

# The study of giant resonances excited by scattered protons at CCB IFJ PAN in Kraków

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6<sup>th</sup> International Conference on  
Collective Motion in Nuclei under  
Extreme Conditions

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# Collaboration

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V. Guadilla - **IFIC Valencia**

Ch. Schmitt, S. Kihel - **IPHC Strasbourg**

LiQuiang Qi - **IPN Orsay**

M. Stanoiu - **NIPNE Bucharest**

# Cyclotron Center Bronowice (CCB) at IFJ PAN

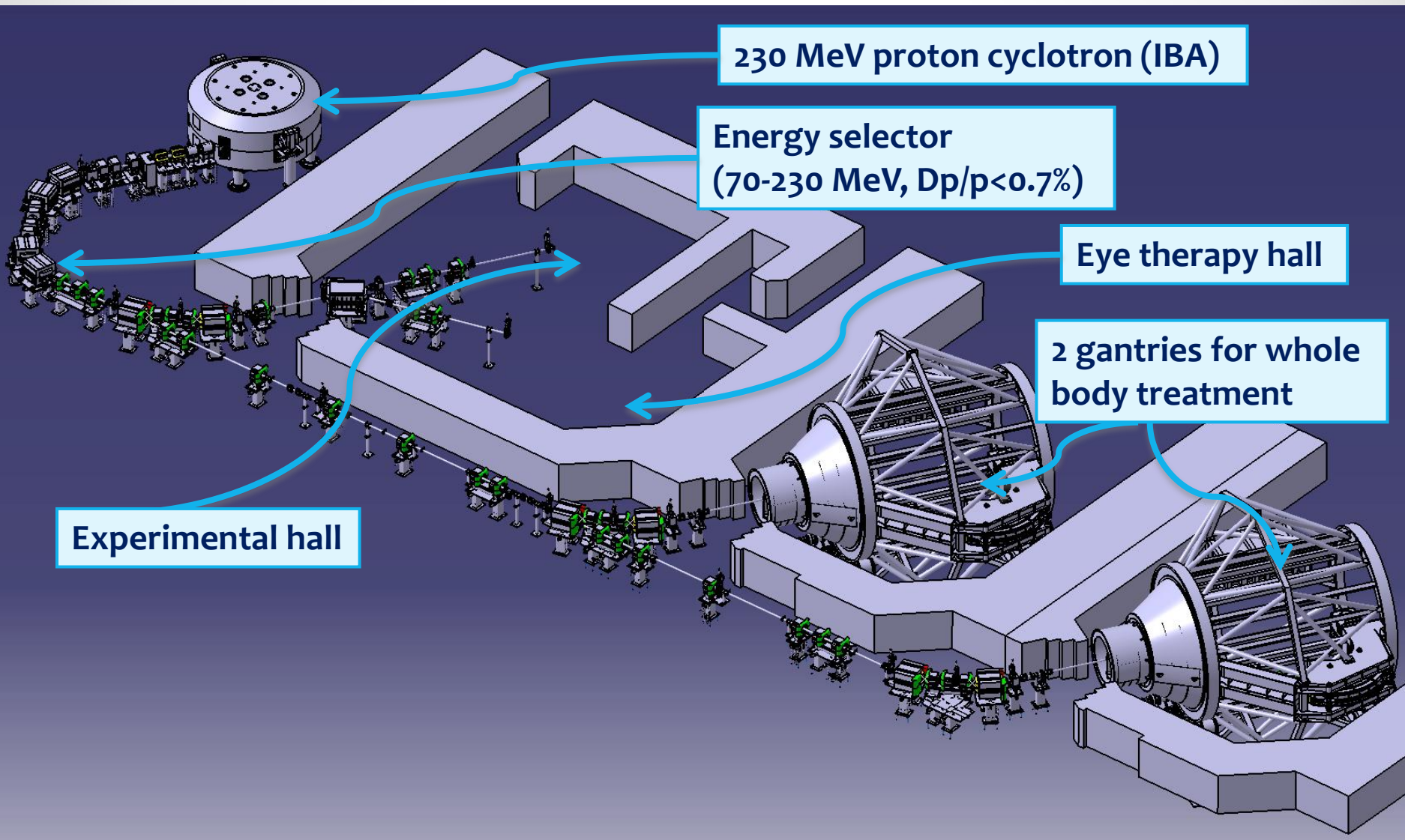
proton cyclotron ( $E_p=70-230$  MeV)

proton cancer therapy,  
and additionally research program  
concerning:

- nuclear physics,
- radiobiology
- dosimetry
- and medical physics

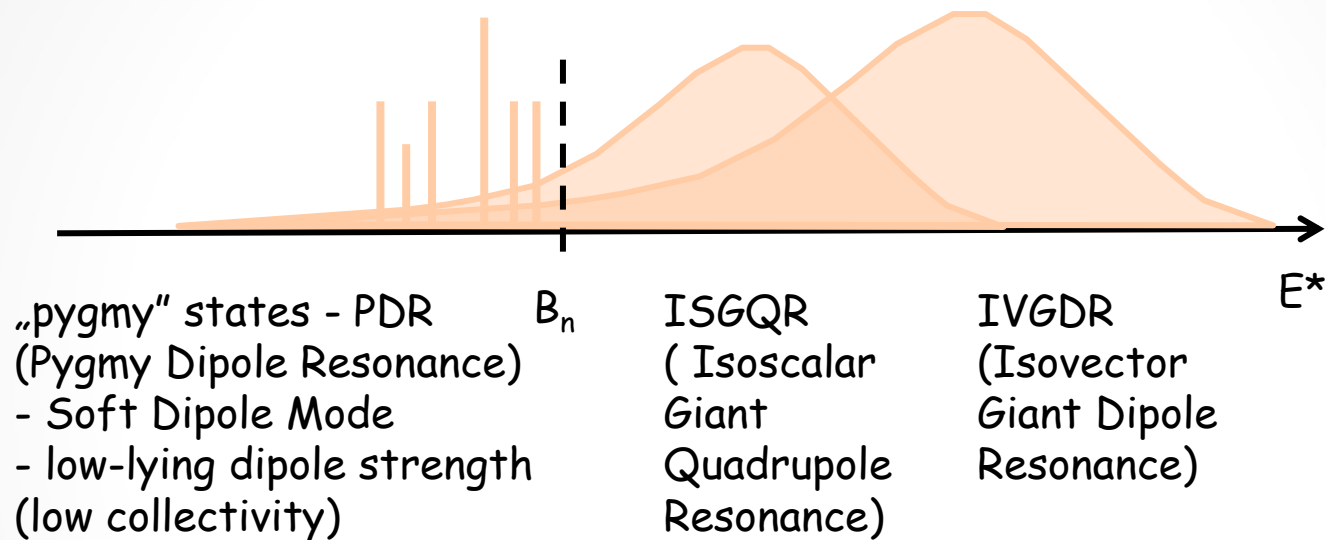


# CCB layout



# Excitations studied with proton beam

## Giant Resonances - GR



Usually excited in:

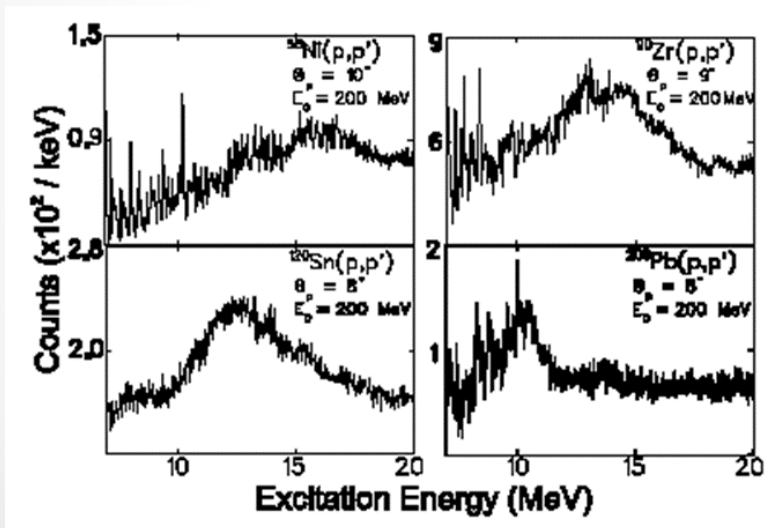
- fusion - evaporation
- or inelastic scattering ( $\gamma, \gamma'$ ), ( $p, p'$ ), ( $\alpha, \alpha'$ ), heavy ions

main aim of the ( $p, p'\gamma$ ) measurement at CCB - GR gamma decay

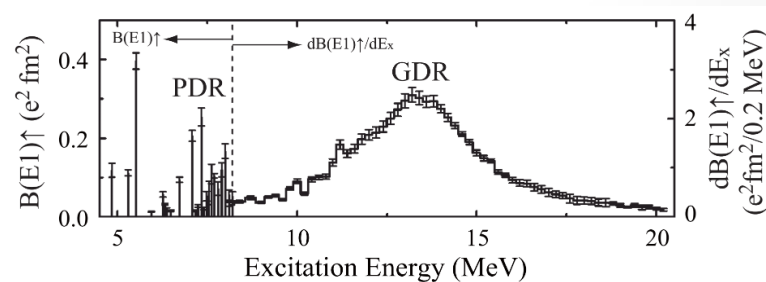
# Motivation

- GDR - rather well known - information on nuclear shape
- GQR not well known, studied mainly using (p,p') and (e,e') due to small yield ( $\sim 10^{-4}$ ) GQR gamma decay measured so far only in  $^{208}\text{Pb}$

