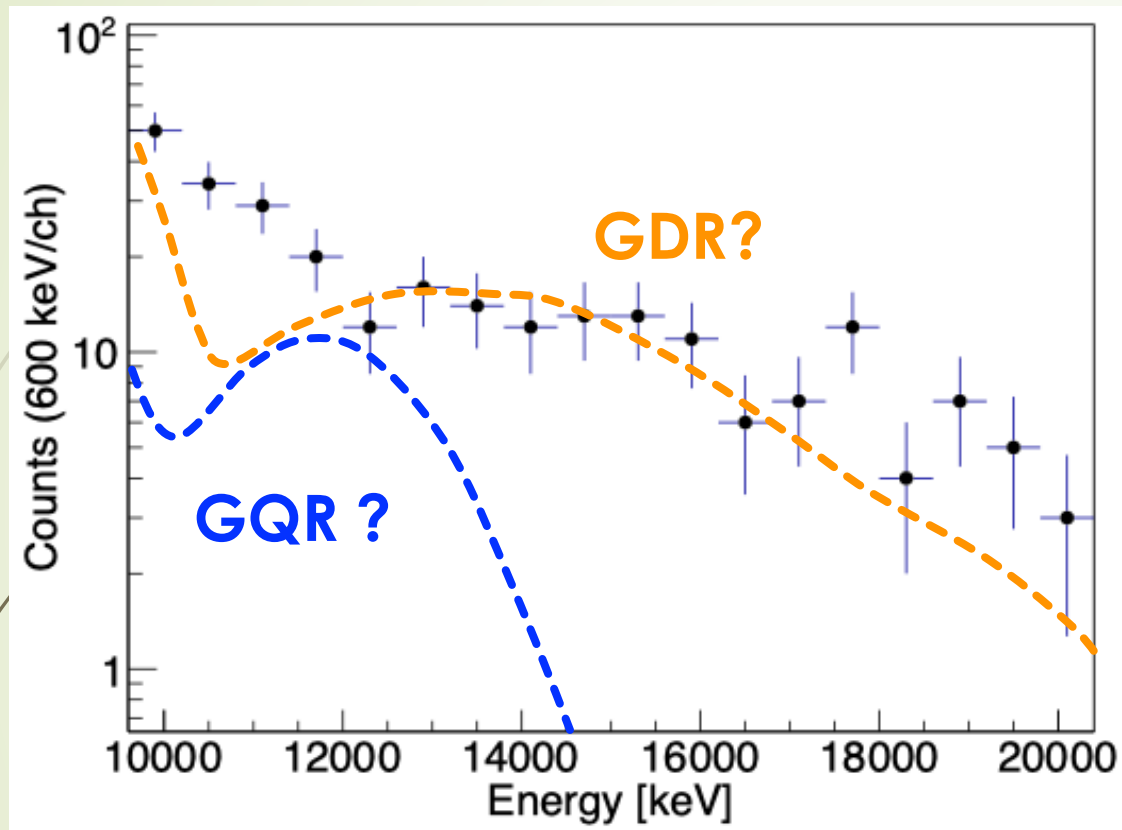


Courtesy: Agnese Giaz

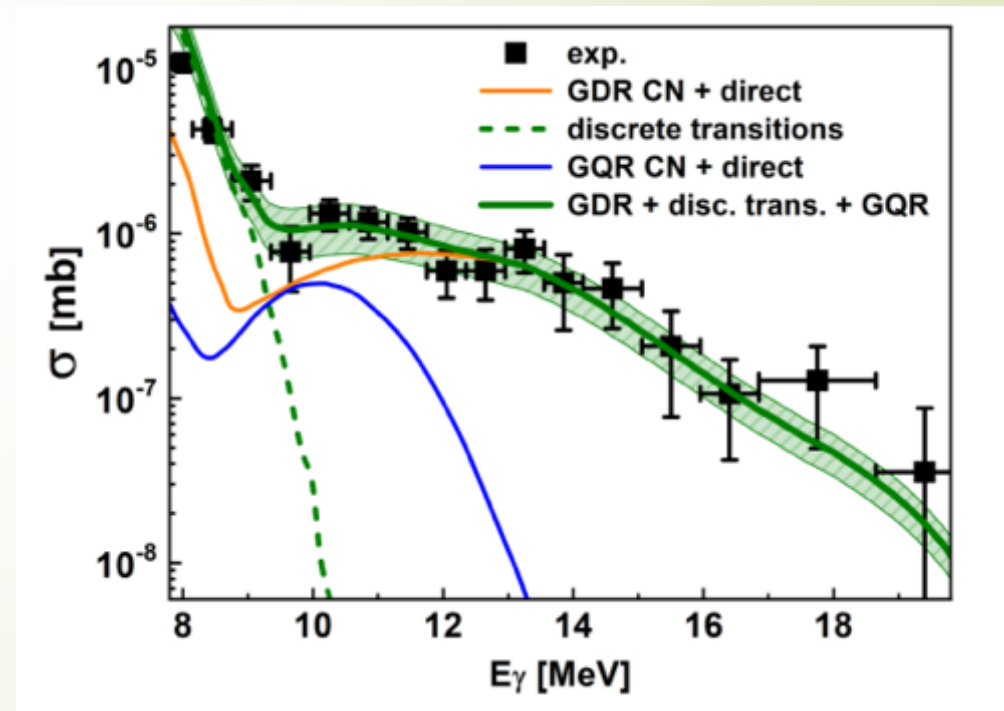


High energy γ -rays from ^{120}Sn decay

$2^+ \rightarrow 0^+$



Courtesy: Agnese Giaz



B. Wasilewska et al. PRC 105, 014310 (2022)

PDR in Ni isotopes

PROPOSAL FOR EXPERIMENT AT CCB

July 15, 2022

Study of the Pygmy Dipole Resonance states in $^{58,62}\text{Ni}$ isotopes using the inelastic proton scattering at CCB

Spokespersons:

Oliver Wieland (INFN Milano) & **Maria Kmiecik** (IFJ PAN Krakow)

Participants:

INFN and Uni Milano (Italy): O. Wieland, A. Bracco, F. Camera, S. Leoni, F. Crespi,
G. Benzoni, S. Brambilla

IFJ PAN Krakow (Poland): M. Kmiecik, M. Ciemała, A. Maj, B. Fornal, P. Bednarczyk,
