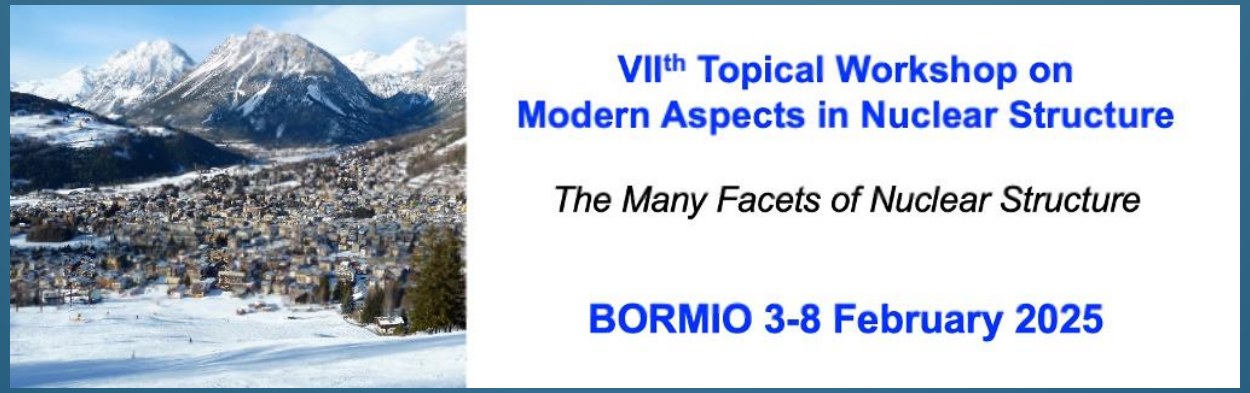
Pygmy and giant resonances studied at CCB of IFJ PAN Kraków - highlights from the experimental campaign

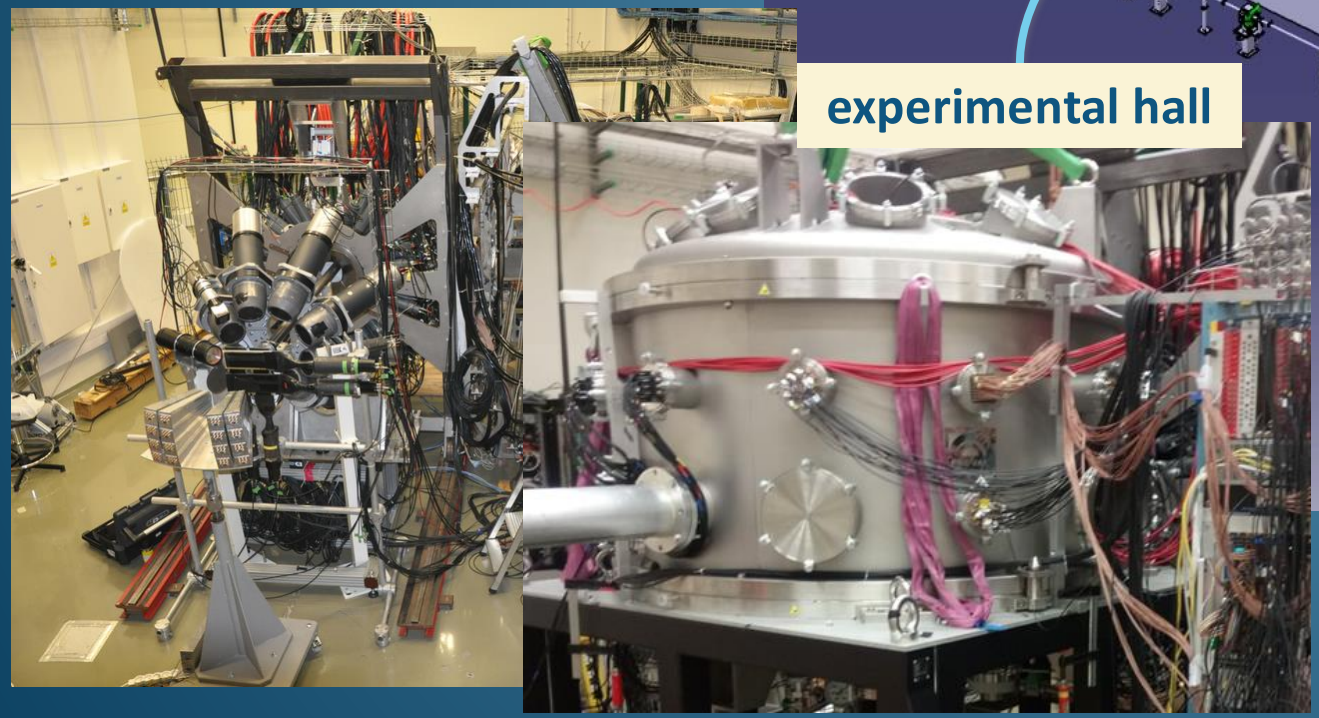
Maria Kmiecik IFJ PAN Kraków

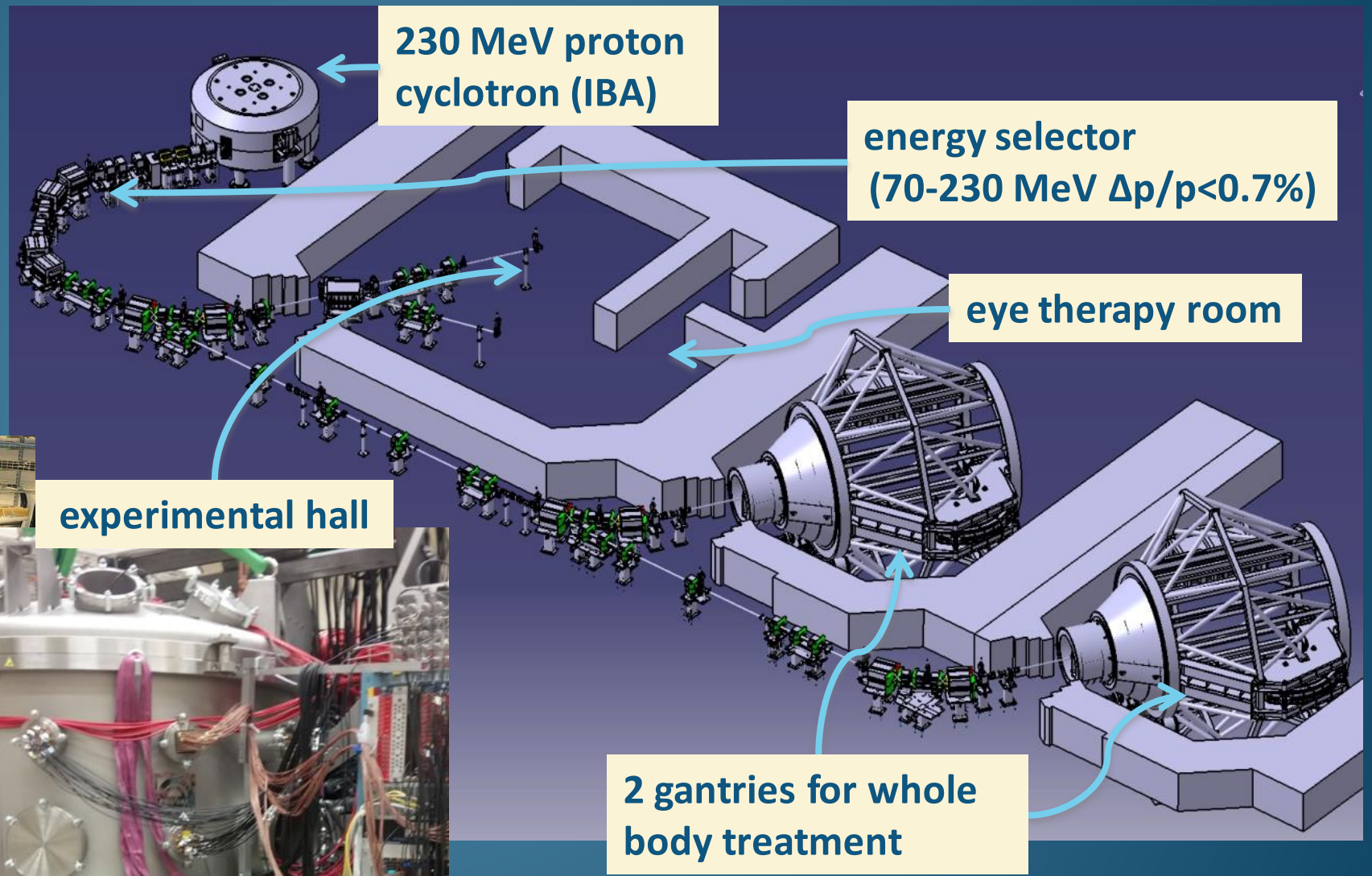


Cyclotron Center Bronowice (CCB) of IFJ PAN

proton cancer therapy and additionally research program on:

- nuclear physics,
- radiobiology
- dosimetry
- medical physics

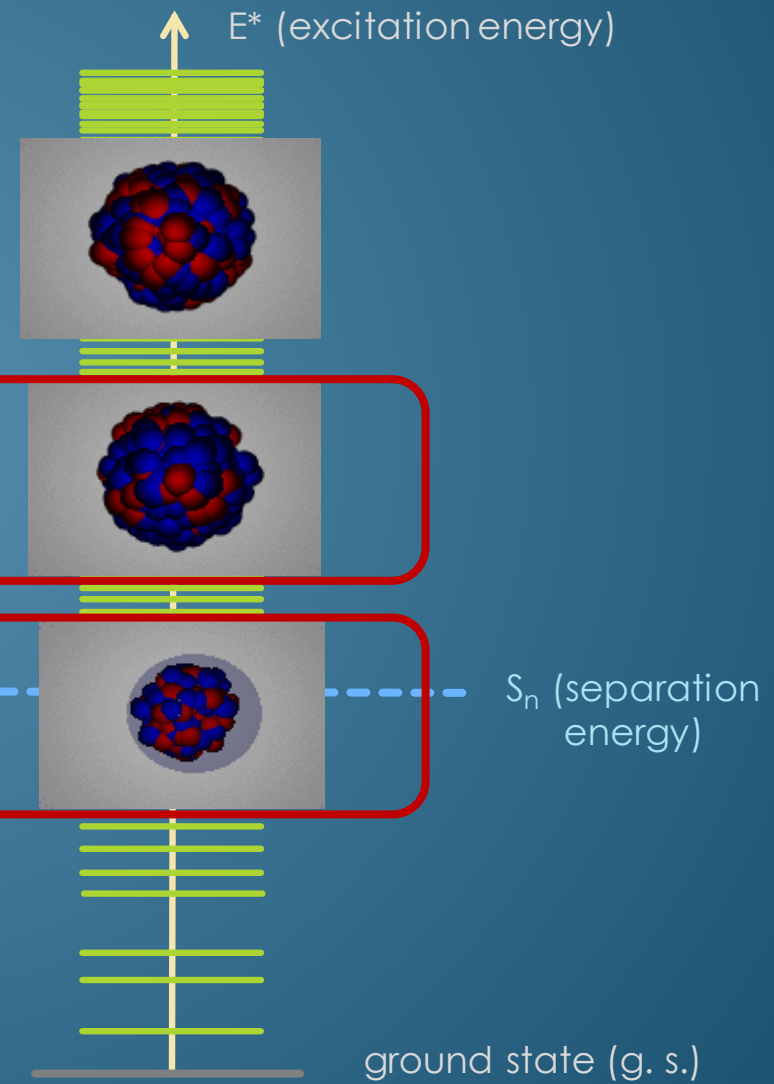




experiments during weekends

Aim of the investigations

nuclear excitations induced by **proton inelastic scattering**



IVGDR (Isovector Giant Dipole Resonance)

main aim – γ decay

ISGQR (Isoscalar Giant Quadrupole Resonance)

PDR (Pygmy Dipole Resonance)

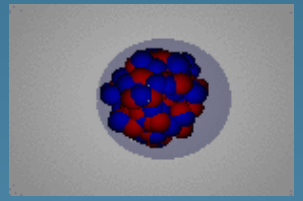
measurement of γ-rays emitted from the decay
(above neutron threshold hindered by neutron emission)

10^{-2} for GDR and 10^{-4} for GQR

Motivation

Motivation to study PDR

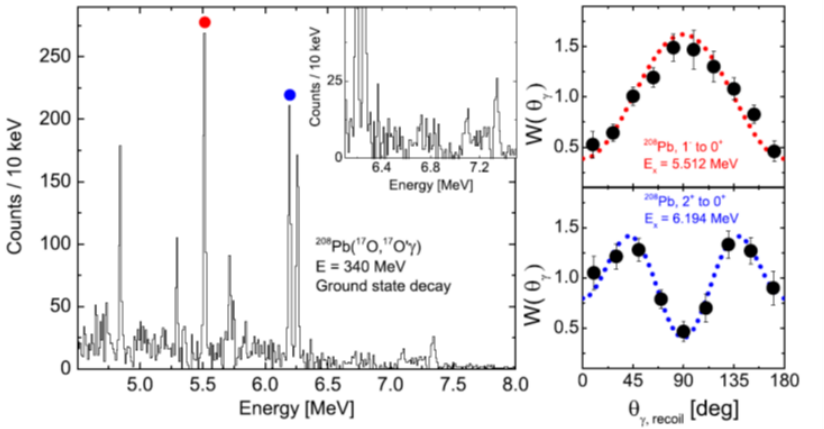
PDR – low-energy part of the E1 response below and above Sn (soft dipole mode)



Studied so far using mainly:

- Nuclear resonance fluorescence,
- (γ, n) reactions (above Sn),
- (α, α'γ) and (^{17}O,^{17}O'γ),

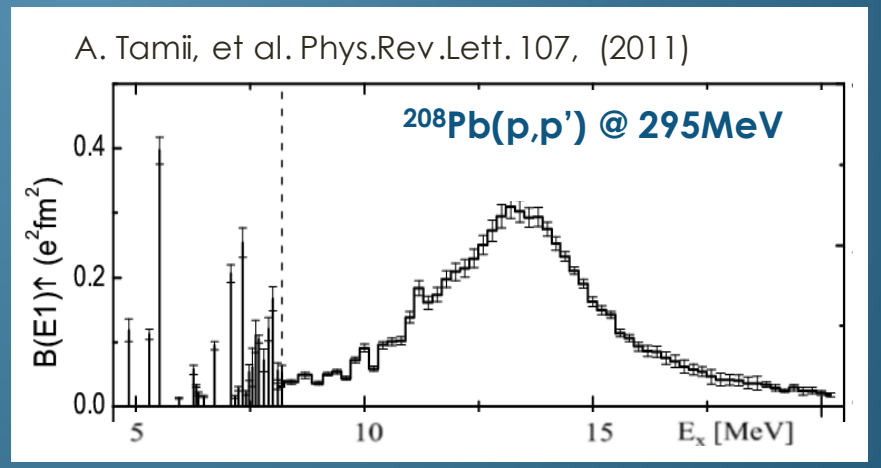
(^{17}O,^{17}O'γ) @ 20 MeV/u on ^{208}Pb



F.C.L. Crespi et al., Phys.Rev.Lett. 113, 012501 (2014)

- (p,p') (above and below Sn)