Shevchenko PRL93(2004)122501-1



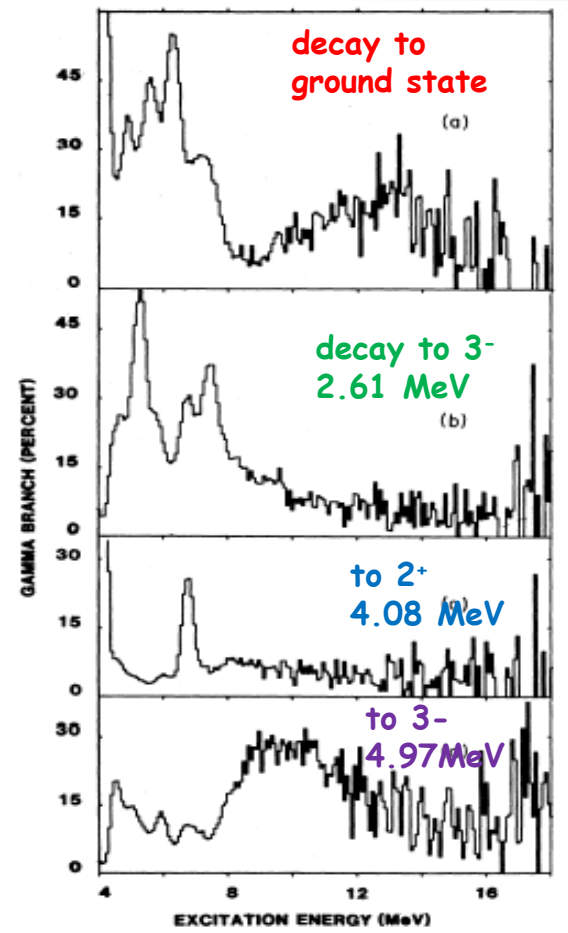
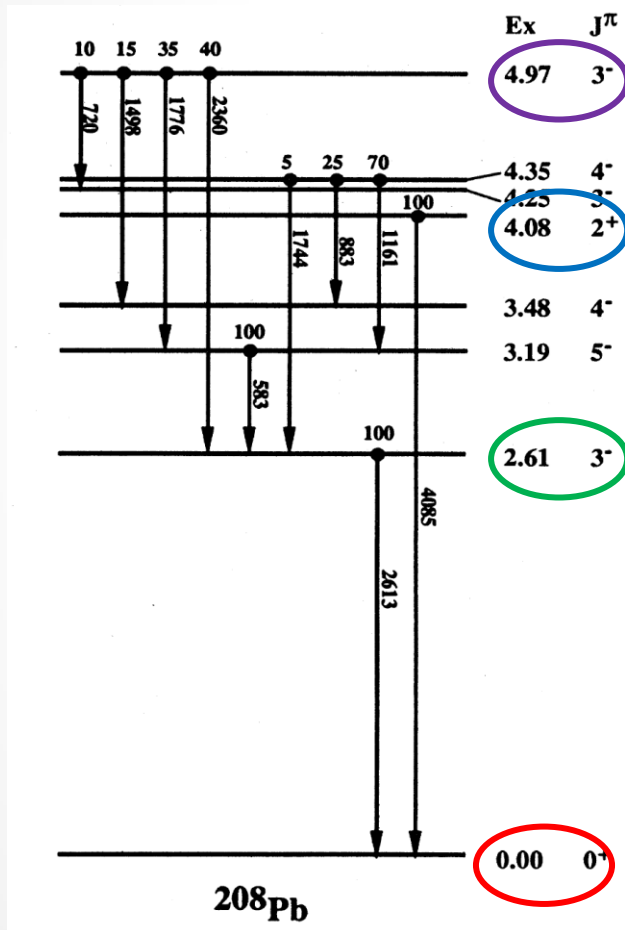
A. Tamii et al., PRL107 (2011) 062502;  
A. Tamii et al., Eur. Phys. J. A50 (2014) 28



# Giant resonances gamma decay in $^{208}\text{Pb}$

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

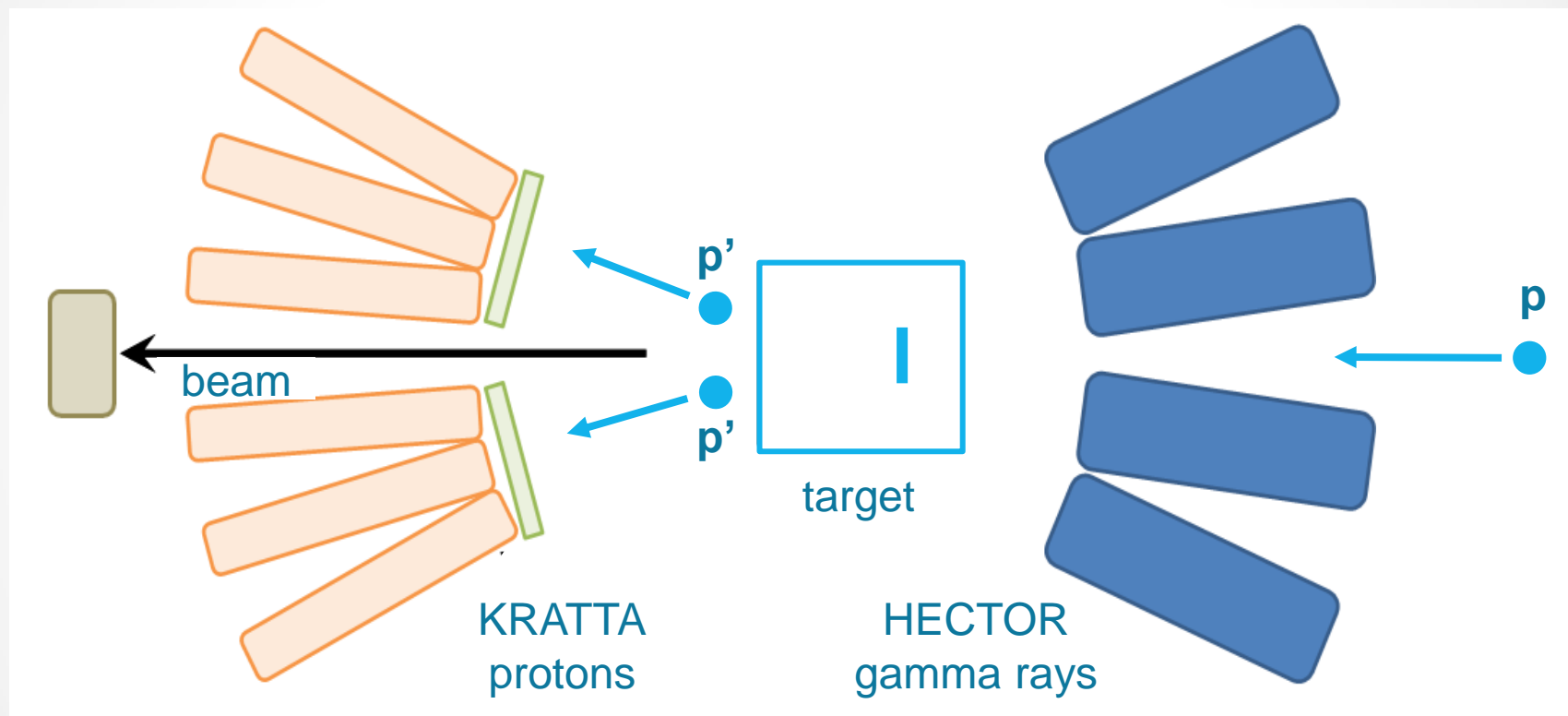
J.Beene et al., PRC39(1989)1307



Excitation energy measured in coincidence with  $\gamma$ -ray

# Idea of the experiment

p @ 85 MeV on  $^{208}\text{Pb}$  target  $48\ \mu\text{m}$  ( $54.5\ \text{mg}/\text{cm}^2$ ) thick