M. Matejska-Minda, M. Ziębliński, J. Łukasik, P. Pawłowski, J. Grębosz

University of Groningen (The Netherlands): M.N. Harakeh

GANIL (France): M. Lewitowicz,

IJCLab Orsay (France): I. Matea, J. Wilson, C. Hiver, A. Dey

CEA Saclay (France): M. Vandebrouck

RCNP Osaka (Japan): A. Tamii

IKP Cologne (Germany): A. Zilges, B. Wasilewska

SLCJ UW (Poland): P. Napiorkowski, K. Hadyńska-Klęk



Pygmy dipole resonances

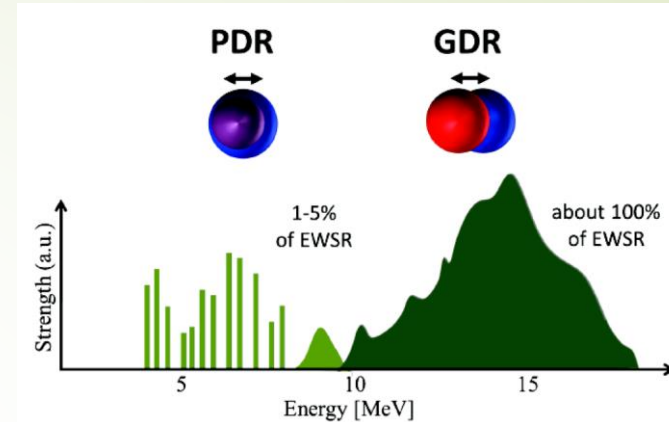
low-energy part of the E1 response (soft dipole mode)

Studied so far using mainly:

- Nuclear resonance fluorescence,
- (γ, n) reactions (above S_n),
- (p, p') (above and below S_n),
- $(\alpha, \alpha'\gamma)$ and $(^{17}\text{O}, ^{17}\text{O}'\gamma)$