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

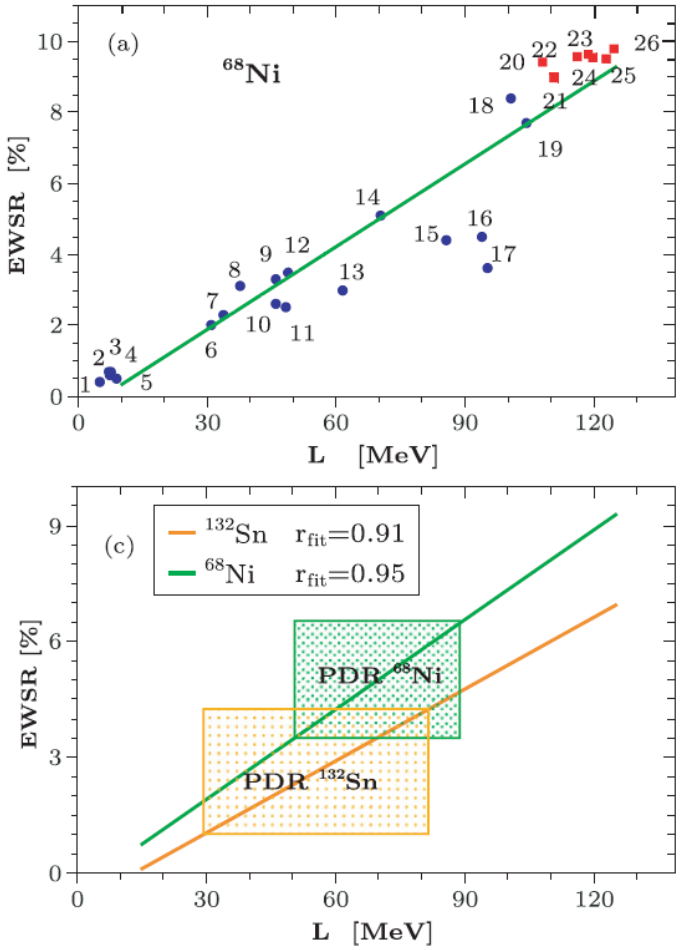


now in (p,p'γ) reaction

Studies with various probes allow to learn on the structure of PDR states

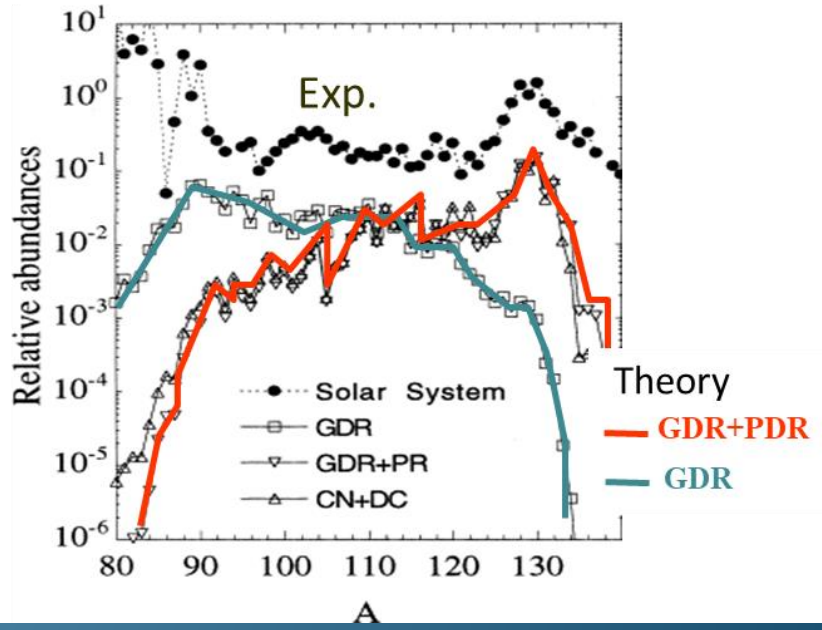
PDR

A.Carbone, Phys. Rev. C 81, 041301 (2010)



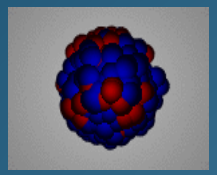
symmetry energy S $S'(\rho)|_{\rho=\rho_0} = \frac{L}{3\rho_0}.$

S.Goriely, Phys. Lett. B436 10 (1998)
S.Goriely and E. Khan, Nucl. Phys. A706 (2002) 217

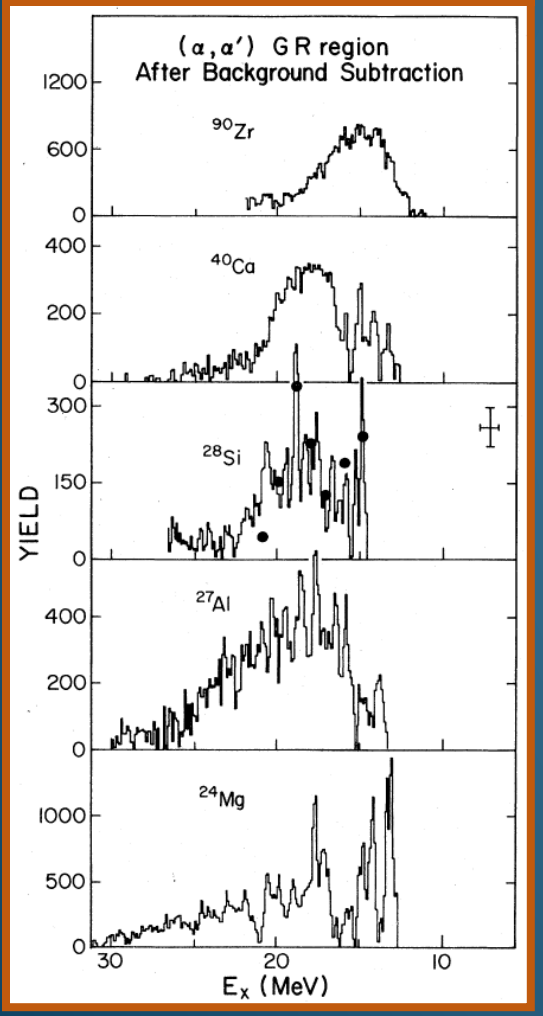


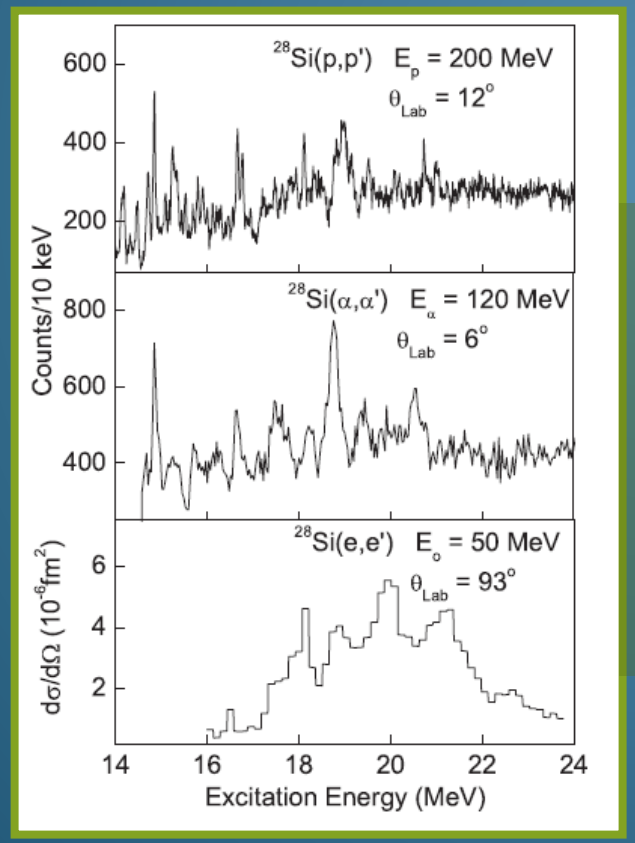
- Implications of the low-lying E1strength on the **r-process nucleosynthesis**
- related to determination of **nuclear symmetry energy** (neutron rich matter)
- can be used for **neutron skin thickness** determination (neutron stars)

ISGQR

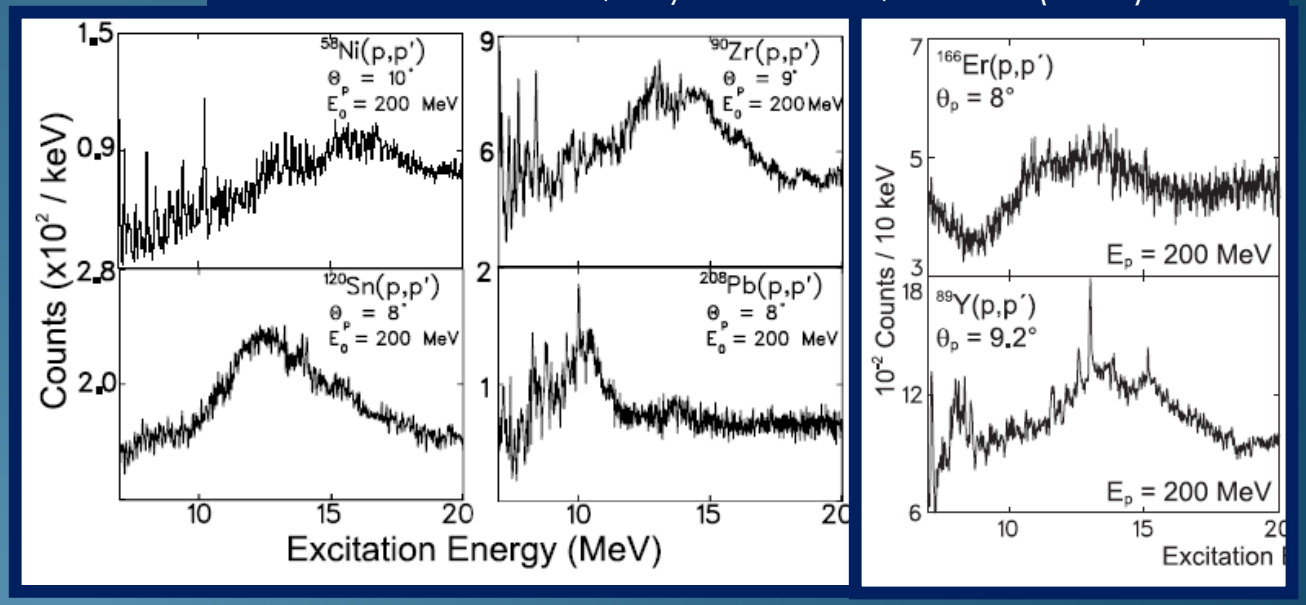


D.H. Youngblood et al.,
Phys. Rev. C15, 1644 (1977)





A. Shevchenko et al., Phys. Rev. Lett. 93 (2004) 122501-1
A. Shevchenko et al., Phys. Rev. C79, 044305 (2009)



I.T. Usman et al.,
Phys. Rev. C94, 024308 (2016)

K. van der Borg et al.,
Nucl. Phys. A341, 219 (1980)

A. Richter, Prog. Part.Nucl.
Phys. 13, 1 (1985)

structure, fragmented strength and decay needed to be investigated

ISGQR γ-decay

GQR γ–decay observed previously **only once**, in 1980s

Inelastic scattering of 381 MeV ^{17}O on ^{208}Pb

coincidence measurement of gamma rays and scattered ions

excitation energy obtained from measured scattered beam energy

E* = E beam – E scattered ion

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

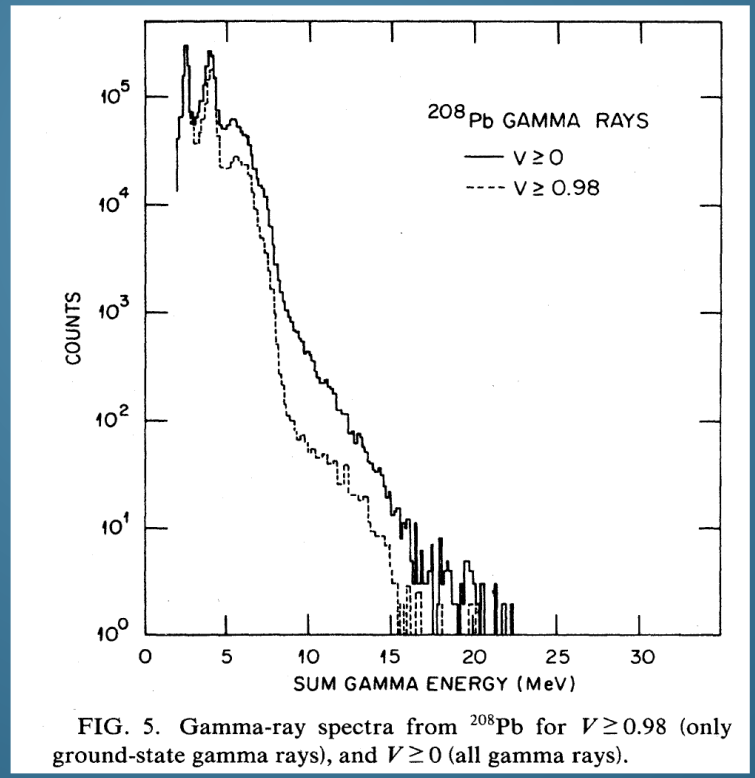
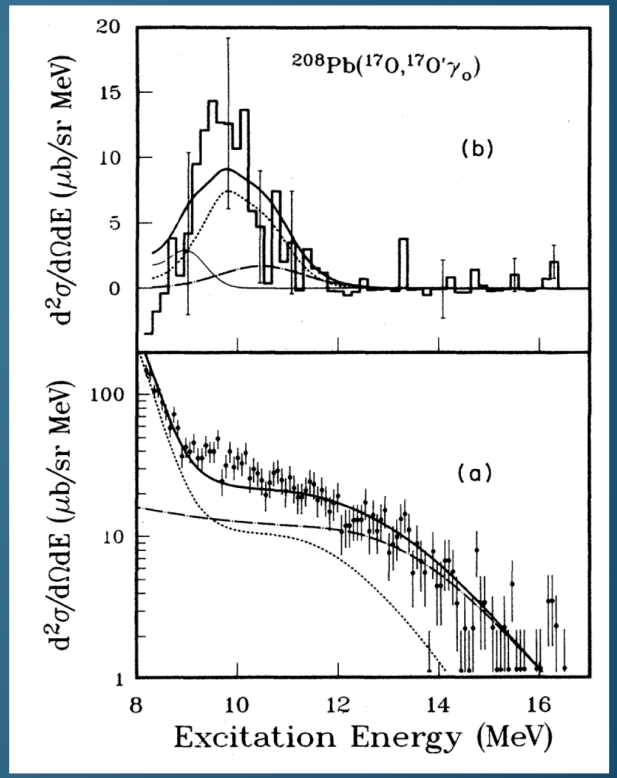


FIG. 5. Gamma-ray spectra from ^{208}Pb for $V \geq 0.98$ (only ground-state gamma rays), and $V \geq 0$ (all gamma rays).