coincidence measurement of gamma rays and scattered protons



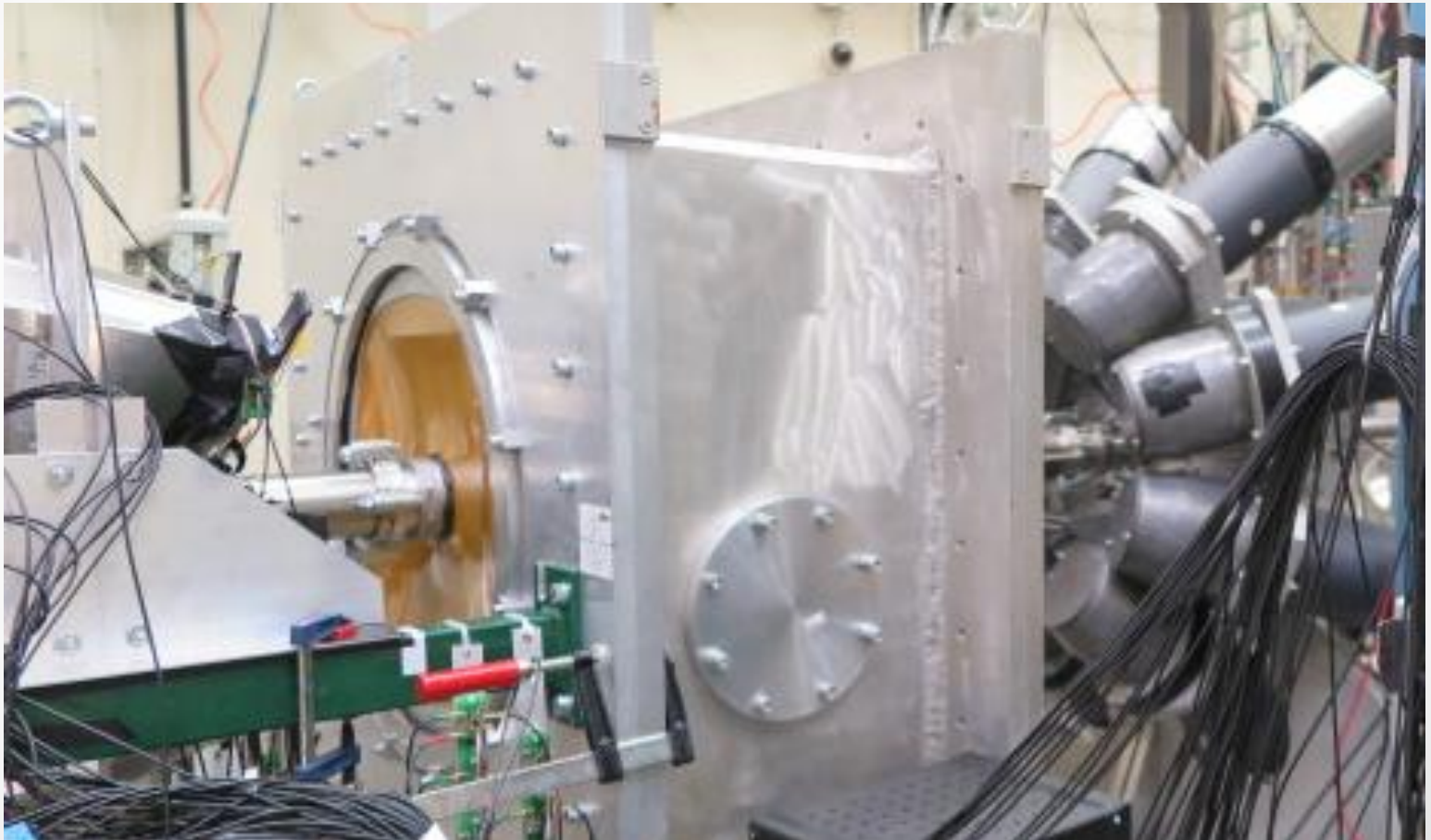
# Experimental setup

**KRATTA** (16 CsI telescopes)

**HECTOR** (8 BaF<sub>2</sub>)

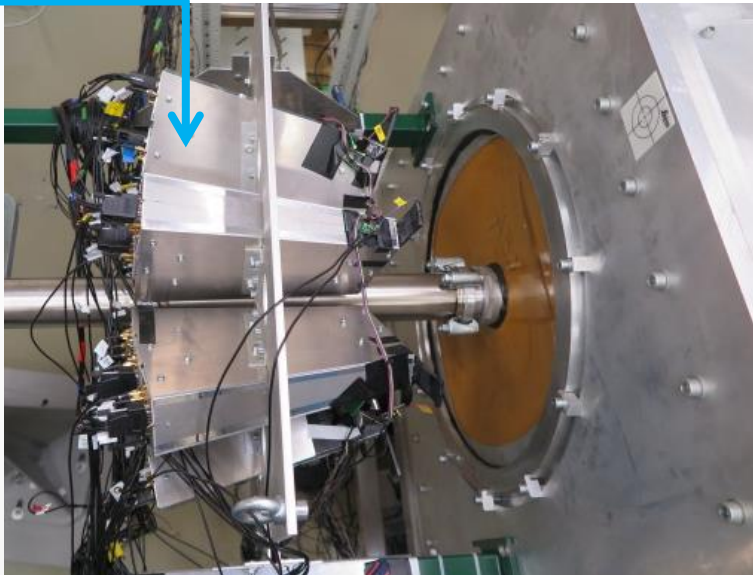
**LaBr<sub>3</sub>** (large volume 8"x3.5")

**PARIS** (cluster of 9 „phoswiches”  
LaBr<sub>3</sub>/CeBr<sub>3</sub> + NaI)



# Detectors

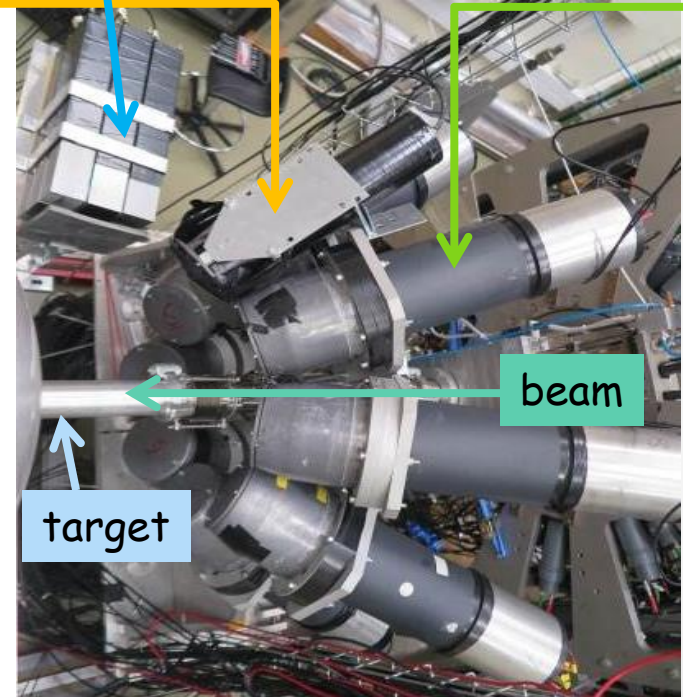
**KRATTA** (16 CsI telescopes,  
at 8-15.3°)  
fast plastic scintillators  
in the front of KRATTA



**HECTOR** (8 BaF<sub>2</sub>)

**LaBr<sub>3</sub>** (large volume 3.5"x8")

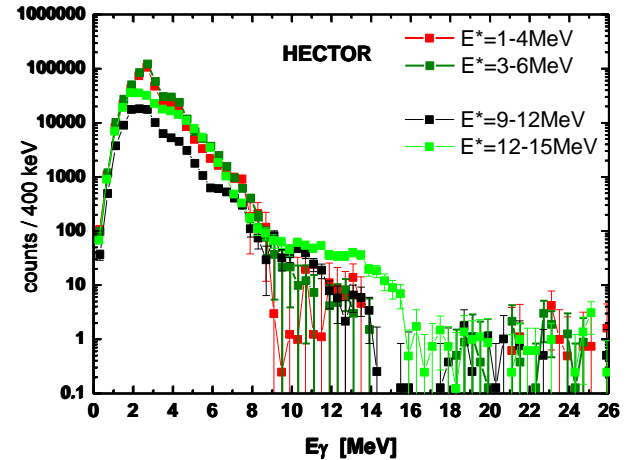
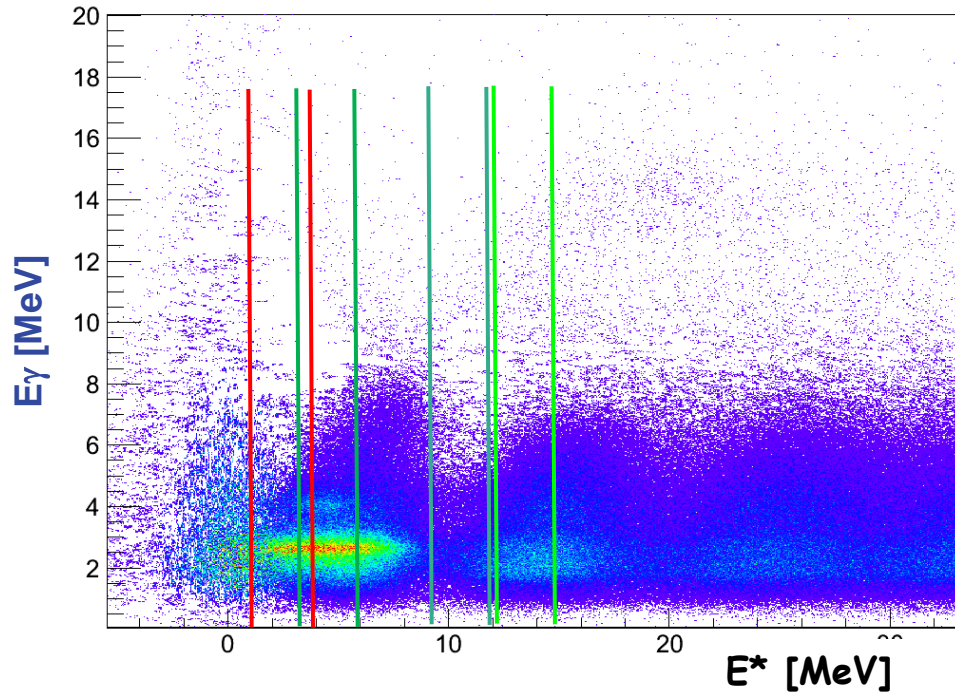
**PARIS** (cluster of 9 „phoswiches”  
LaBr<sub>3</sub>/CeBr<sub>3</sub> + NaI)