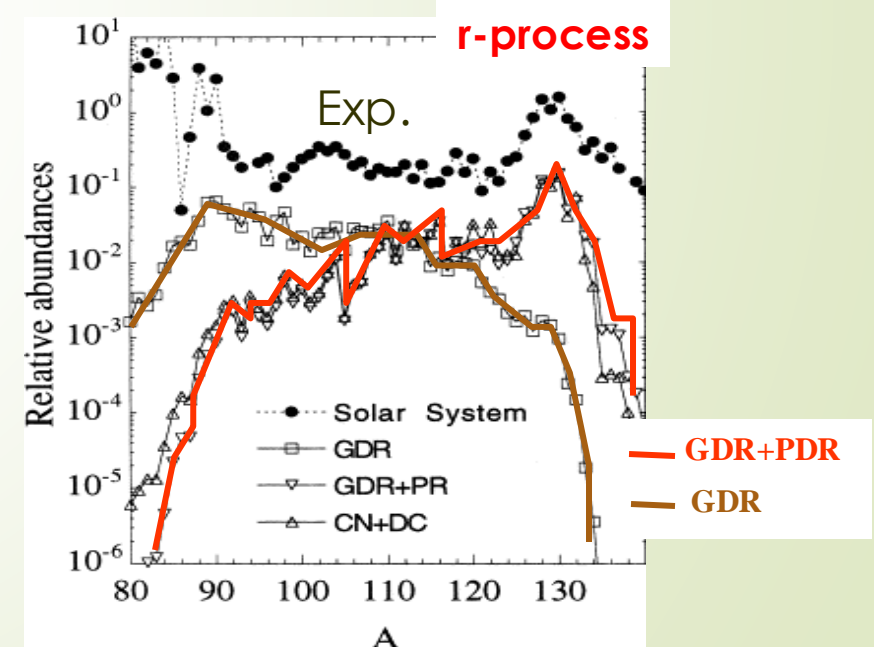
now in $(p, p'\gamma)$ reaction

- ❑ Studies with different probes allow to learn on the **structure of PDR states**
- ❑ Possible impact for:
 - **nucleosynthesis r process** (larger cross sections for neutron radiative capture)
 - equation of state of nuclear matter definition – **neutron skin thickness** and **symmetry energy**



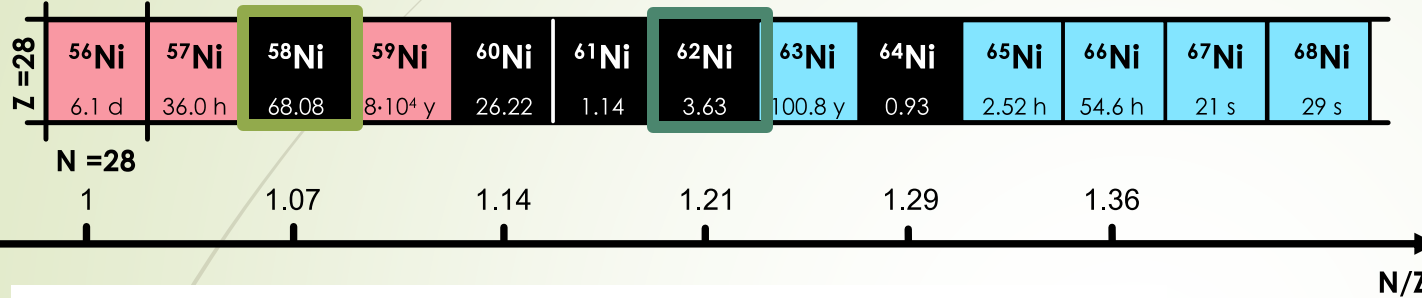
S.Goriely, Phys. Lett. B436 10 (1998)