Eγ [MeV]

Experiments and results

Idea of first experiment

proton inelastic scattering

proposal

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

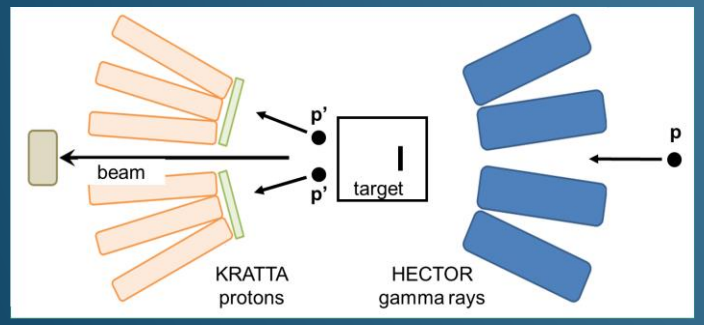
F. Crespi[1], M. Kmiecik[2],

A. Bracco[1], F. Camera[1], S. Leoni[1], G. Benzoni[1], S. Brambilla[1], A. Giaz[1], L. Pellegri[1], O. Wieland[1] et al.,

A. Maj[2], B. Wasilewska[2], P. Bednarczyk[2], B. Fornal[2], M. Krzysiek[2], N. Cieplicka[2], K. Mazurek[2], M. Ziębliński[2], J. Grębosz[2], M. Jastrząb[2], J. Łukasik[2], P. Pawłowski[2] et al.

[1]University of Milano and INFN

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



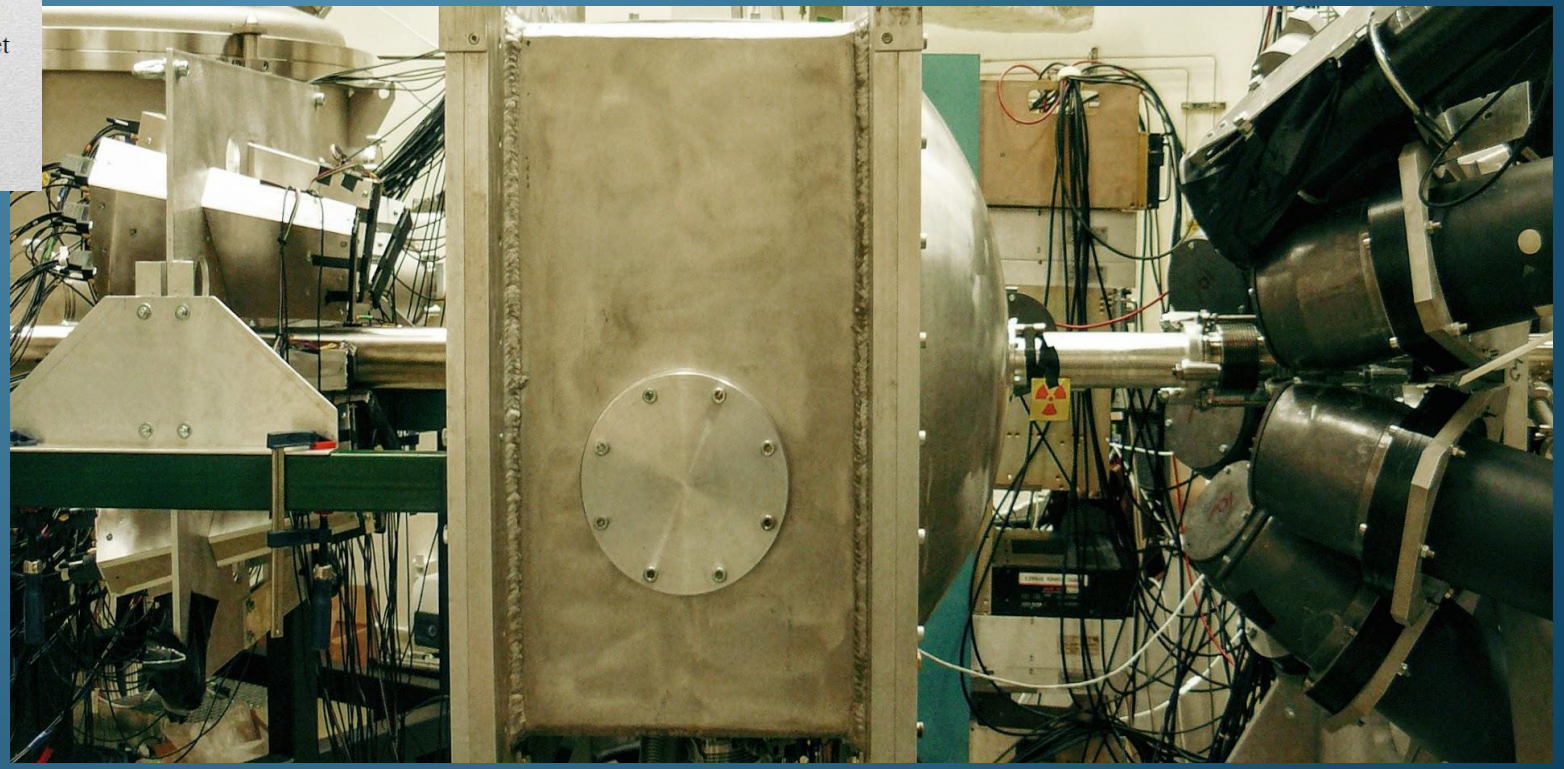
coincidence measurement
of gamma rays and scattered protons

p @ 85 MeV on ^{208}Pb target 48 mm (54.5 mg/cm^2) thick

KRATTA
(16 CsI telescopes)
(protons)

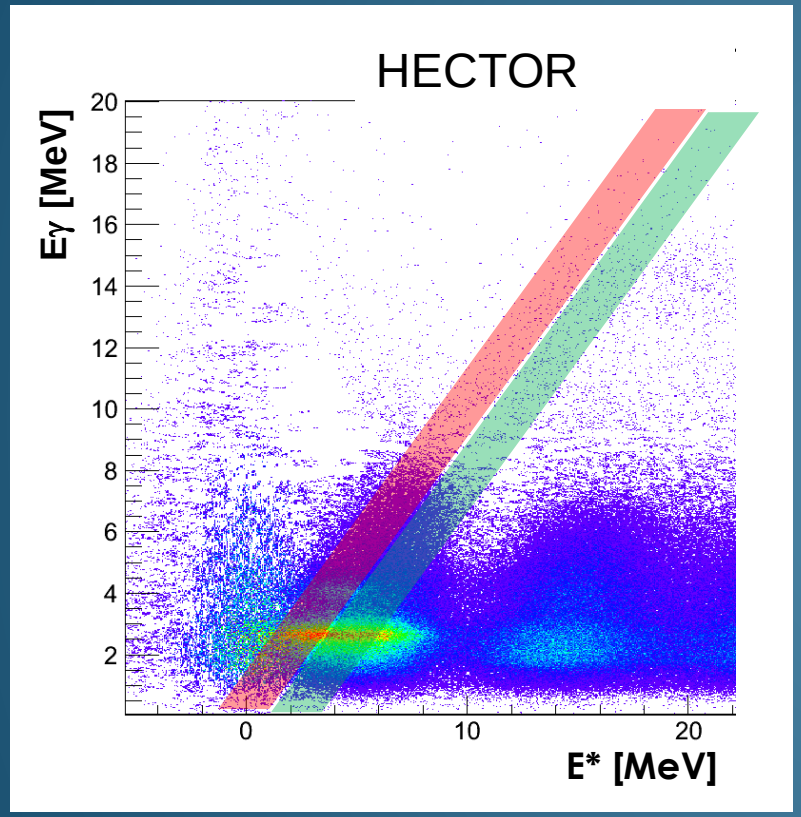
vacuum scattering chamber

HECTOR (8 BaF_2)
$LaBr_3$ (large volume 8"x3.5")
PARIS (cluster of 9 „phoswiches"
$LaBr_3$/$CeBr_3$ + NaI)
(γ-rays)



Method

coincidence measurement of gamma rays and scattered protons



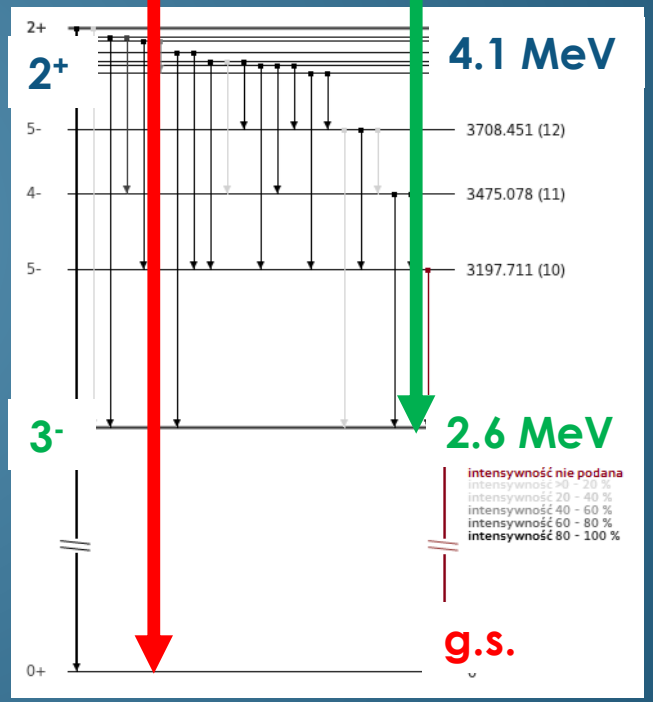
background subtracted

$E^* = E_{beam} - E_{scattered\ proton}$

decay to the ground state

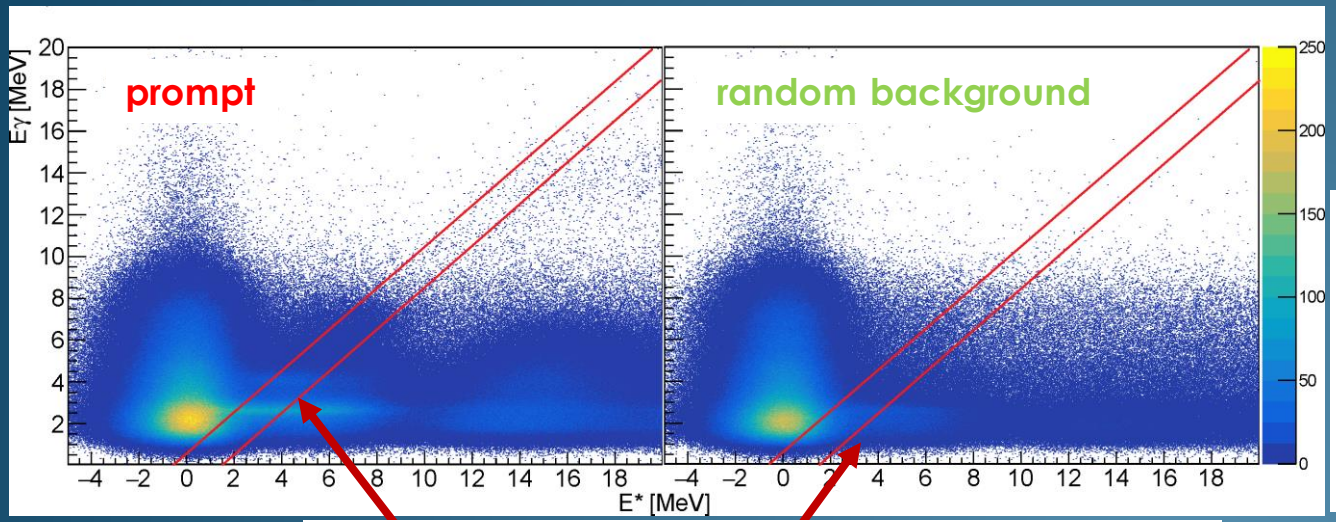
g.s. : E* = Eγ

decay to 3⁻ : E* = Eγ+2.6 MeV

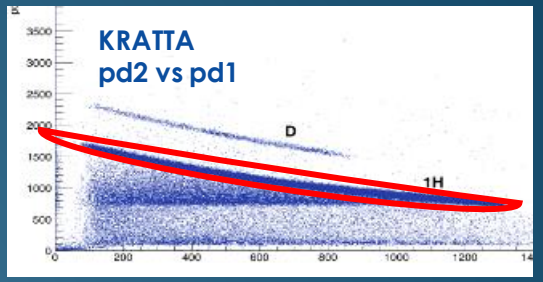


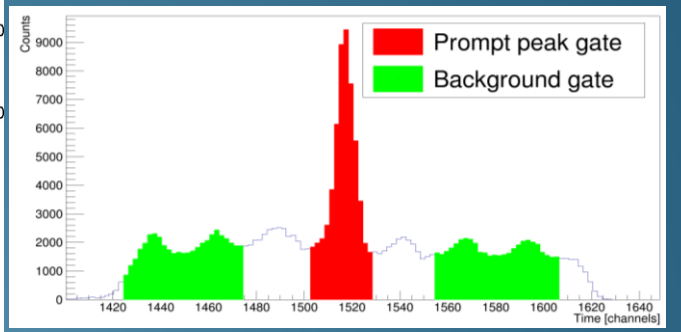
$^{208}Pb\ S_n = 7.368$ MeV

Analysis

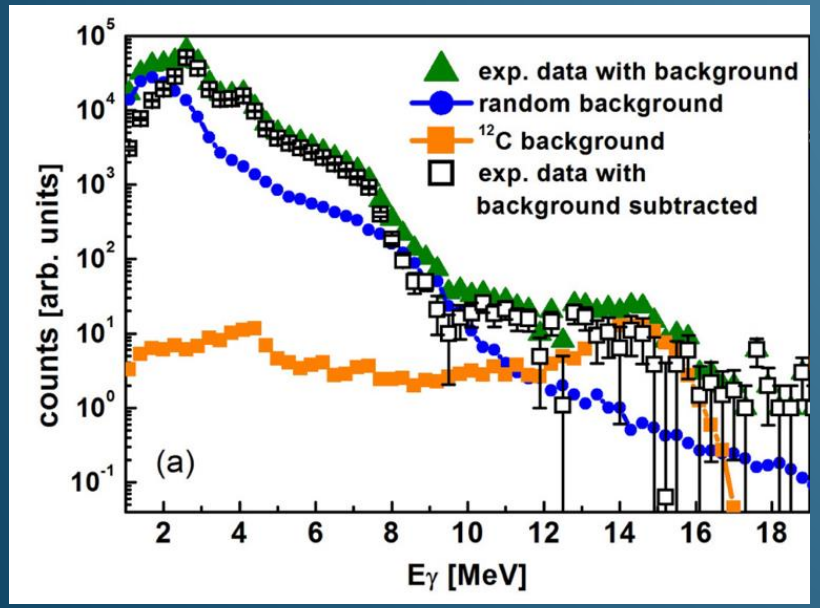


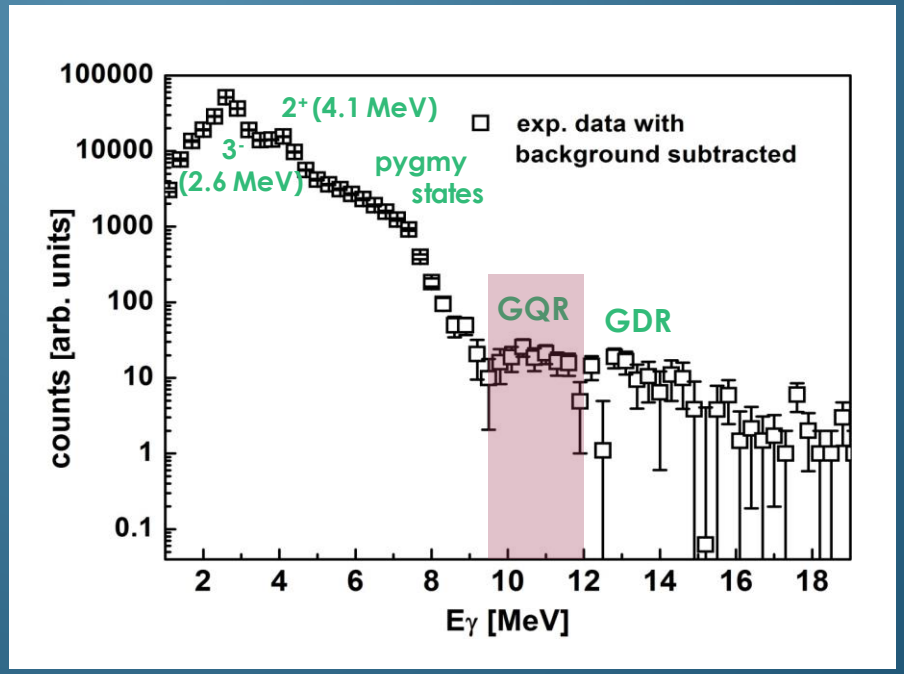
gated on scattered proton
and γ prompt





decay to the ground state ([Eγ+0.5-E*] ≤ 1 MeV)