# proton - $\gamma$ coincidence matrix

Analysis and results: Basia Wasilewska,  
PhD thesis submitted

HECTOR



gamma decay for different  
excitation energy ranges

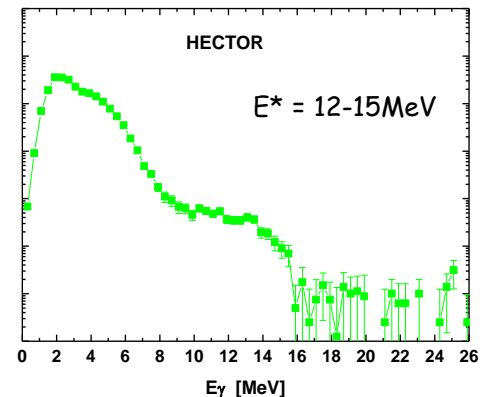
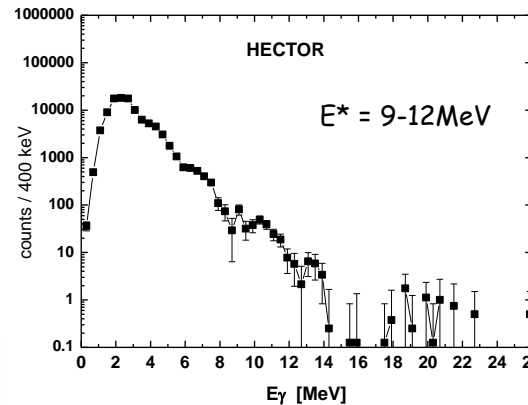
$$E^* = E_{\text{beam}} - E_{\text{scattered proton}}$$

gamma energy vs. excitation energy  
background subtracted

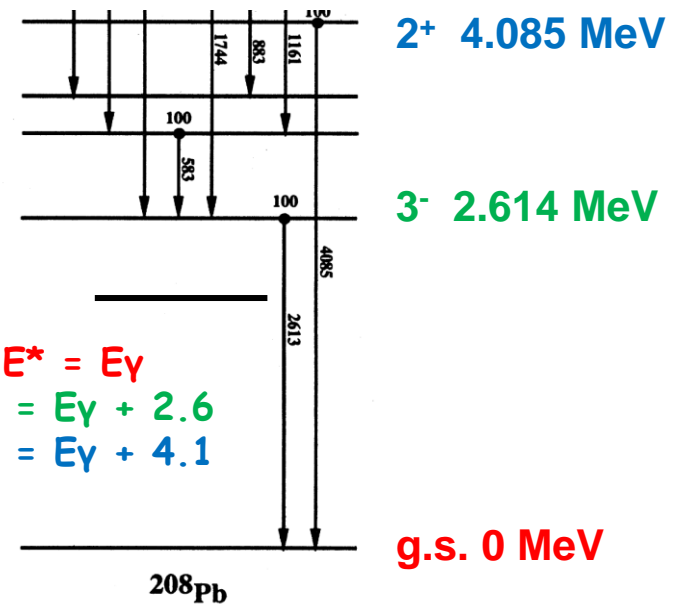
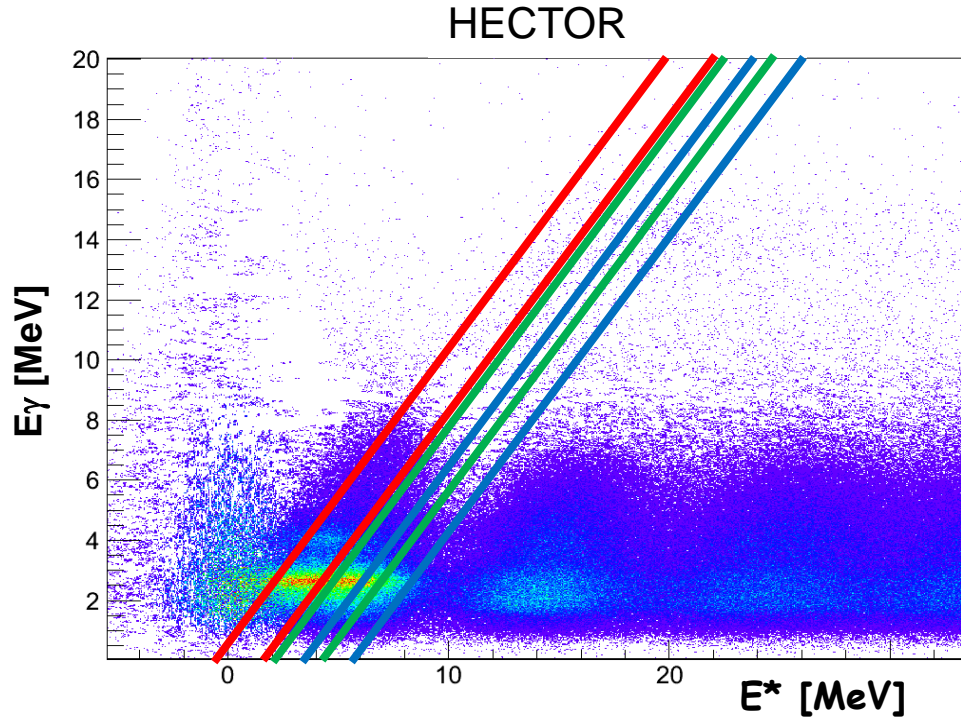
gated by:

proton

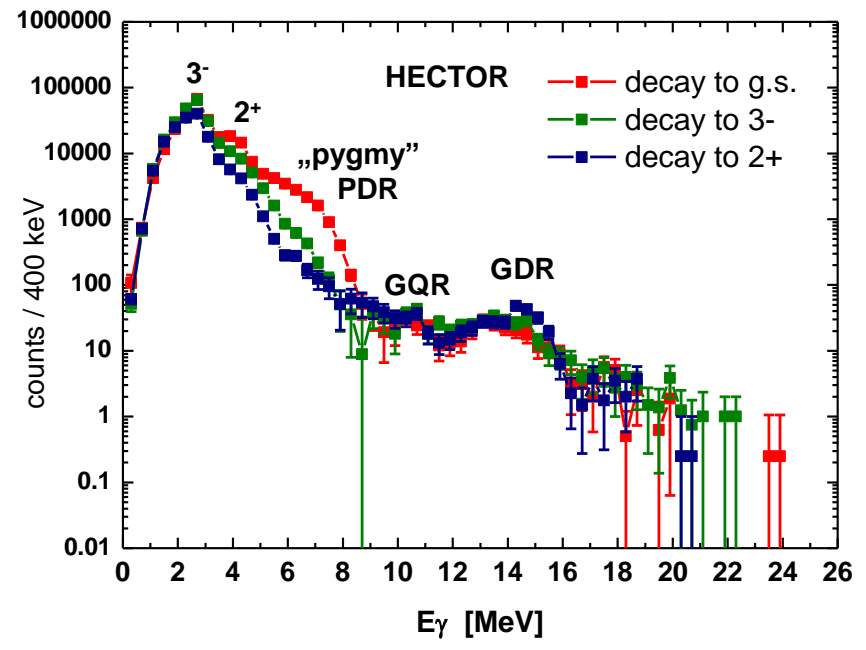
proton and gamma times



# Decay to final states

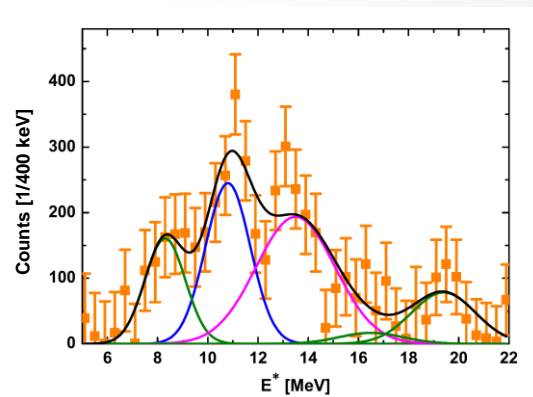
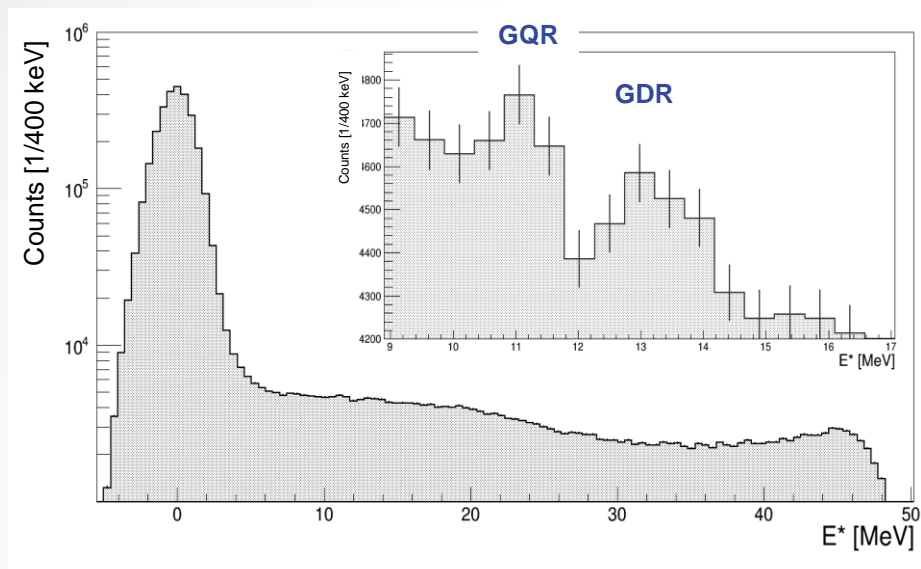


gamma decay from the region of GDR, GQR and low-lying states (PDR) observed

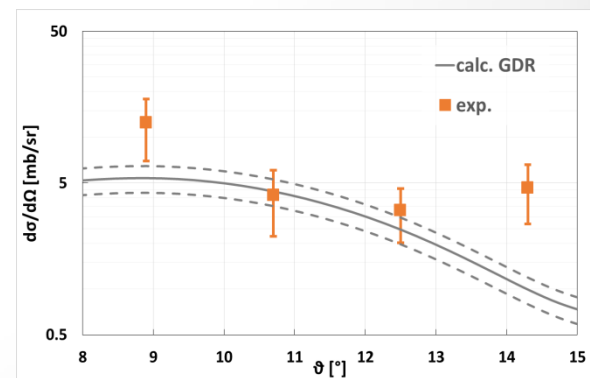
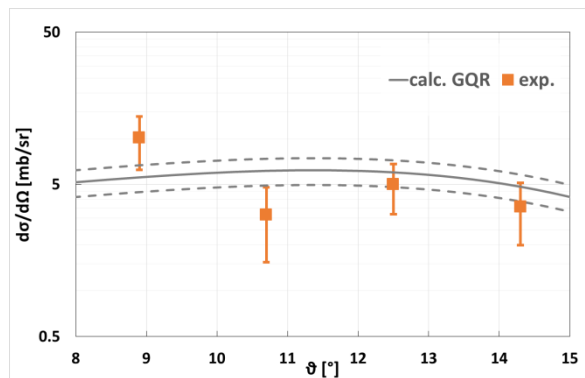
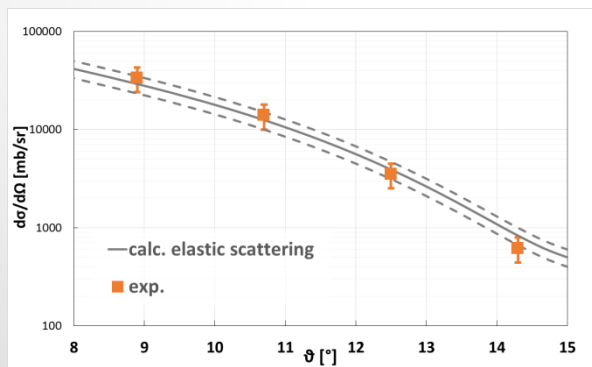