S.Goriely and E. Khan, Nucl. Phys. A706 (2002) 217

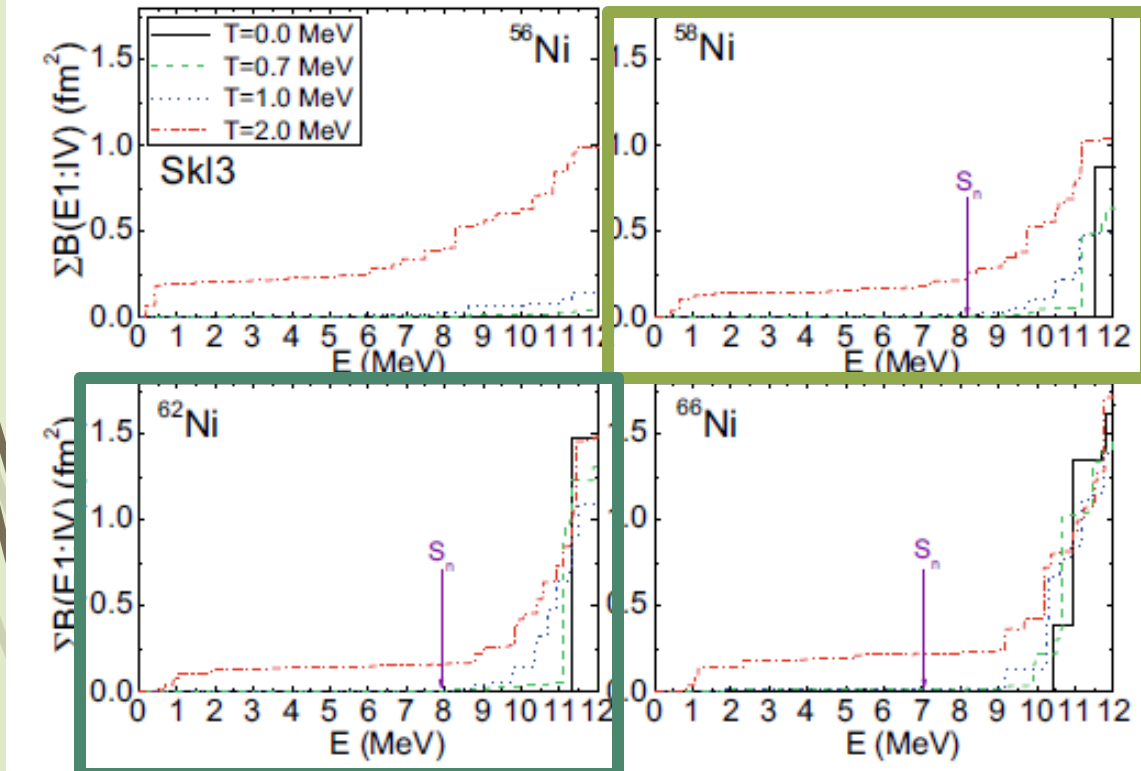


PDR in Ni isotopes - motivation

Study PDR strength as a function of neutron number to understand the role of neutrons in states at the onset of the existence of the pygmy strength