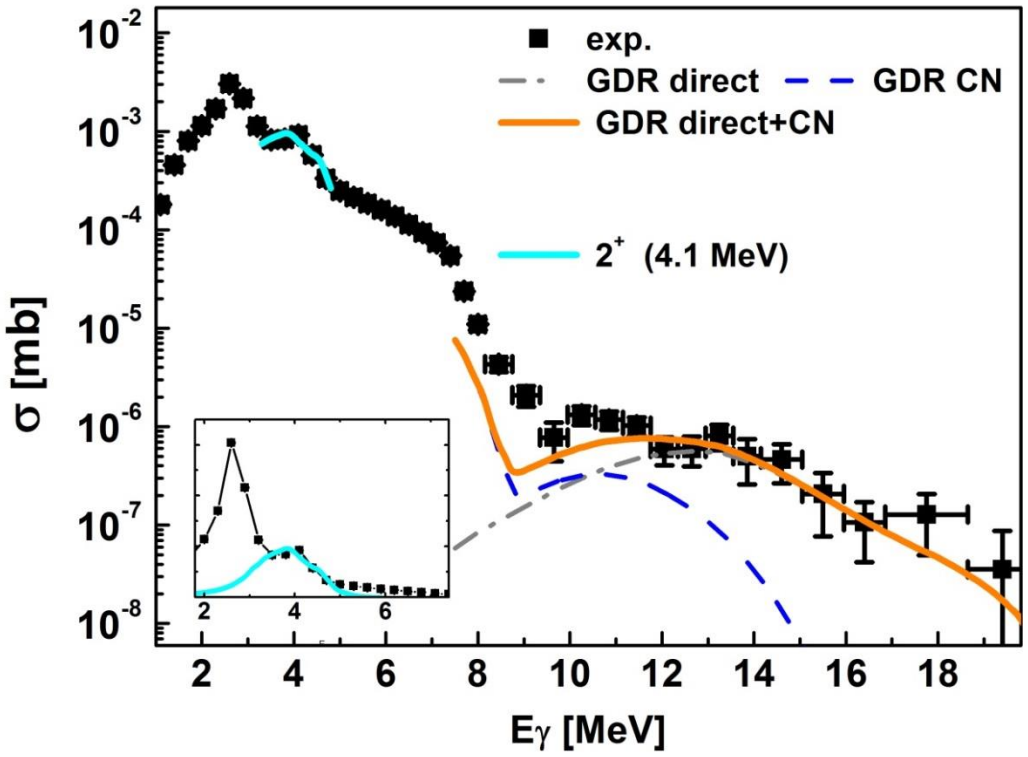


B. Wasilewska et al. PRC 105, 014310 (2022)

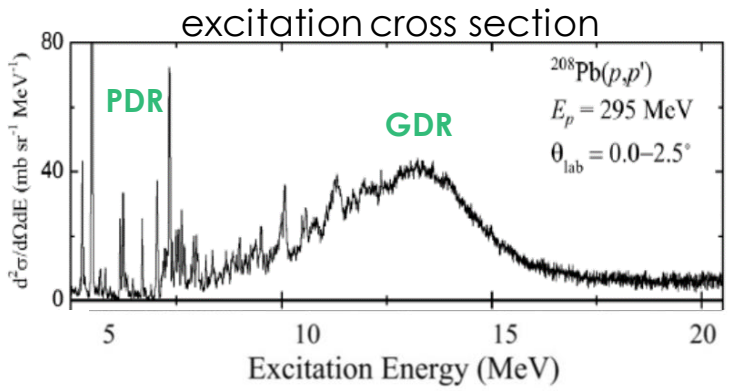
GDR analysis

$$\sigma_{p,p'\gamma 0}(E) = \sigma_{p,p'}(E; B(E1) = 1) b_{E1}(E) \left[\frac{\Gamma_{\gamma 0}}{\Gamma} + \frac{\Gamma\downarrow}{\Gamma} B_{CN}(E) \right] = \sigma_{direct} + \sigma_{CN}$$

direct decay — statistical (CN) decay



calculated for:
B(E1) for 111% EWSR;
E_{GDR} = 13.4 MeV;
Γ_{GDR} = 3.9 MeV



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

GDR γ-ray decay to the g.s. branching ratio:

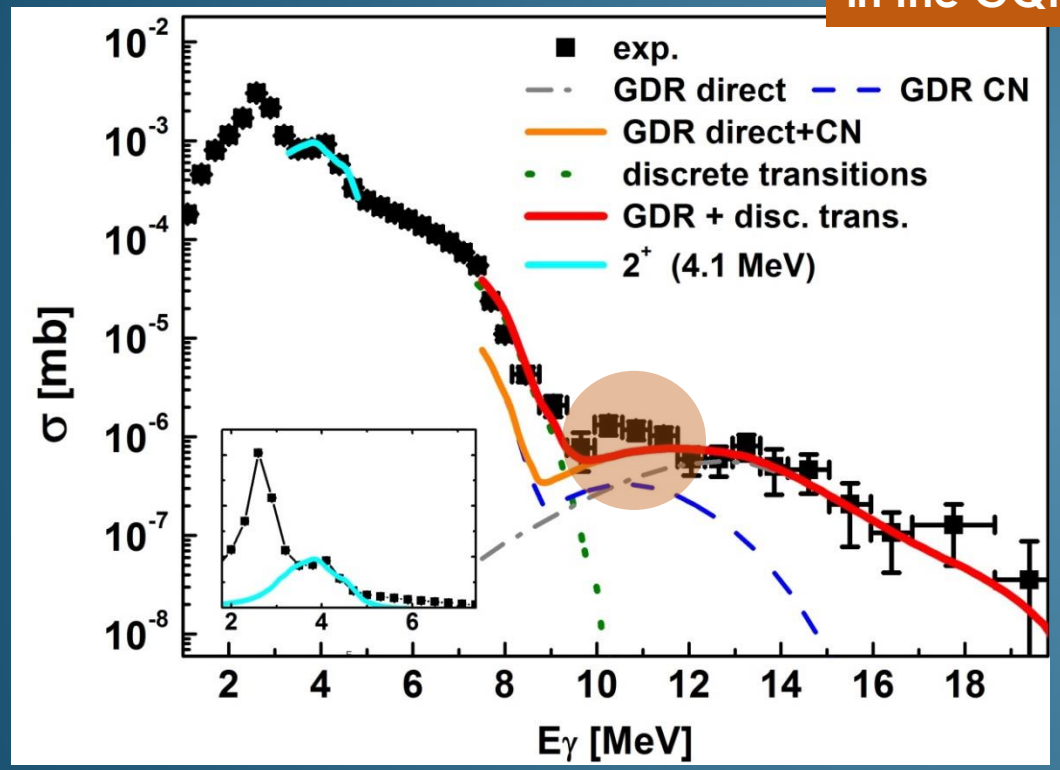
$$\left(\frac{\Gamma_{\gamma 0}}{\Gamma}\right)_{GDR} = 1.7 \times 10^{-2} \pm 0.5 \times 10^{-2}$$

In agreement with published value

γ-decay to the g.s. in ^{208}Pb from ISGQR region

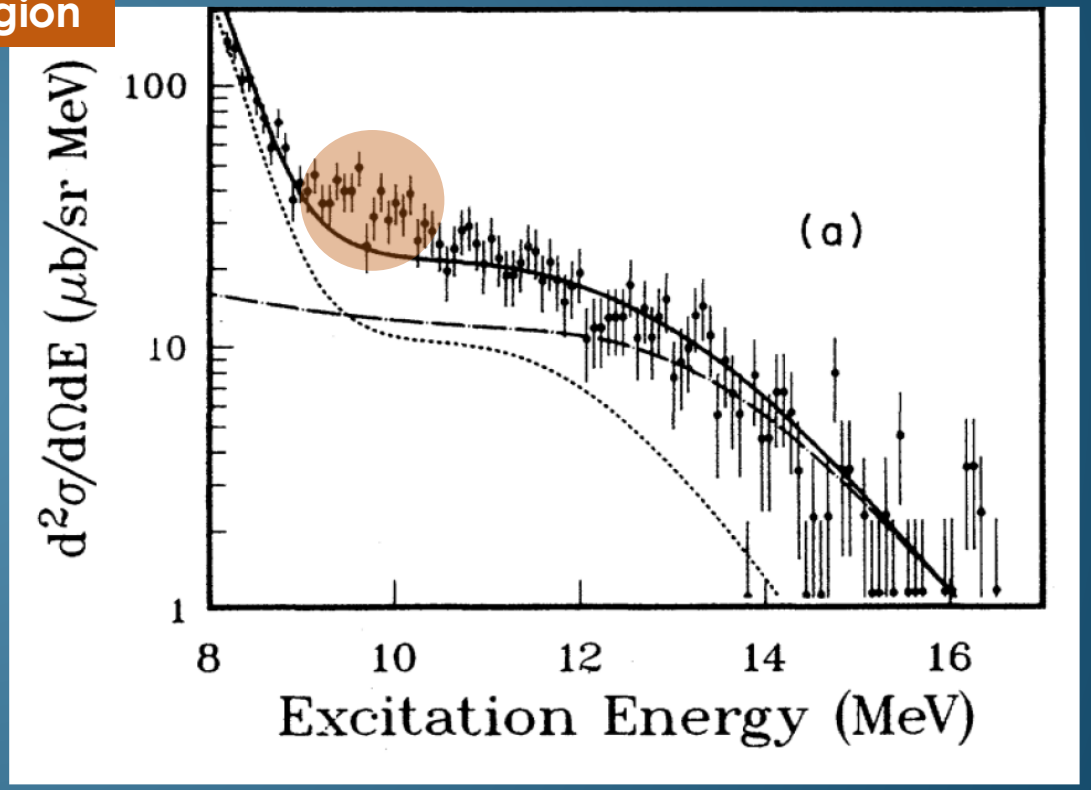
^{208}Pb(p,p'γ) @ 85 MeV

excess
in the GQR region



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

^{208}Pb (^{17}O,^{17}O'γ) @ 381 MeV

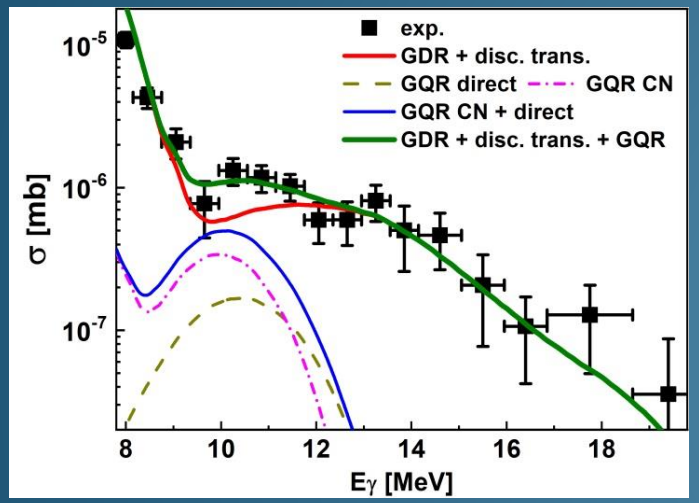


J.Beene et al., PRC39, 1307 (1989)

GQR γ-decay in ^{208}Pb

^{208}Pb(p,p'γ) @ 85 MeV

γ-ray energy

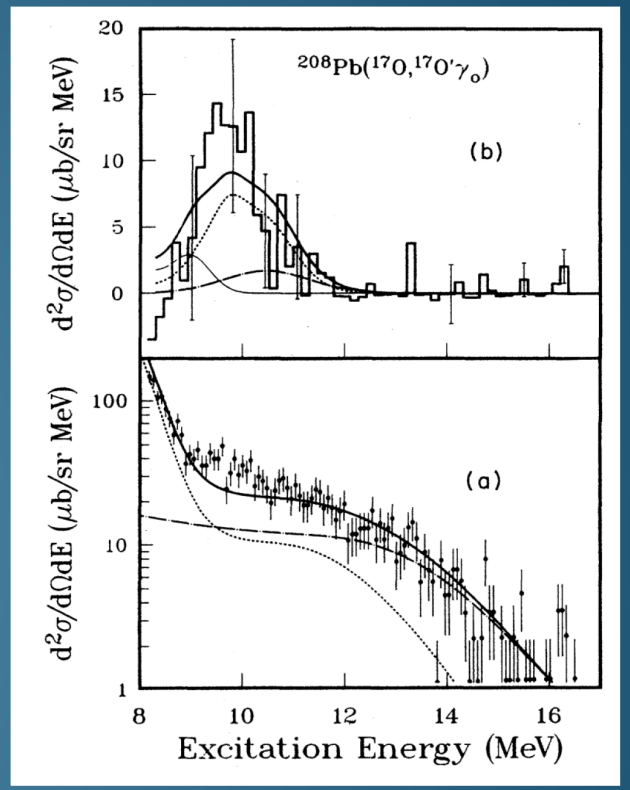


B. Wasilewska al., PRC105, 014310 (2022)

Observation, for the 2nd time, of the gamma decay of the ISGQR

^{208}Pb (^{17}O,^{17}O'γ) @ 381 MeV

excitation energy measured in coincidence with γ-rays



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

branching ratio:

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

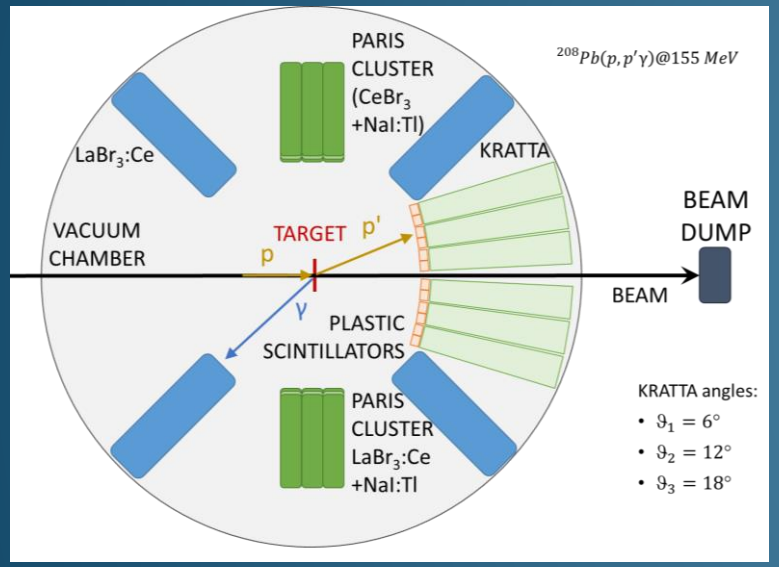
$$\left(\frac{\Gamma_{\gamma 0}}{\Gamma}\right)_{GQR} = 4 \times 10^{-4} \pm 1 \times 10^{-4}$$

branching ratio for the GQR gamma decay to the ground state obtained with the use of proton beam - **in agreement** to previous value measured with heavy ions

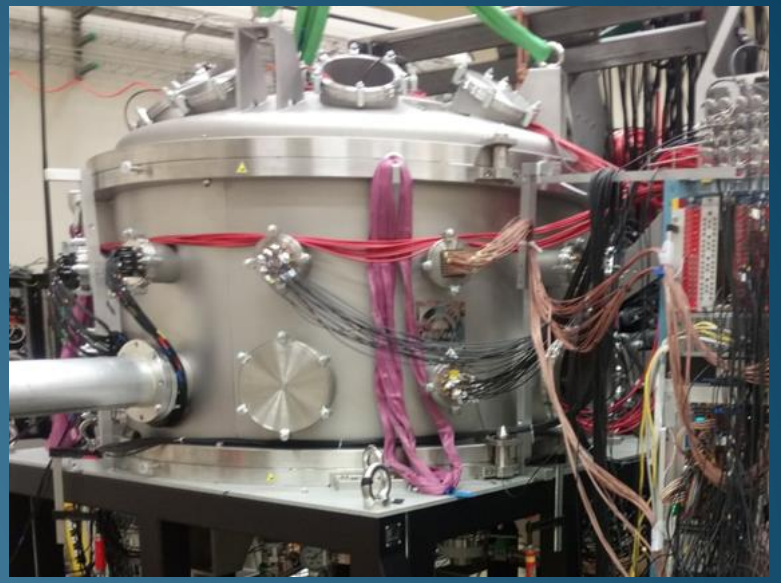
Next measurements

(p,p'γ) on ^{208}Pb @ ~155 MeV

(p,p'γ) on ^{120}Sn @ ~200 MeV

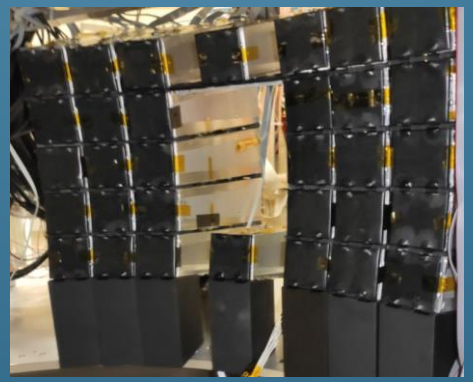


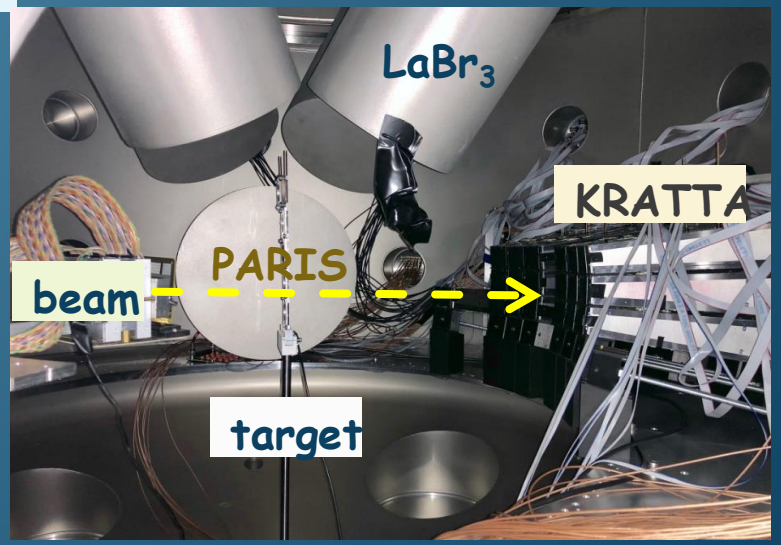
KRATTA inside the chamber – in the vacuum
gamma detectors outside
mounted using holders / cylindrical pockets



- 4 large volume LaBr3 (3.5"x8") at top
- 2 PARIS clusters: (9 $LaBr_3$+NaI and 9 $CeBr_3$+NaI) at 90°
- KRATTA covering angles from ~8° to ~24°

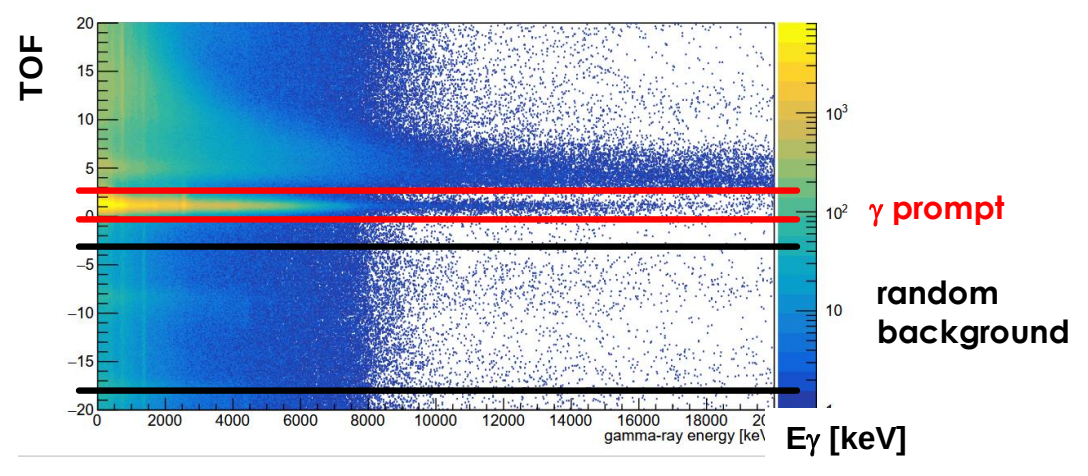
4 plastic scintillators
for each KRATTA module
mounted in the front

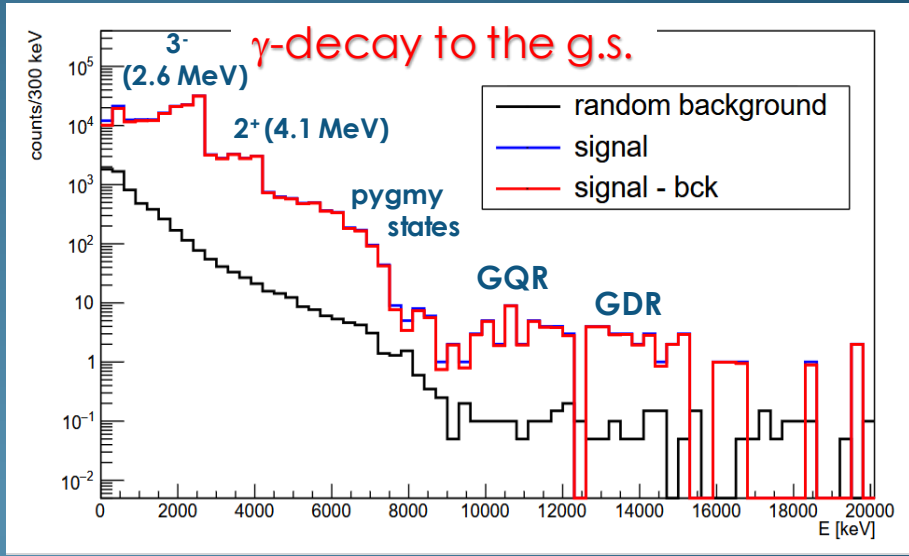


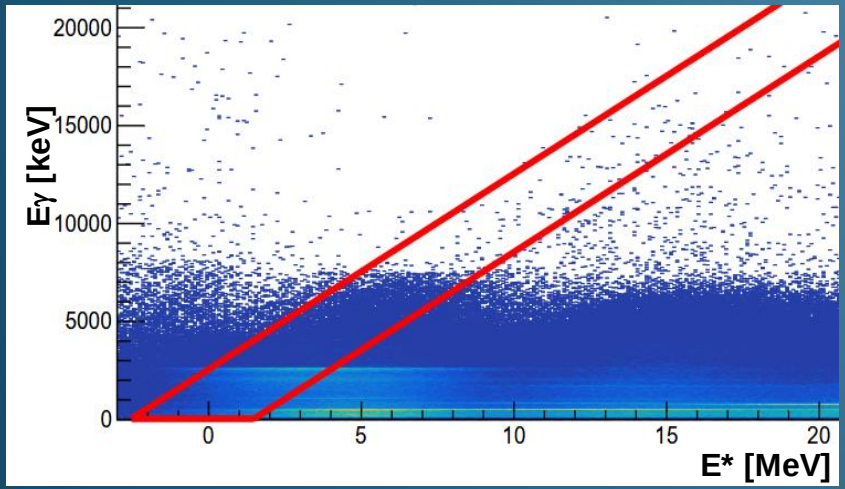


- New setup – better energy resolution
- Higher beam energy – enchancement of GQR

(p,p'γ) on ^{208}Pb @ 155 MeV

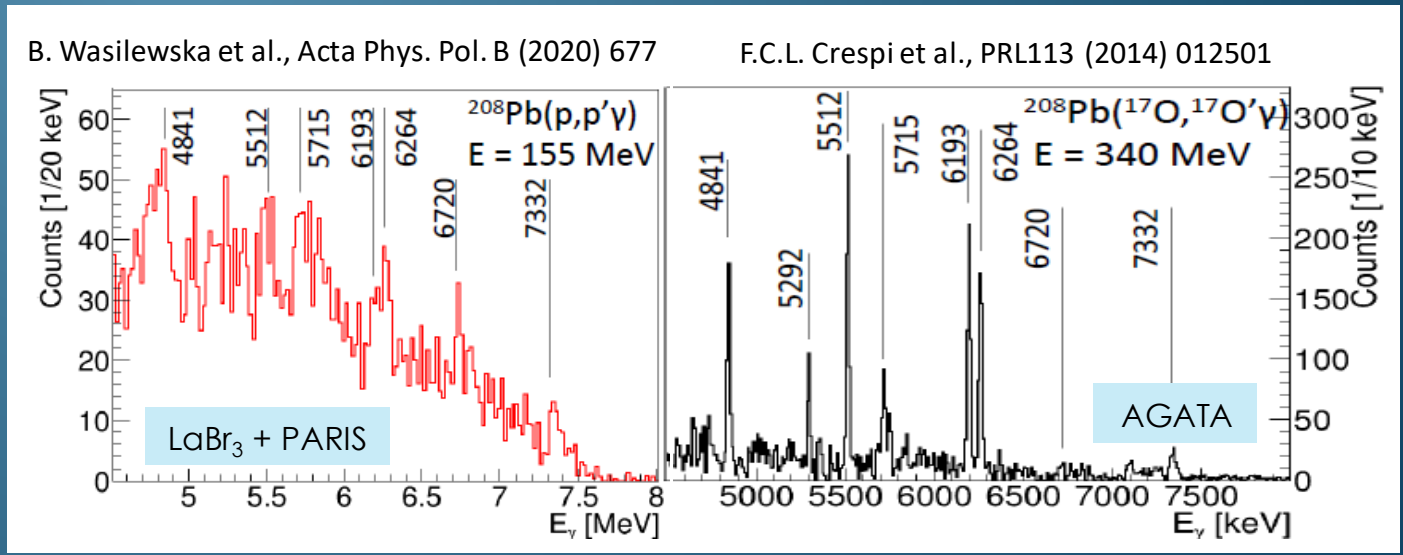






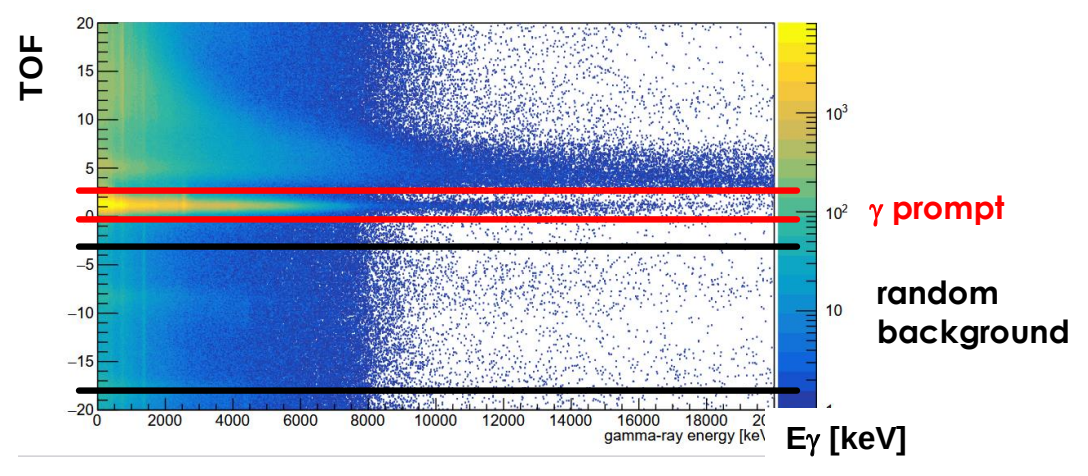
B. Wasilewska et al., Acta Phys. Pol. B (2020) 677