# GR excitations

Singles - excitation energy, 1 h of measurement



## Cross sections FRESCO calculations



# GDR gamma decay to g.s.

direct and statistical GDR decay to ground state via  $\gamma$  emission

$$\Gamma = \Gamma\uparrow + \Gamma\downarrow$$

GDR parameters

$$B(E1) = 67 \text{ e}^2\text{fm}^2 = 120\% \text{ EWSR}$$

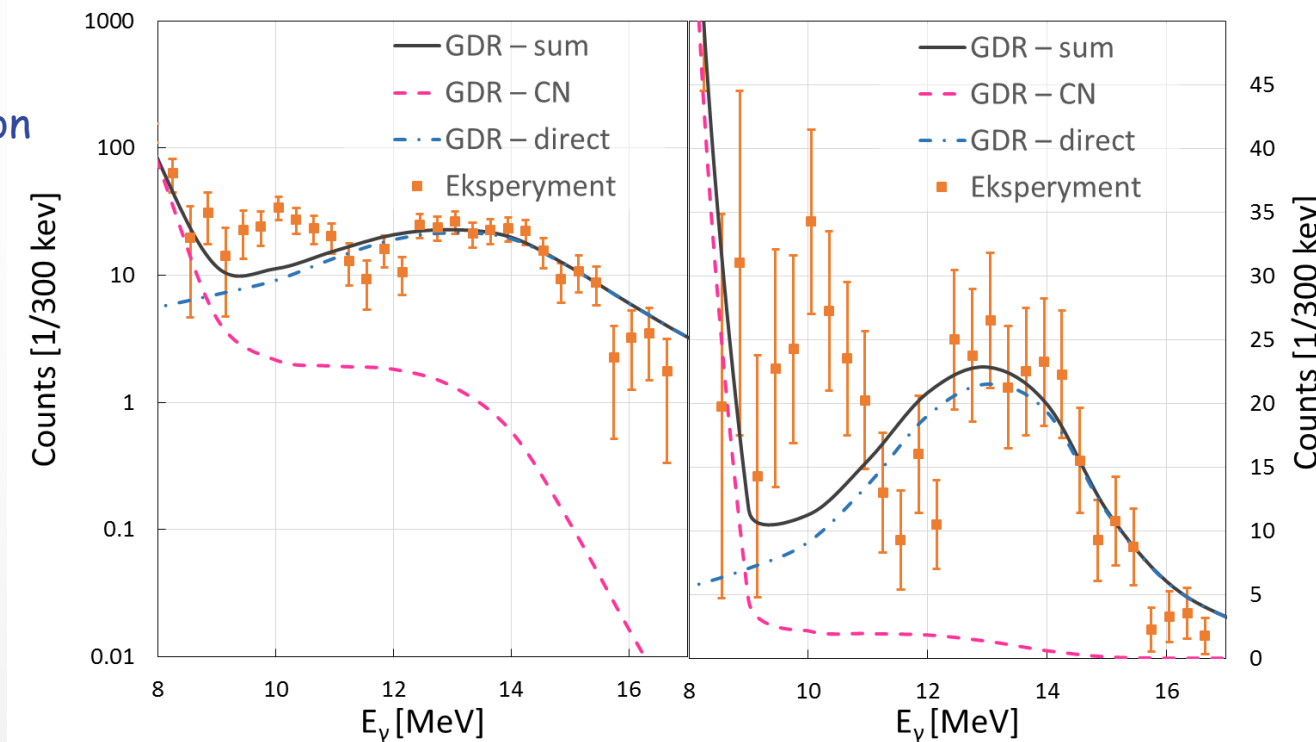
$$E_{\text{GDR}} = 14 \text{ MeV}$$

$$\Gamma = 3.7 \text{ MeV}$$

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

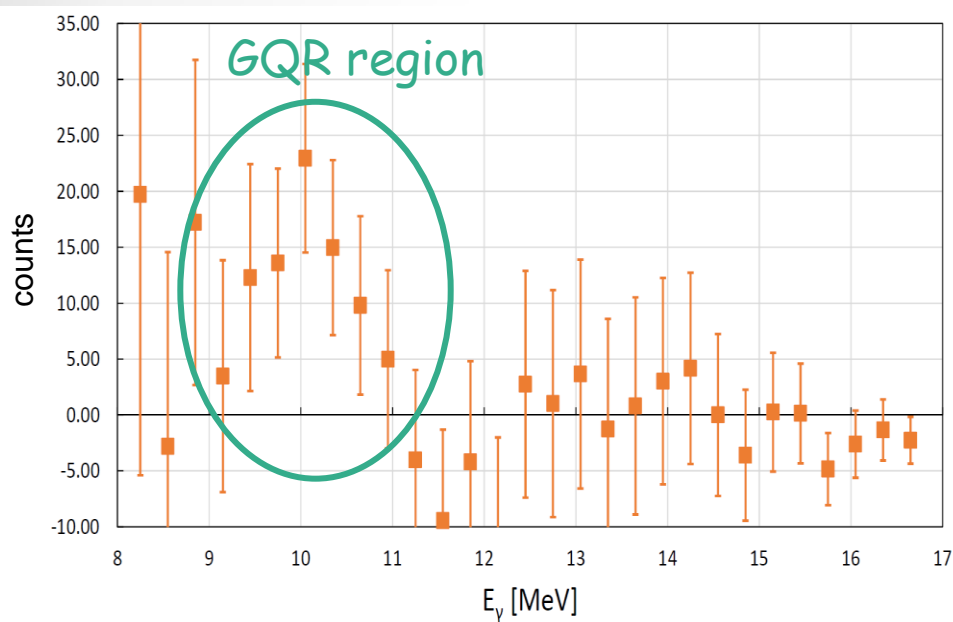
Calculations using: Fresco (excitation cross section) + OneStep (CN decay)

$\gamma$  decay cross section converted to counts



# GQR energy region

difference: total  $\gamma$  ray spectrum - GDR part



cross section for  $\gamma$  decay to g.s.  
in GQR region

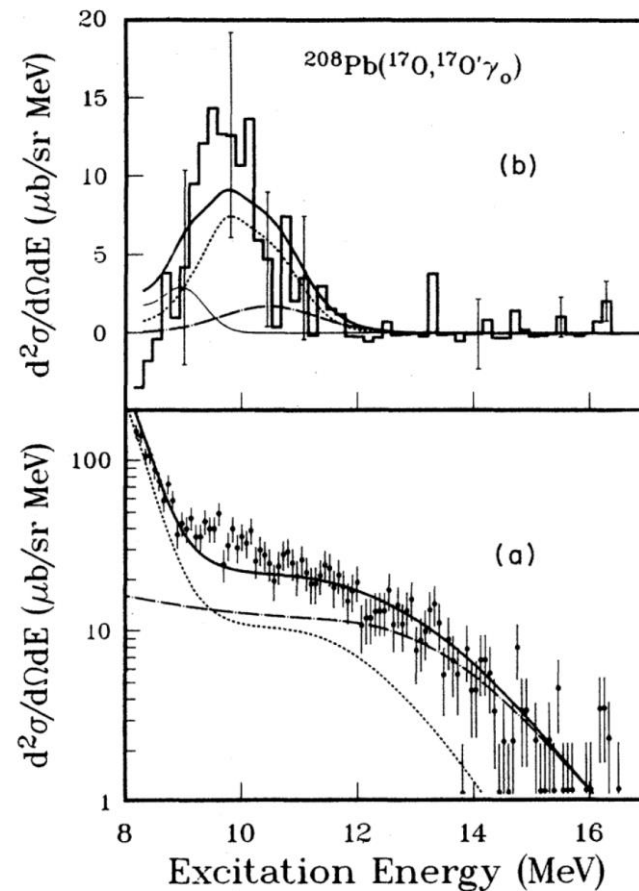
$$\sigma_{p,p'\gamma_0}^{ISGQR}(\vartheta_K) = 18 \pm 10 \mu\text{b}$$