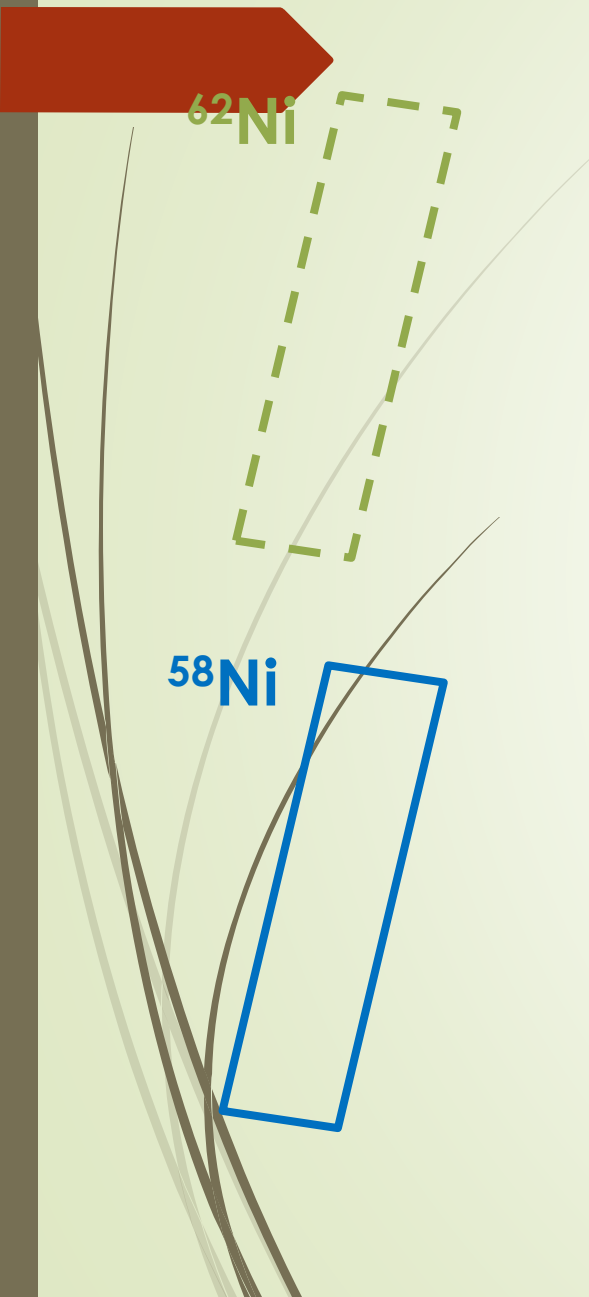
The PDR strength below 10 MeV observed :
 for ^{60}Ni 0.5-0.8 % of EWSR (NRF)
 for ^{68}Ni 3-5% of EWSR (Coulomb excitation)



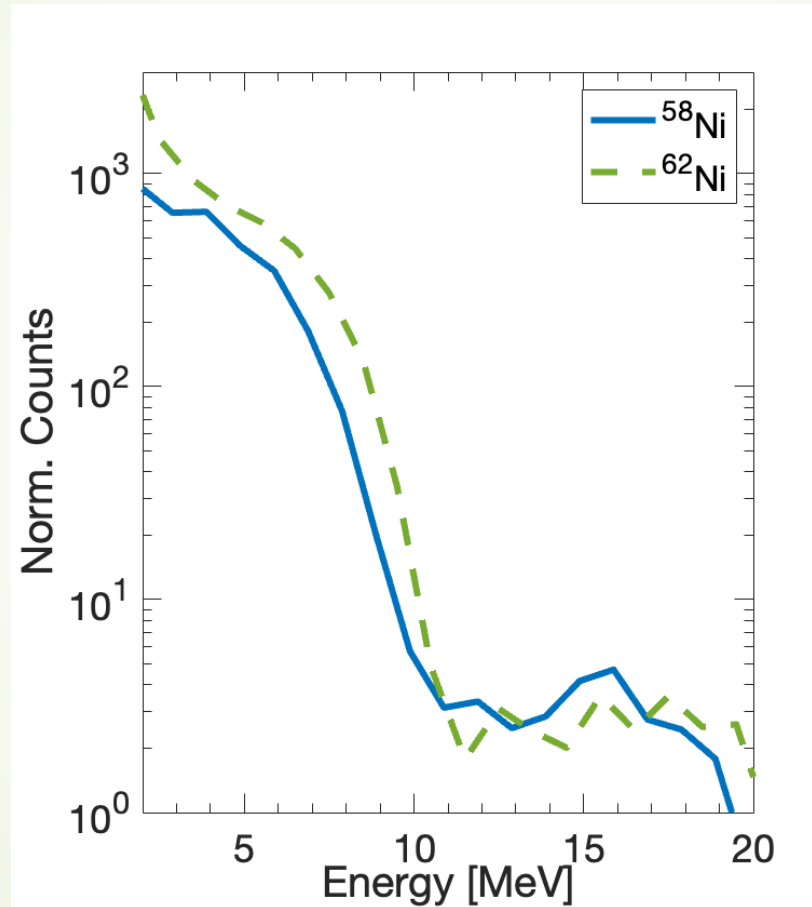
Complementary to investigations done at IFIN labs with same isotopes but with fusion evaporation reactions at finite temperature.