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

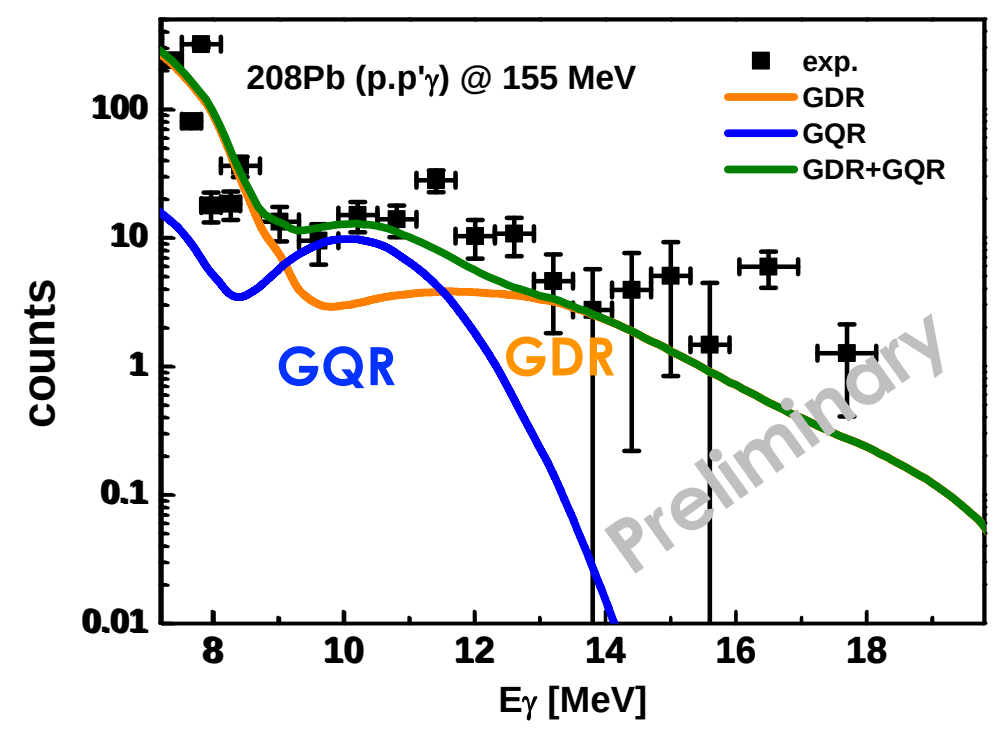


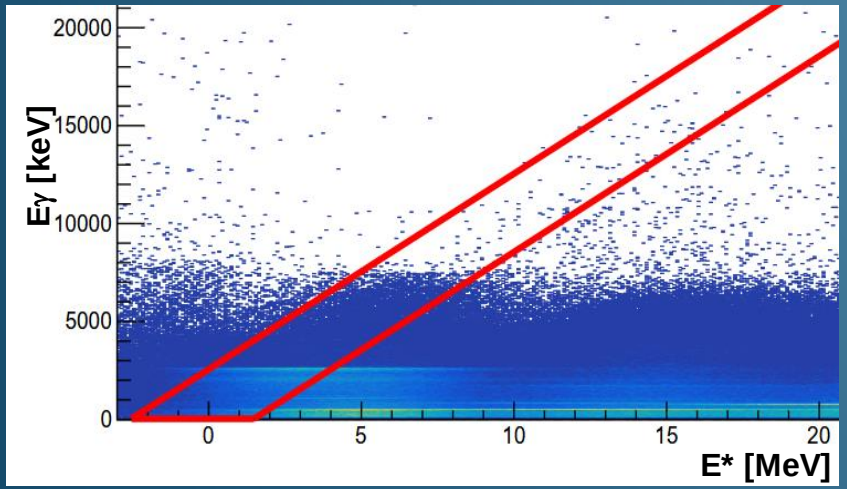
Thanks to better energy resolution
more detailed study of pygmy region possible

(p,p'γ) on ^{208}Pb @ 155 MeV



γ-decay to the g.s.

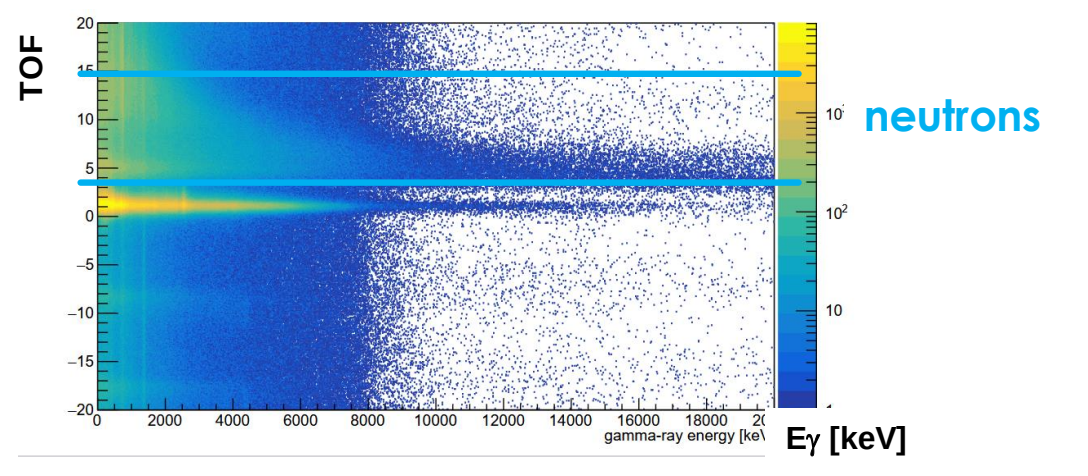




larger GQR excitation cross section than measure for 85 MeV

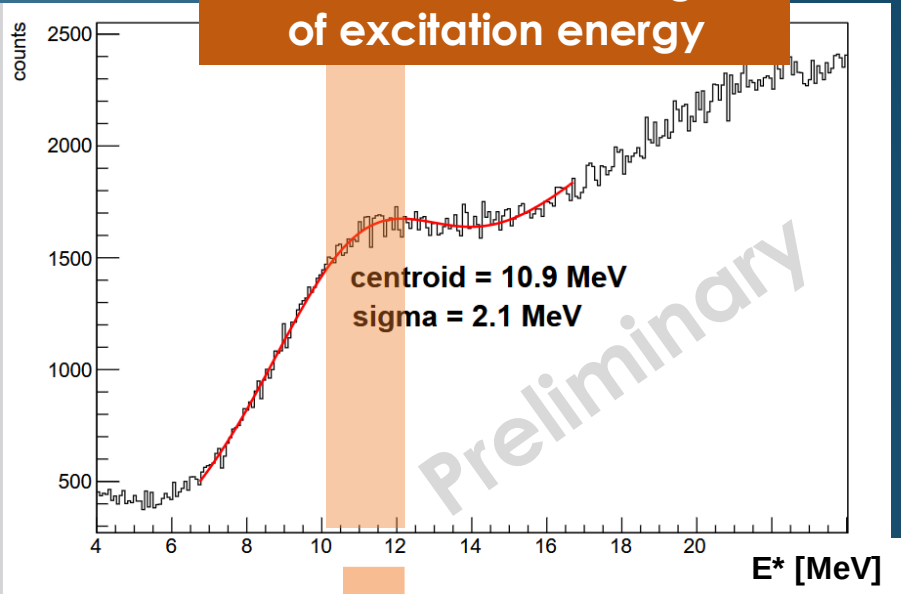
analysis ongoing

Decay from GQR region in ^{208}Pb - preliminary

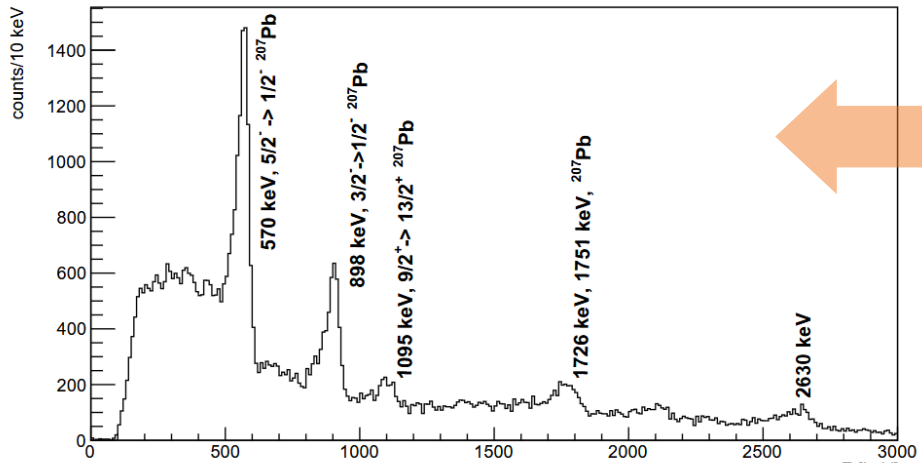


gating on neutron emission

excess in the GQR region of excitation energy



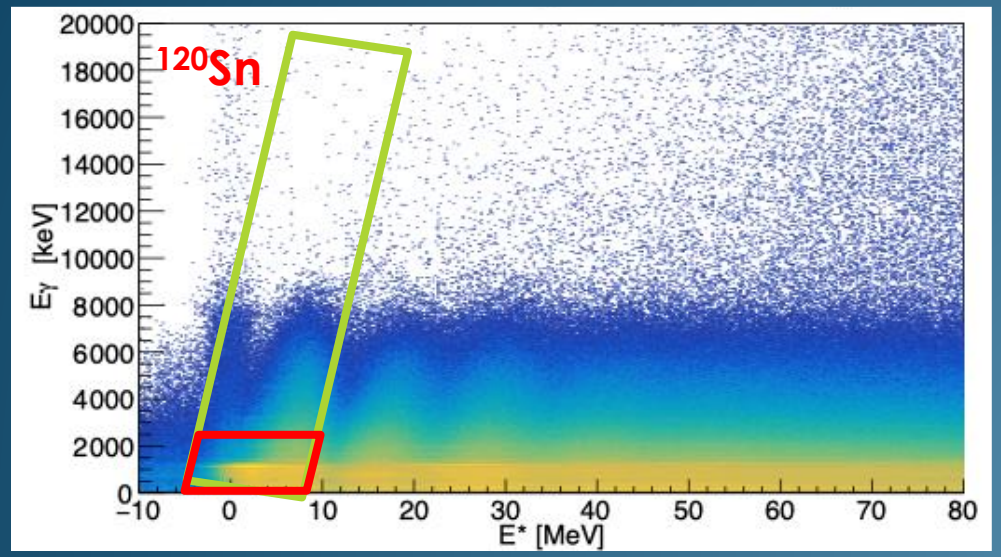
gated on excitation energy region 10-12 MeV (GQR)

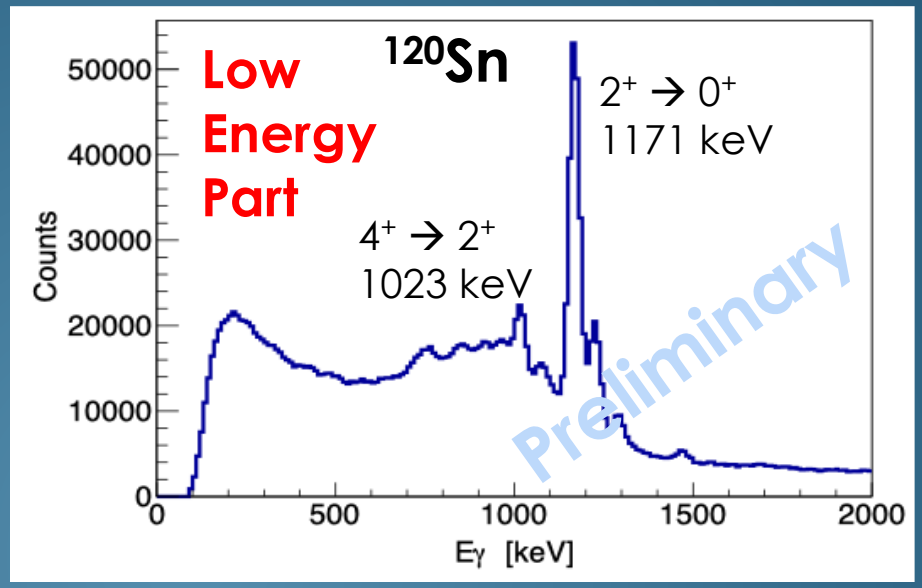


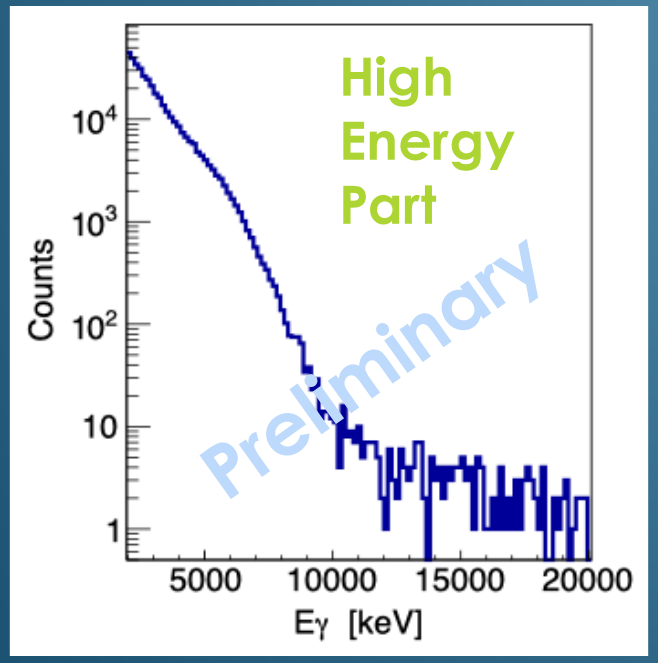
possible study of GQR decay via neutron emission to excited states in ^{207}Pb