estimated branching ratio

$$\Gamma_{\gamma_0} / \Gamma = 12 \pm 8 \times 10^{-4}$$

surprisingly large value for E2

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



$$\Gamma_{\gamma_0} / \Gamma = 4 \pm 1 \times 10^{-4}$$

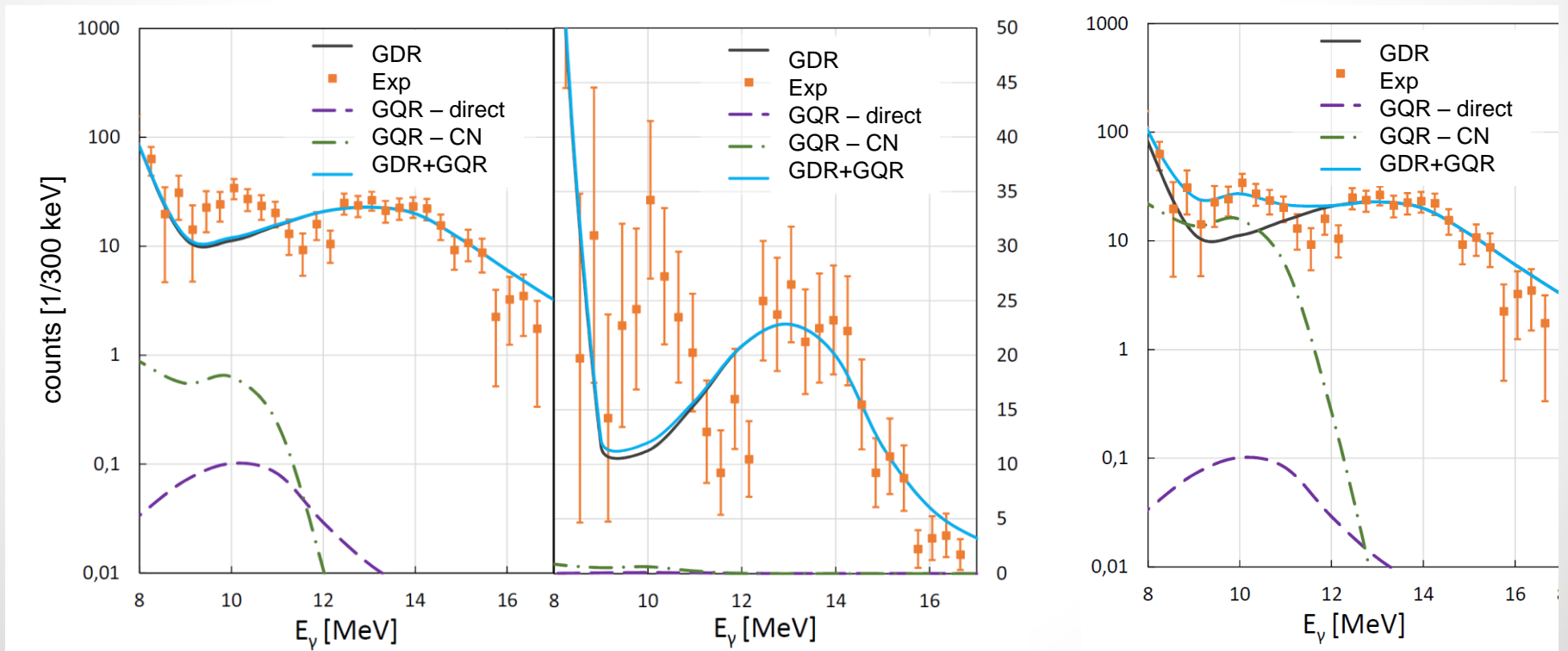
# GQR decay calculations

similar as for GDR decay - direct + statistical

$B(E2) = 4200e^2fm^4 = 47\%$  ISEWSR  
 $E_{GQR} = 10.6$  MeV  
 $\Gamma = 2$  MeV

G. S. Adams, et al.,  
*Phys. Rev. C*, **33**:2054,1986

statistical part  $\times 25$   
 to reproduce GQR region





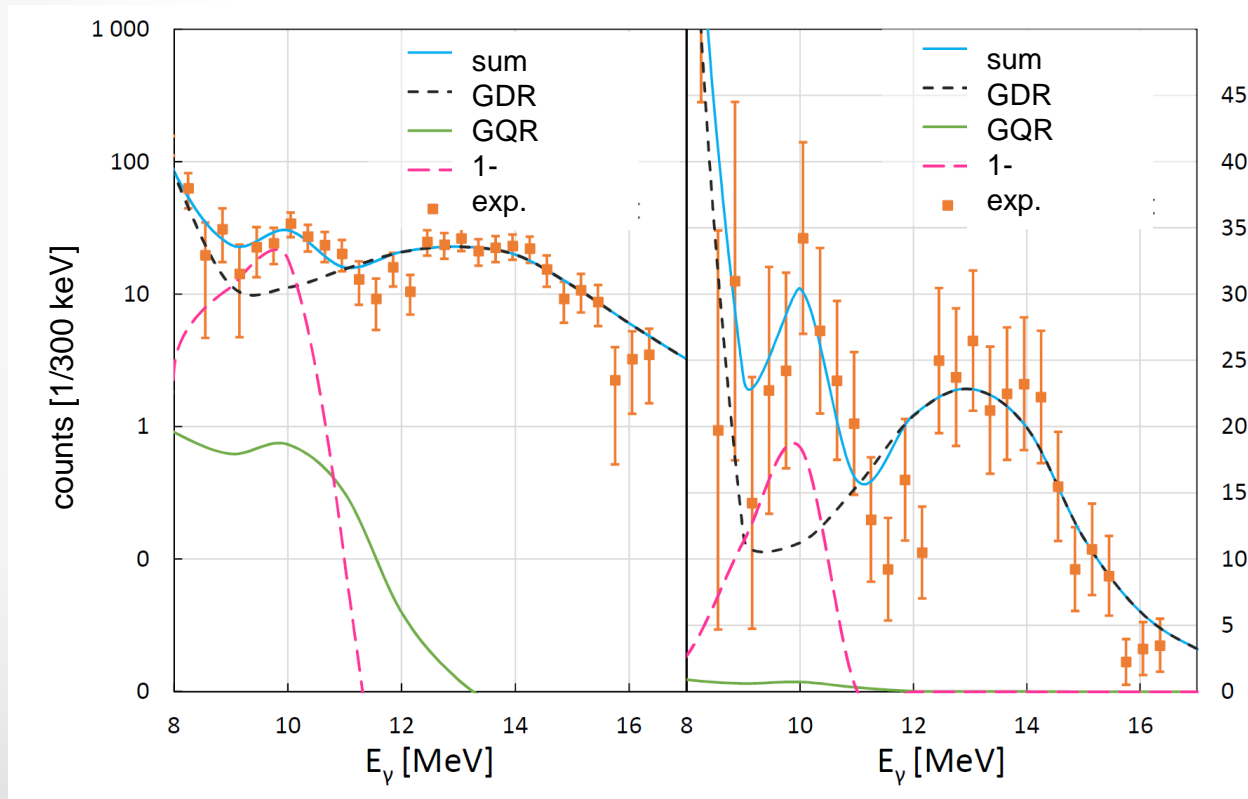
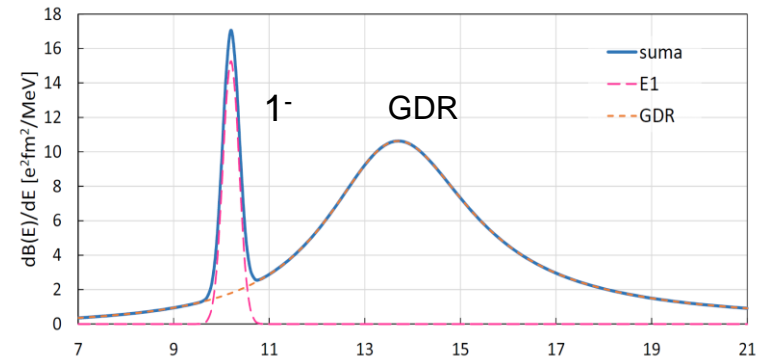
# hypothesis of additional E1 strength in GQR region

additional  $1^-$  states decay fitted

$$B(E1) = 7e^2\text{fm}^2$$

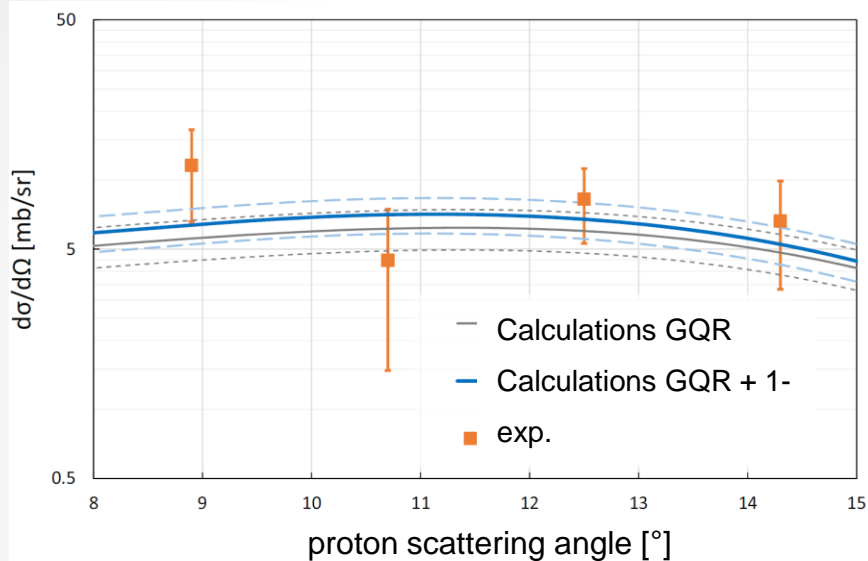
$$E = 10.2 \text{ MeV}$$

$$\Gamma = 400 \text{ keV}$$



# hypothesis of additional E1 strength - excitation

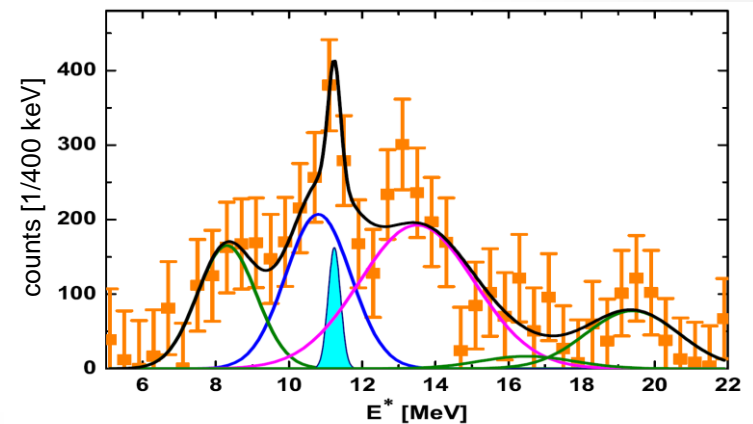
- additional E1 strength in excitation data