E. Yüksel et al., Eur. Phys. J. A (2019) 55: 230

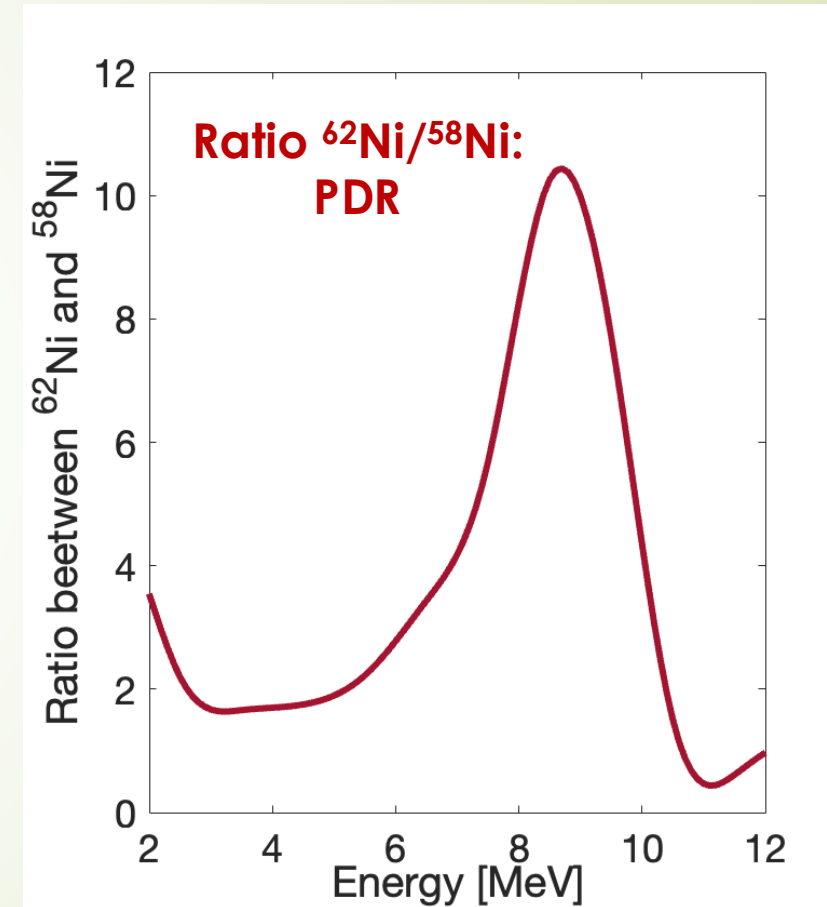
Preliminary results from study of PDR in Ni isotopes



^{62}Ni $N/Z = 1.21$
Pygmy expected



^{58}Ni $N/Z = 1.07$
No Pygmy or negligible Pygmy expected



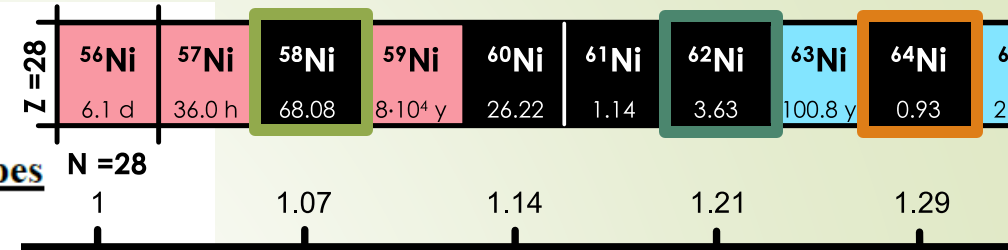
Courtesy: Agnese Giaz

New proposal for study of PDR in Ni isotopes

PROPOSAL: CONTINUATION EXPERIMENT AT CCB

July 8, 2024

PDR in ^{64}Ni as systematic sequel of the study in $^{58,62}\text{Ni}$ isotopes
using the inelastic proton scattering at CCB



Spokespersons:

A. Giaz (INFN Milano) & M. Ciemala (IFJ PAN Krakow)

Participants:

INFN and Uni Milano (Italy): A. Giaz, O. Wieland, G. Benzoni, S. Bottoni, A. Bracco, S. Brambilla, F. Camera, G. Corbari, F. Crespi, S. Leoni, M. Luciani, B. Million,