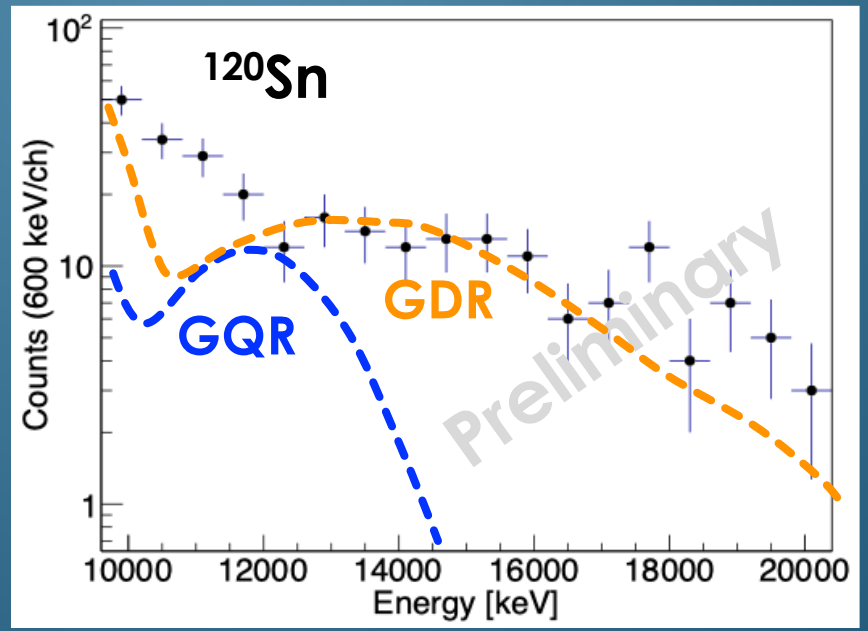
Courtesy: Michał Ciemała

Preliminary results from (p,p'γ) on ^{120}Sn @ 200 MeV







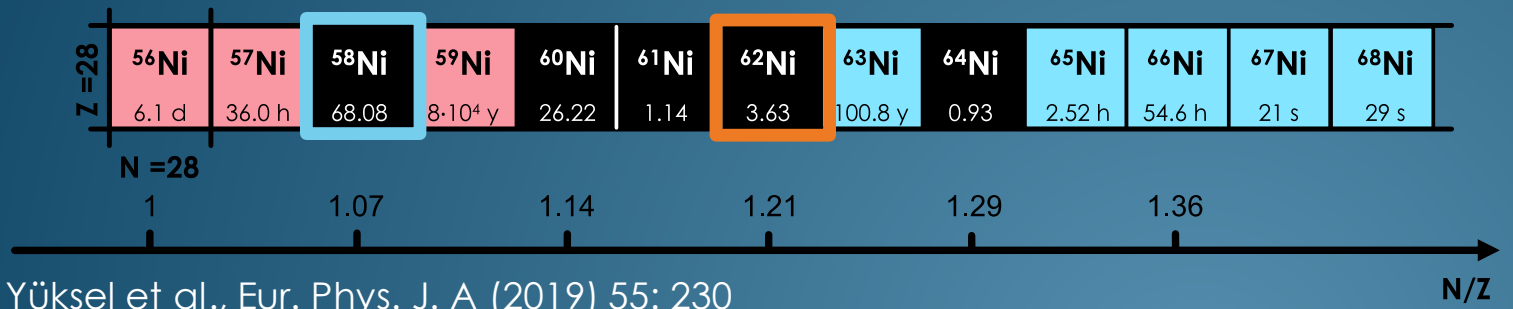


Courtesy: Agnese Giaz

analysis ongoing

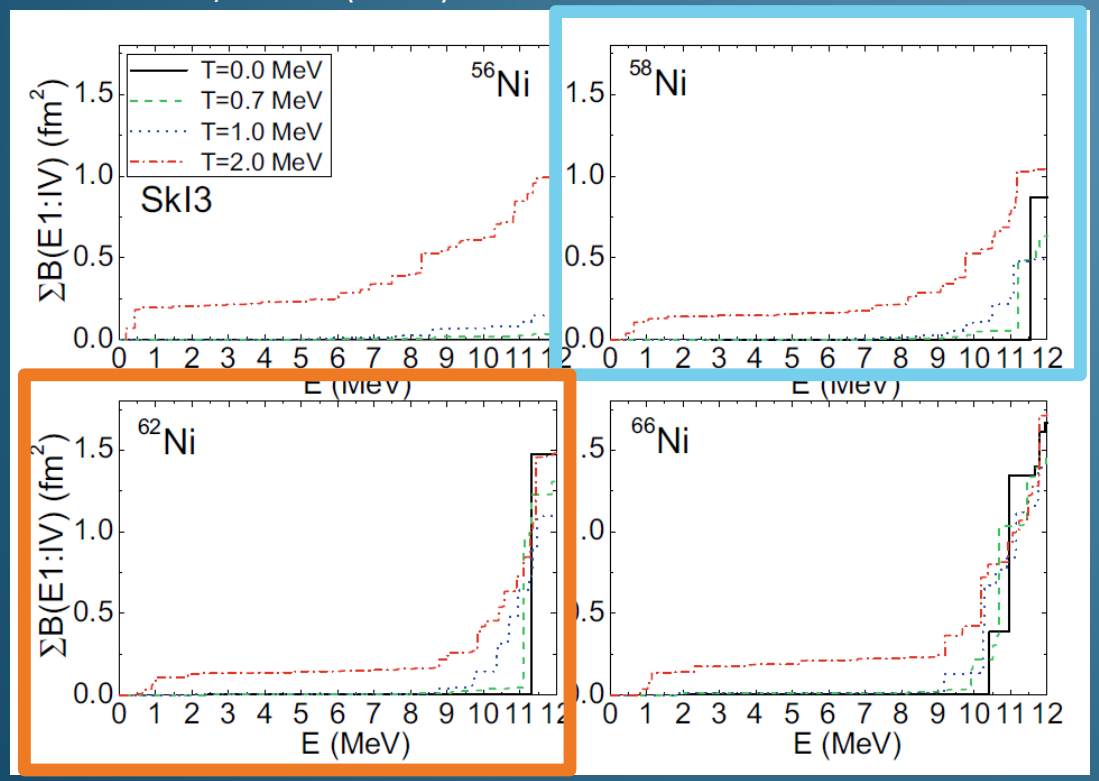
Motivation for study PDR in Ni isotopes

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

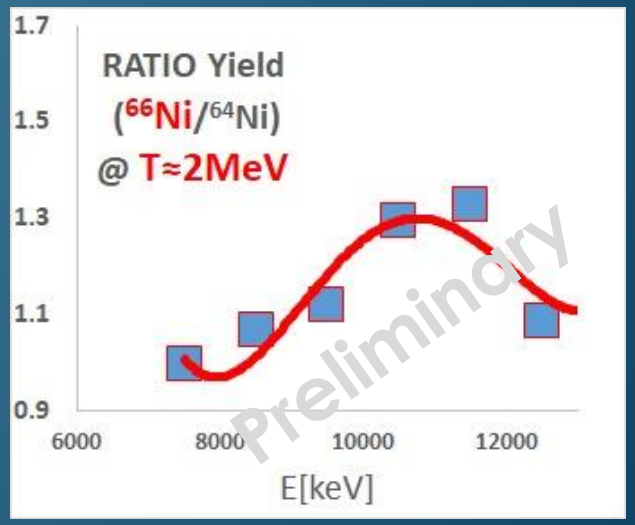


E. Yüksel et al., Eur. Phys. J. A (2019) 55: 230

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)



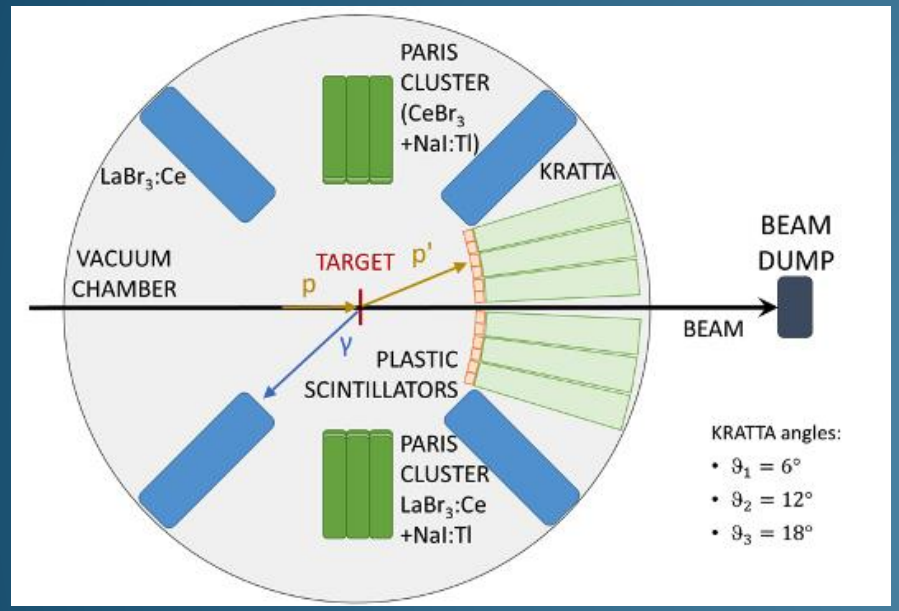
Complementary to investigations done at IFIN labs with same isotopes but with fusion evaporation reactions at finite temperature.

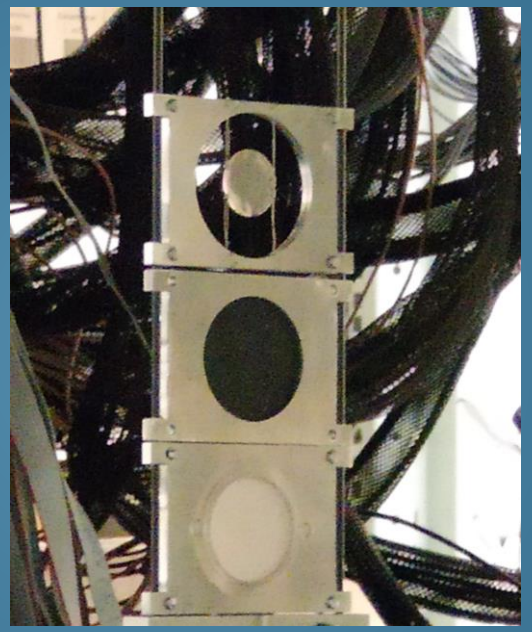


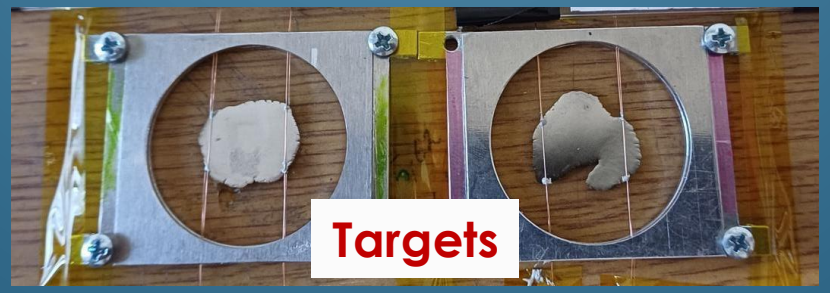
Courtesy: Oliver Wieland

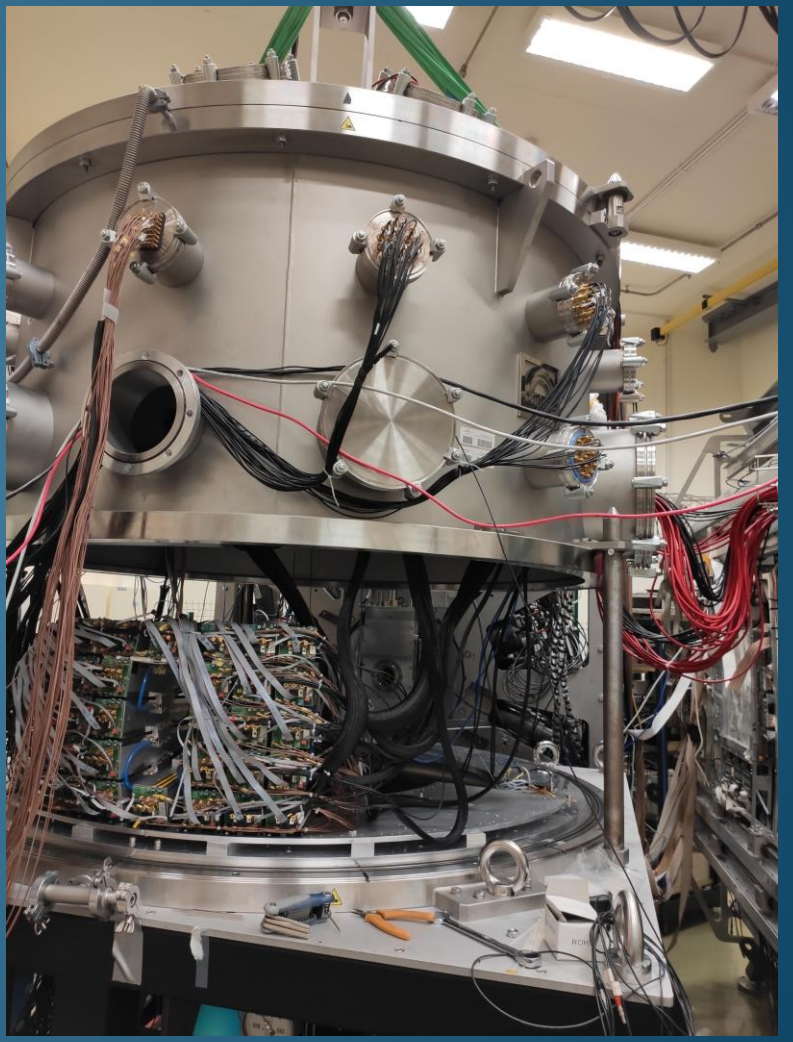
The setup for ^{58,62}Ni (p,p'γ) @ 180 MeV