excitation cross section for 1- states  
- small comparing to GQR

additional peak in excitation spectrum

number of counts agree  
with calculated cross section



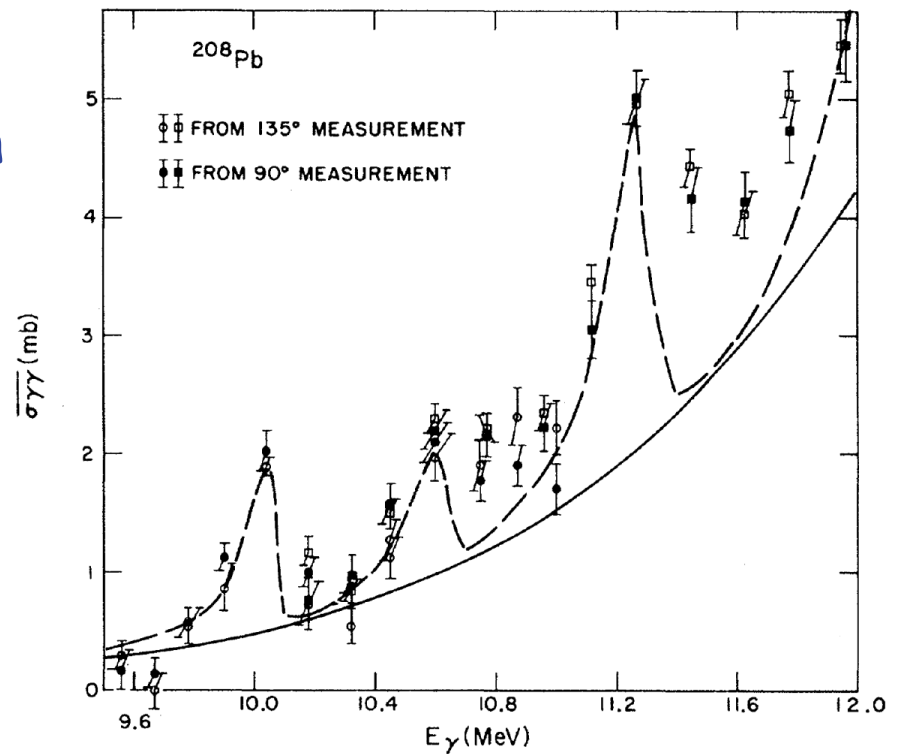
# hypothesis of additional E1 strength - $1^-$ states

- $1^-$  states in 10-11.5 MeV region

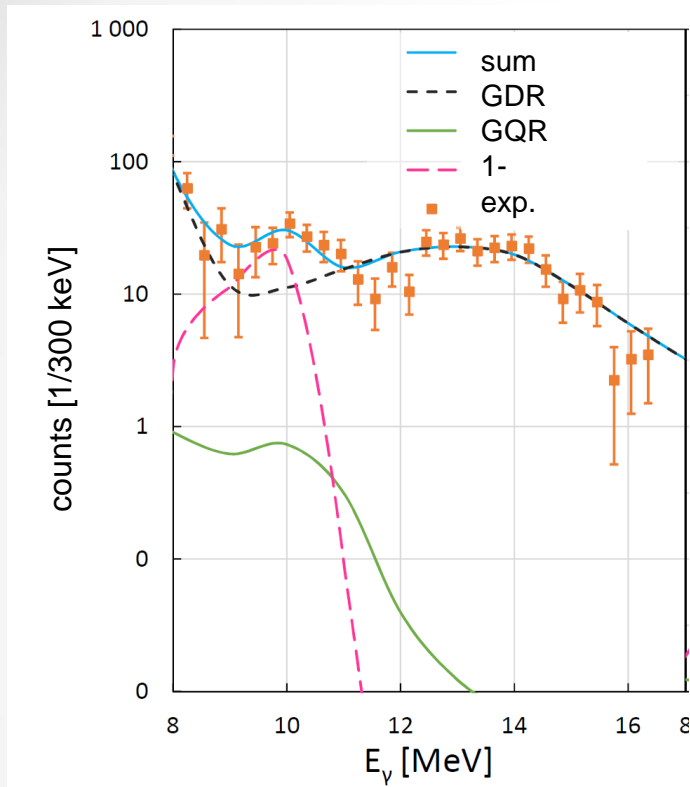
observed in  $^{208}\text{Pb}(\gamma,\gamma')$  reaction

R. D. Starr, P. Axel, and L. S. Cardman.  
„Elastic photon scattering between  
9.5 and 12 MeV in  $^{208}\text{Pb}$  and  $^{206}\text{Pb}$ ”,  
*Phys. Rev. C*, **25**:780–790, 1982.

Z. Berant, S. Kahane, R. Moreh, and O. Shahal,  
„Probing the microstructure of the giant dipole  
resonance in  $^{208}\text{Pb}$ ”,  
*Phys. Rev. C*, **31**:1553–1555, 1985.



# Conclusions on $\gamma$ decay from GQR region



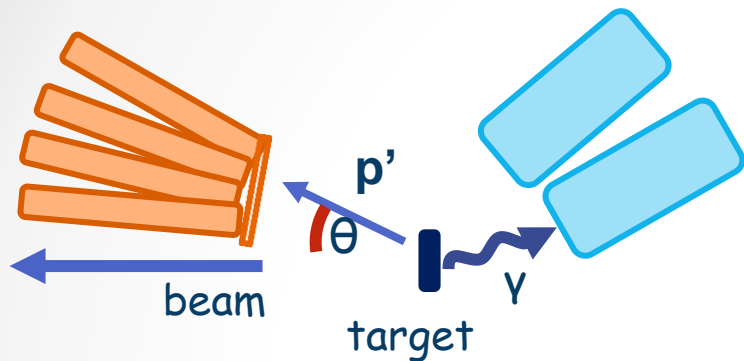
decay to ground state  
from 9-12 MeV region  
by  $\gamma$  emission dominated by 1- states

estimated GQR part - 4%

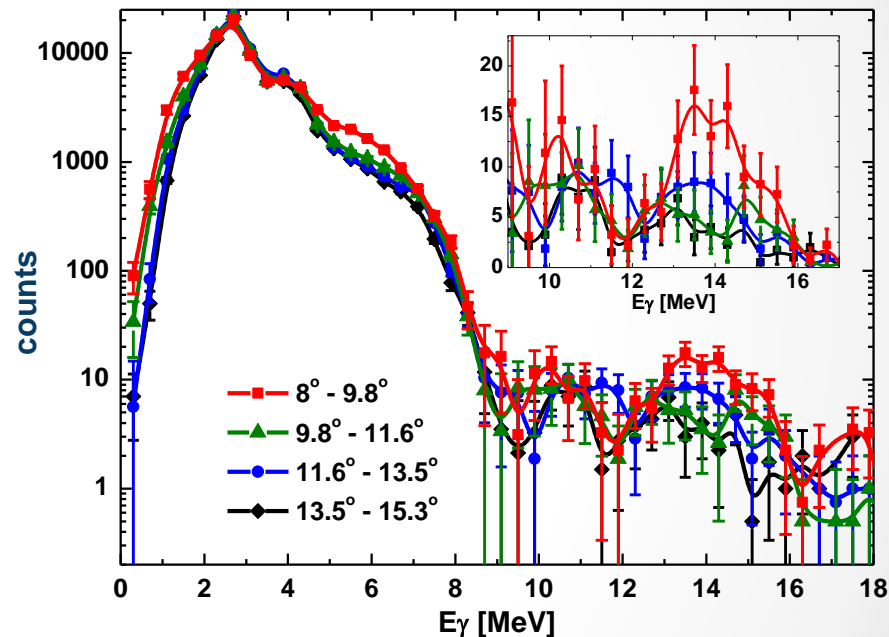
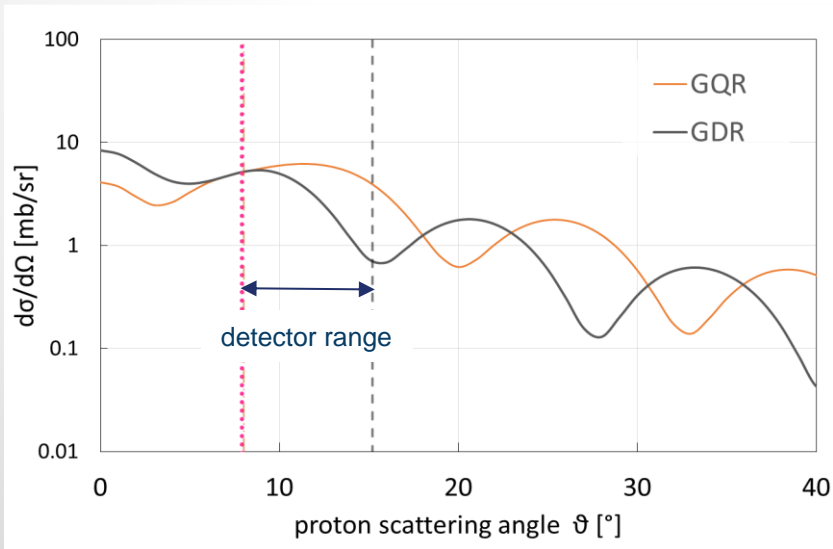
Confirmation of additional E1 strength requires following improvement of the measurement:

- better energy resolution  
both for gammas and protons
- better angular resolution

# Decay to ground state as a function of proton scattering angle



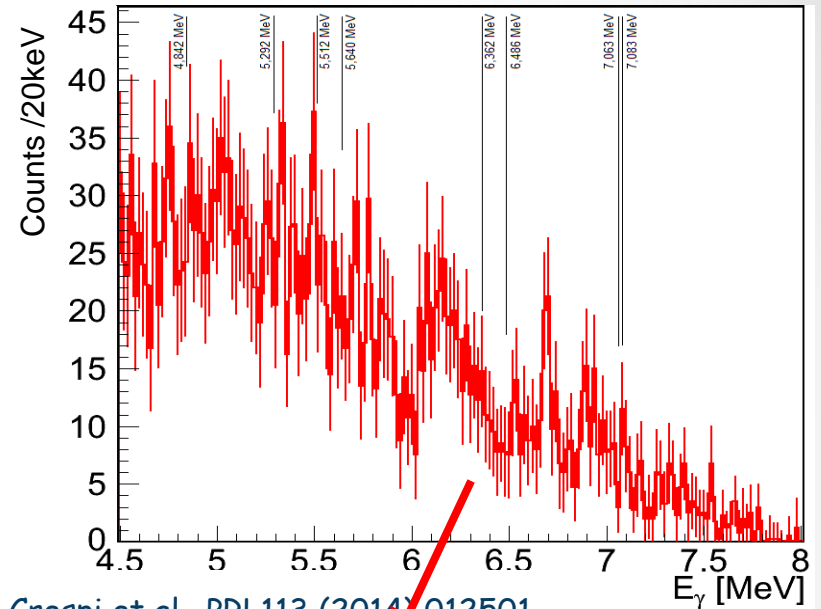
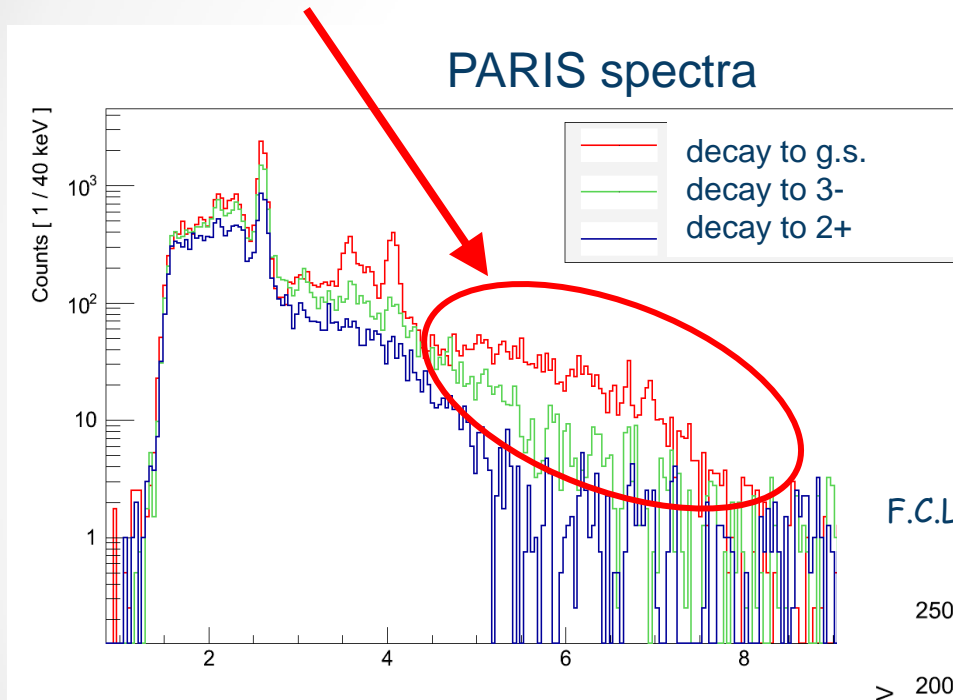
FRESCO calculations



increase of dipole (E1) strength - PDR, GDR for proton scattered at forward angles

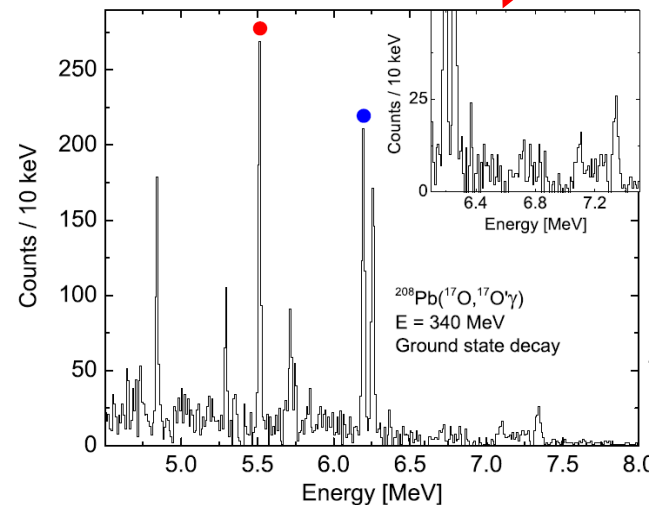
# PARIS spectra

discrete transitions in „pygmy” region



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

similar to previous experiment using AGATA



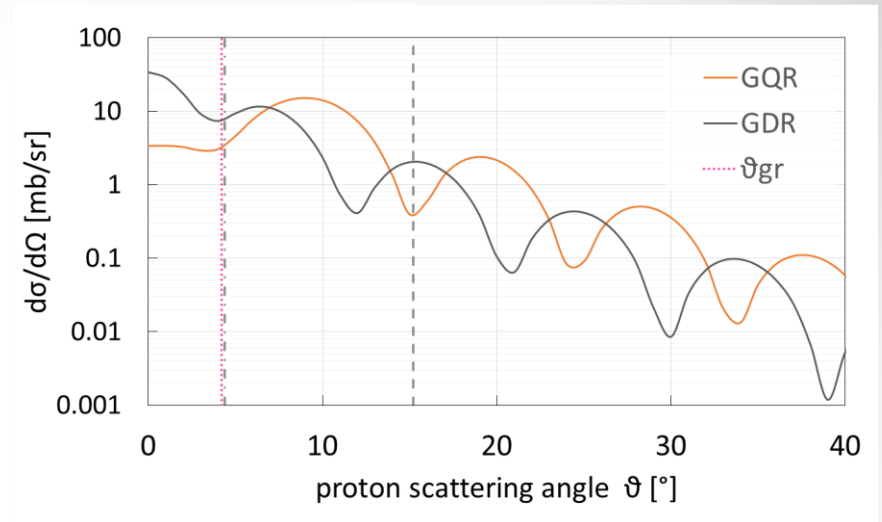
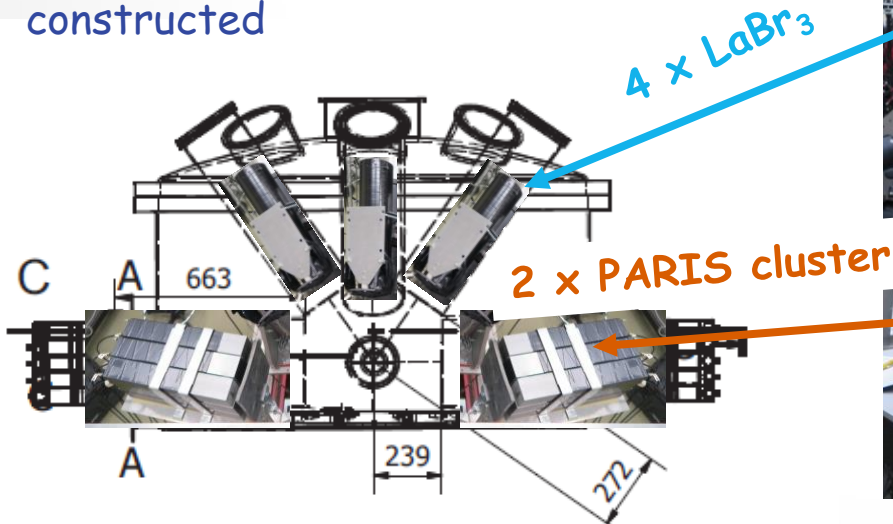
# Future plans

- (p,p'γ) on  $^{208}\text{Pb}$  @ ~150 MeV (GQR enhancement)
- (p,p'γ) on  $^{90}\text{Zr}$

big reaction chamber

➤ KRATTA inside - in vacuum

➤ gamma detectors outside (4 LaBr<sub>3</sub> and 2 PARIS clusters)  
- holders / cylindrical pockets constructed



# Summary

- First experiment using proton inelastic scattering to excite  $^{208}\text{Pb}$  nuclei was performed at Cyclotron Center Bronowice of IFJ PAN in Krakow and gamma rays emitted from the decay were detected in coincidence with scattered protons
- Gamma decay from the region of giant resonances (IVGDR and ISGQR) and „pygmy“ states in  $^{208}\text{Pb}$  have been observed.
- GDR direct and statistical decay to g. s. was investigated and subtracted enabling to obtain the GQR energy region of gamma spectrum.
- GQR part is described well only if decay of 1- states is included in the region of 10-11.5 MeV. The hypothesis of additional E1 strength should be investigated more carefully.
- All the results as well as the analysis are subject of Basia Wasilewska PhD thesis, just submitted and to be defended soon



*„This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 654002”*