IFJ PAN Krakow (Poland): M. Ciemala, M. Kmiecik, P. Bednarczyk, B. Fornal, J. Grębosz, J. Łukasik, A. Maj, M. Matejska-Minda, P. Pawłowski, M. Ziębliński,

University of Groningen (The Netherlands): M.N. Harakeh,

INFN LNL e Uni Padova (Italy) M. Balogh, D. Stramaccioni, J.J. Valiente-Dobon

GANIL (France): M. Lewitowicz,

IJCLab Orsay (France): A. Dey, C. Hiver, I. Matea, J. Wilson,

CEA Saclay (France): P. Miriot-Jaubert, M. Vandebrouck,

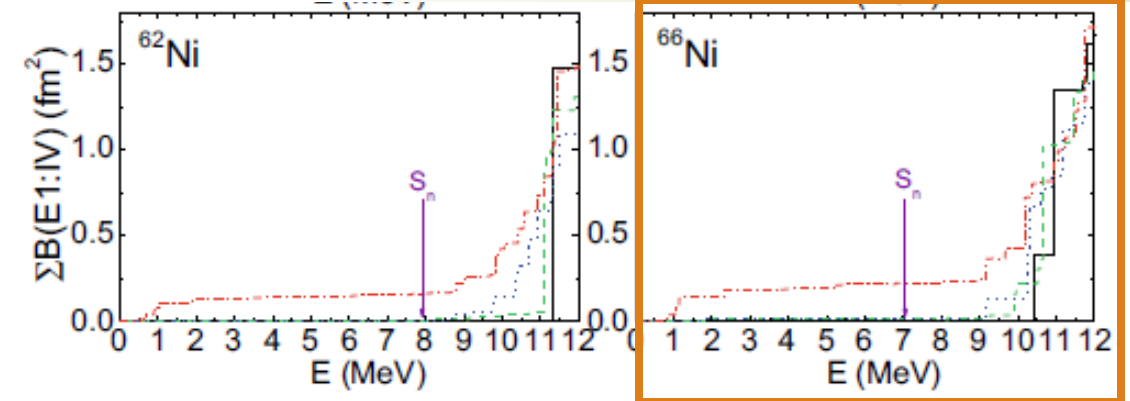
IKP Cologne (Germany): A. Zilges,

SLCJ UW (Poland): K. Hadyńska-Klęk, P. Napiorkowski,

USTHB Algiers (Algeria) N. Benouaret,

Ithemba (South Africa): L. Pellegrini, R. Neveling

for ^{64}Ni PDR expected double as for ^{62}Ni



E. Yüksel et al., Eur. Phys. J. A (2019) 55: 230

Collaboration

- **INFN and Uni Milano (Italy):** G. Benzoni, S. Bottoni, **A. Bracco**, **S. Brambilla**, **F. Camera**, G. Corbari, **F. Crespi**, **A. Giaz**, S. Leoni, M. Luciani, **B. Million**, **O. Wieland**
- **IFJ PAN Krakow (Poland):** P. Bednarczyk, N. Cieplicka-Oryńczak, M. Ciemała, I. Dedes, B. Fornal, J. Grębosz, Ł. Iskra, M. Kmiecik, J. Łukasik, A. Maj, M. Matejska-Minda, K. Mazurek, P. Pawłowski, M. Ziębliński,
- **University of Groningen (The Netherlands):** M.N. Harakeh,
- **INFN LNL e Uni Padova (Italy):** M. Balogh, D. Stramaccioni, J.J. Valiente-Dobon
- **GANIL (France):** M. Lewitowicz,
- **IJCLab Orsay (France):** A. Dey, C. Hiver, I. Matea, J. Wilson,
- **CEA Saclay (France):** P. Miriot-Jaubert, M. Vandebrouck,
- **IKP Cologne (Germany):** M. Weinert, A. Zilges,
- **SLCJ UW (Poland):** K. Hadyńska-Klęk, P. Napiorkowski,
- **USTHB Algiers (Algeria):** N. Benouaret,
- **Ithemba (South Africa):** R. Neveling, L. Pellegrini,
- **IFJ PAN Krakow (Poland) & IPHC Strasbourg (France):** C. Schmitt