The same as for ^{120}Sn experiment

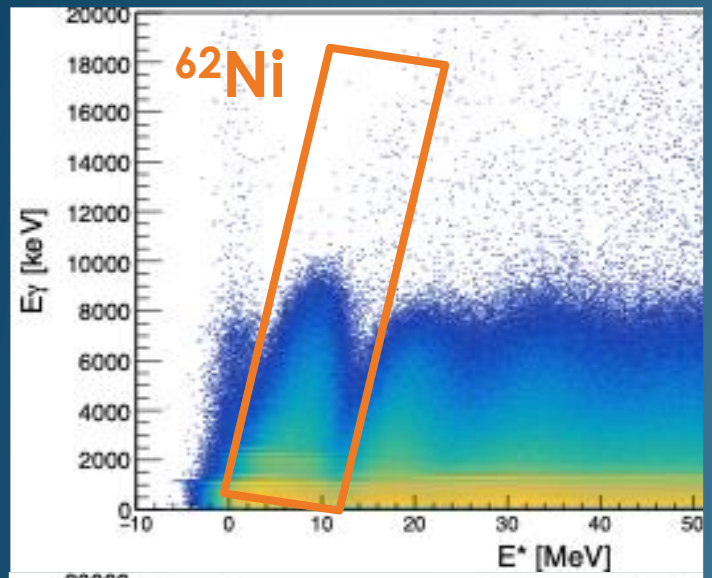


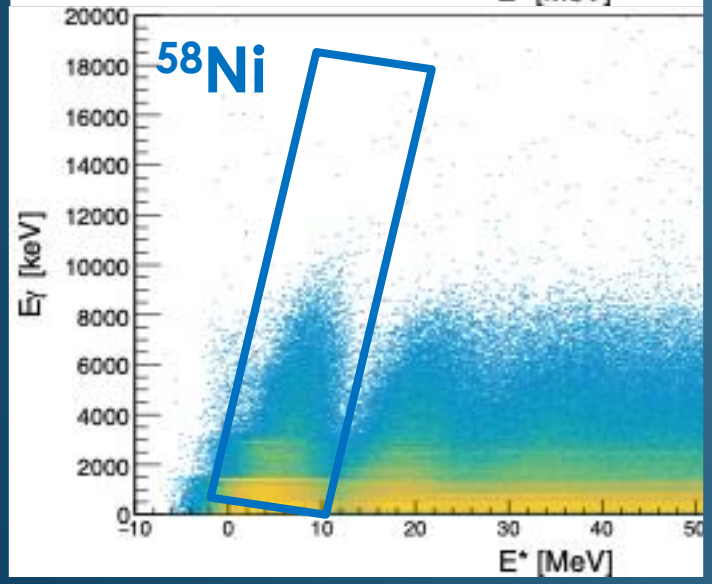




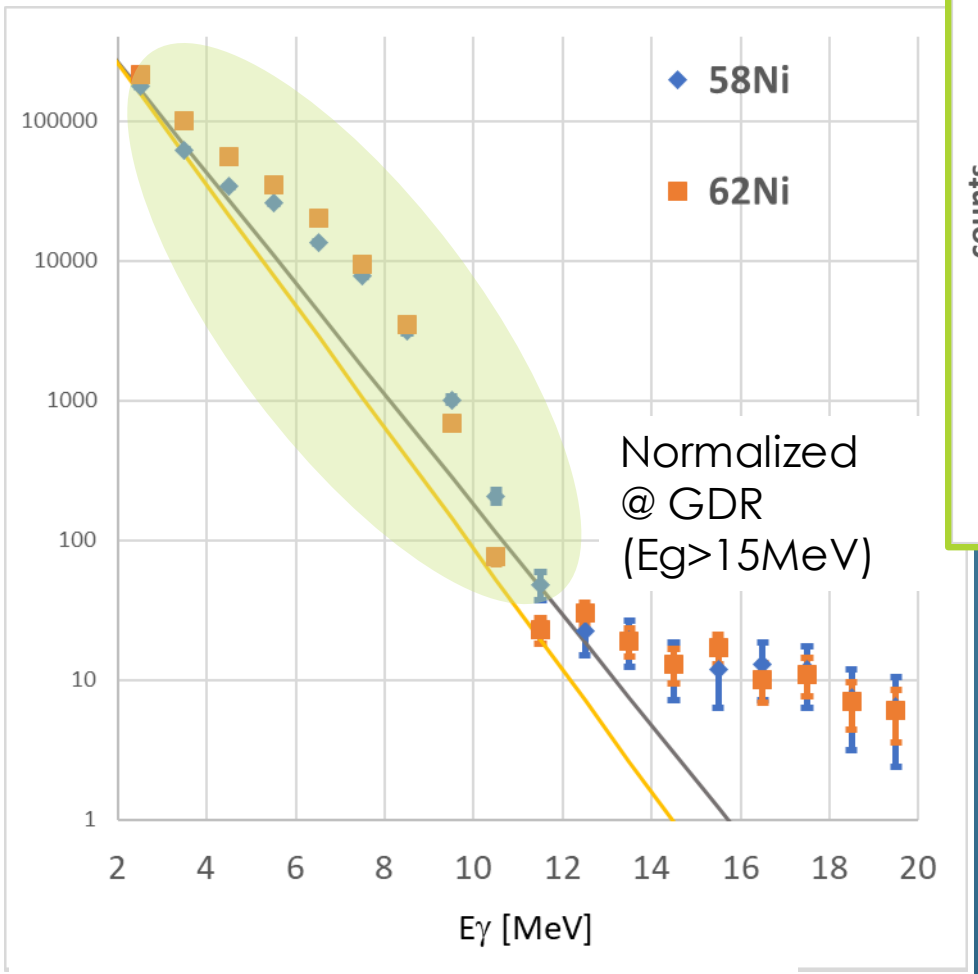


PDR in Ni isotopes – preliminary results

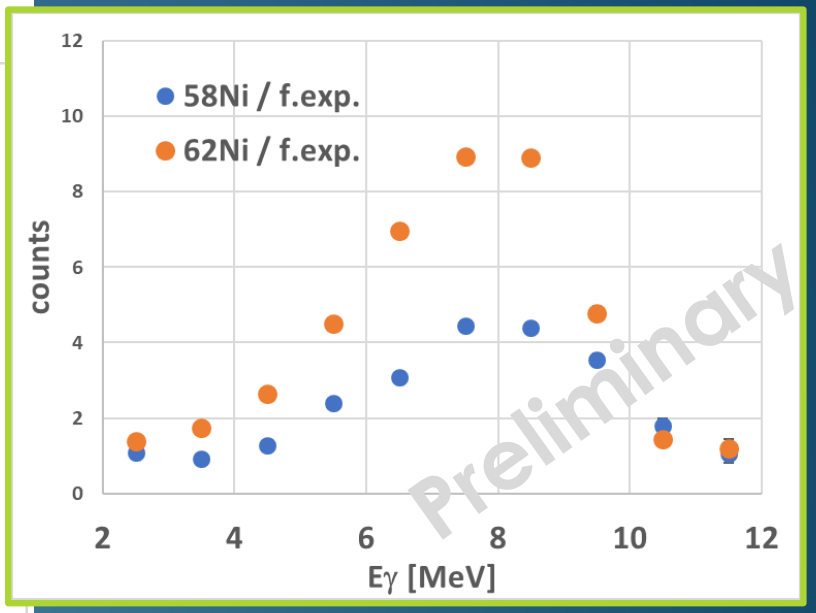




^{62}Ni N/Z = 1.21
Pygmy expected



^{58}Ni N/Z = 1.07
small extra yield expected



increase of counts in PDR region for ^{62}Ni

analysis ongoing

Courtesy: Agnese Giaz, Oliver Wieland

PDR in Ni isotopes – continuation

PROPOSAL: CONTINUATION EXPERIMENT AT CCB

July 8, 2024

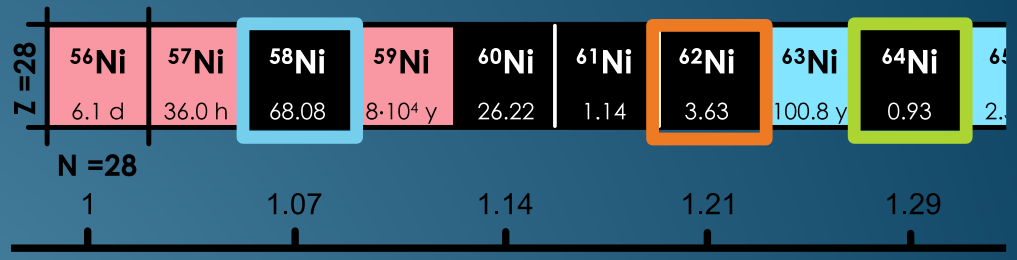
PDR in ^{64}Ni as systematic sequel of the study in ^{58,62}Ni isotopes using the inelastic proton scattering at CCB

Spokespersons:

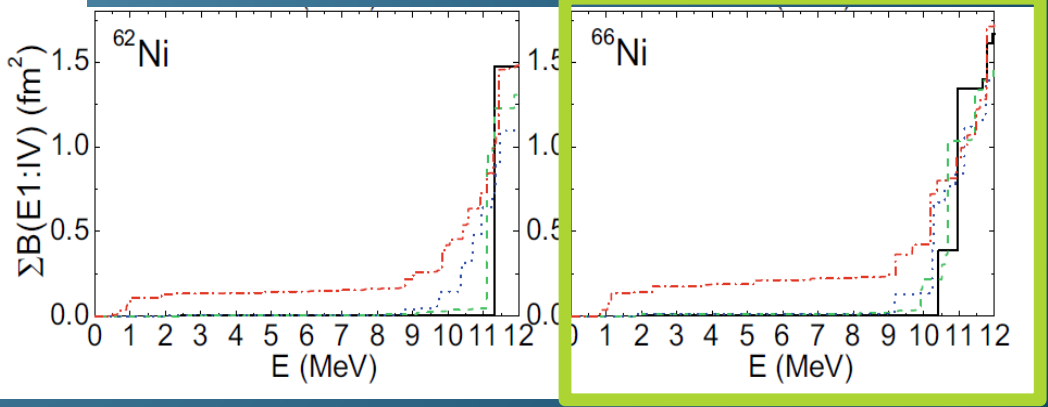
A. Giaz (INFN Milano) & **M. Ciemała** (IFJ PAN Krakow)

Partecipants:

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. Ciemała, M. Kmiecik, P. Bednarczyk, B. Fornal, J. Grębosz, J. Łukasik, A. Maj, M. Matejska-Minda, P. Pawłowski, M. Zięblíński,
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. Pellegri, R. Neveling



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

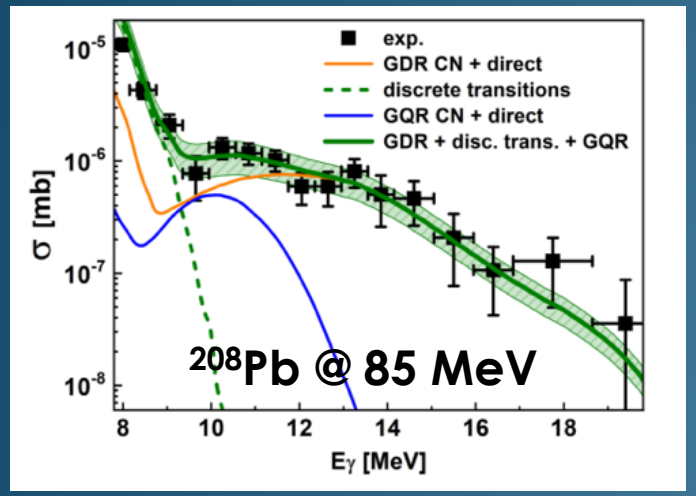


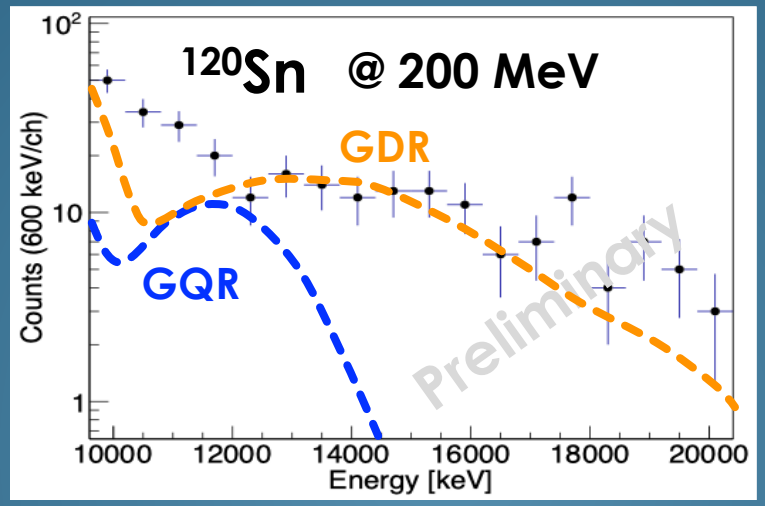
E. Yüksel et al., Eur. Phys. J. A (2019) 55: 230

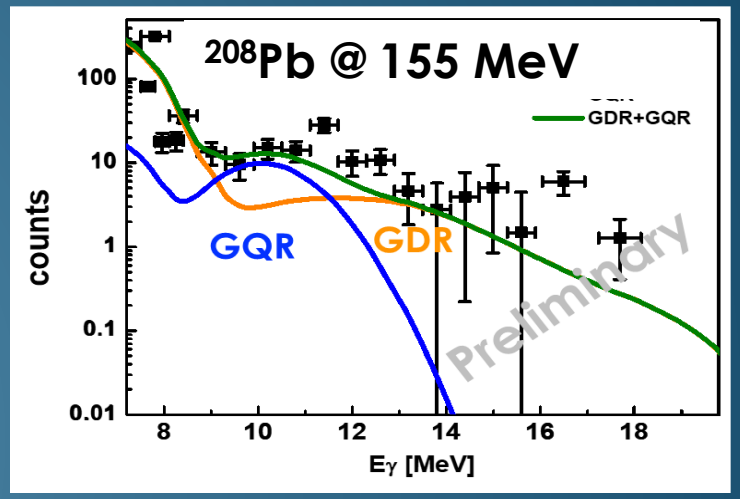
starting in February 2025

Summary

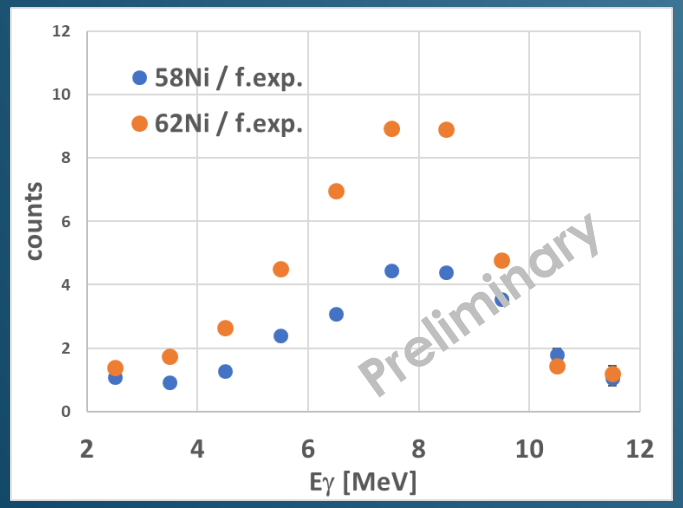
- Using proton beams at CCB IFJ PAN in Kraków and (p,p'γ) reaction we studied ISGQR γ-decay from ^{208}Pb and ^{120}Sn







- and γ-decay from PDR region in ^{58,62}Ni



- The analysis is ongoing.
- Continuation of PDR study in Ni isotopes is going to start next week

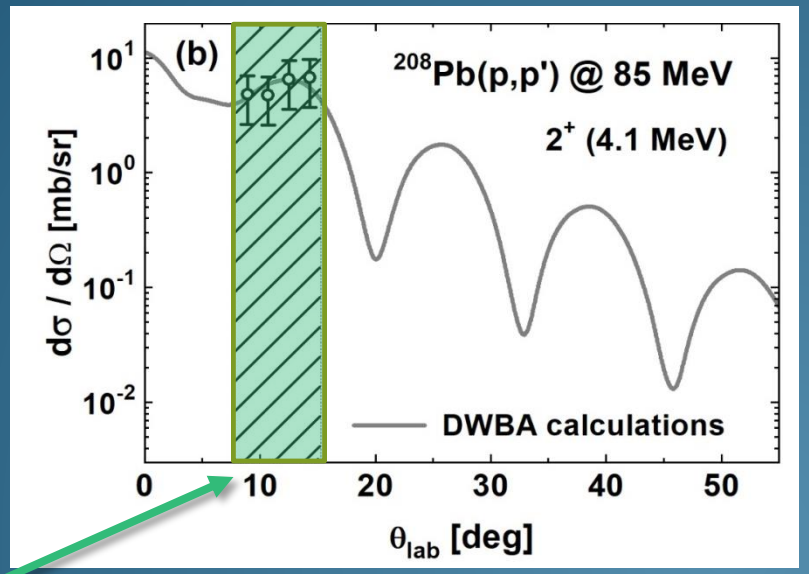
Thanks to:

- 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, B. Sowicki, M. Zięblíński,
- 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): 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. Pellegri,
- IFJ PAN Krakow (Poland) & IPHC Strasburg (France): C. Schmitt

EURO-LABS
EUROPEAN LABORATORIES FOR ACCELERATOR BASED SCIENCES

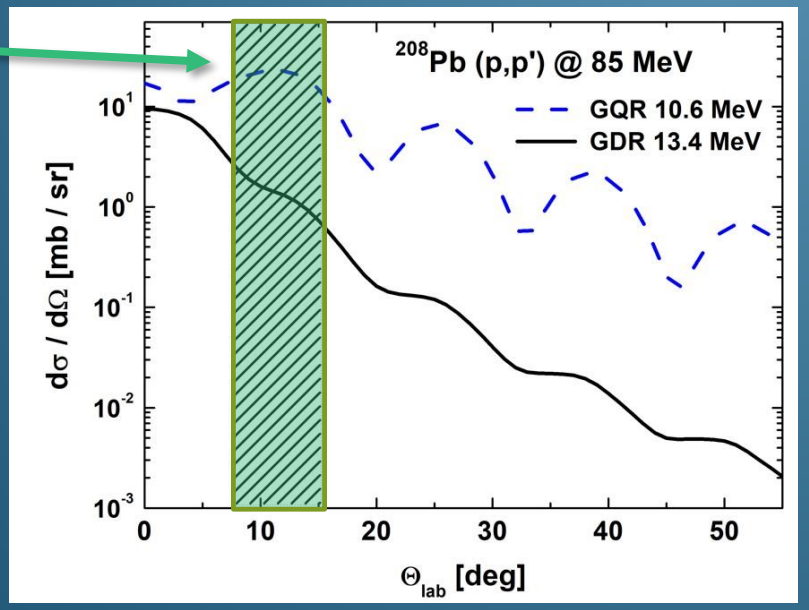
Cross sections for excitations in ^{208}Pb

(p,p')@85 MeV



2^+ state

the angles covered by the experimental setup



GQR

GDR

(p,p')@155 MeV