GDR measurements present and future

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OUTLINE

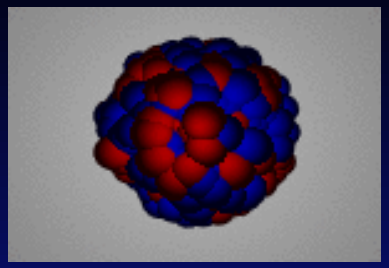
Giant Dipole Resonance (GDR) – general features

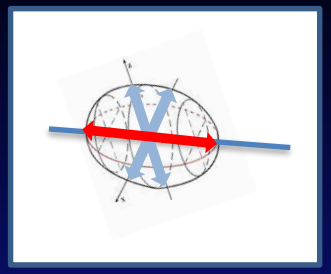
The GDR as a probe to study the feeding of superdefomed bands
The GDR as a probe to study Isospin Mixing.

PDR

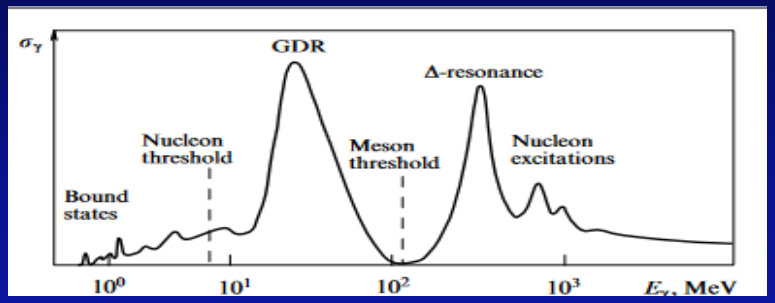
ELI-NP

Isovector Giant Dipole Resonance (IVGDR, GDR)



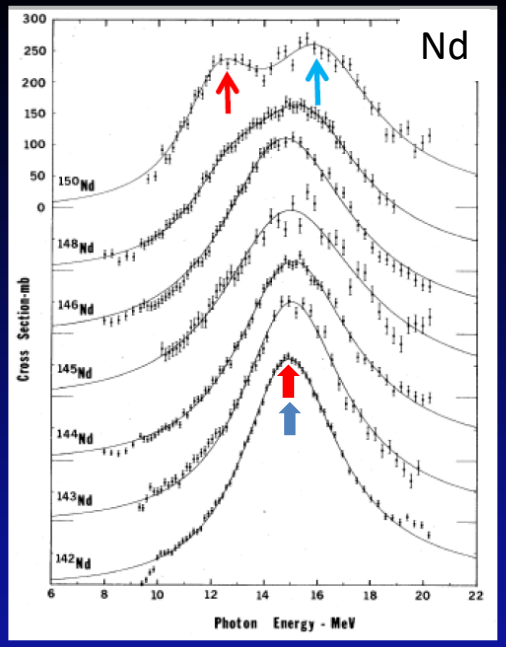


GDR couples to quadrupole deformation



B S Ishkhanov and I M Kapitonov 2021 Phys.-Usp. 64 141

Photoabsorption measurements

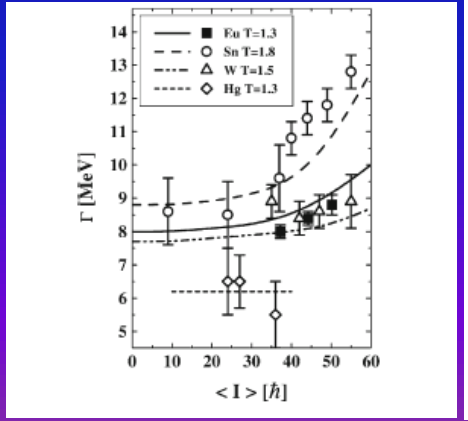


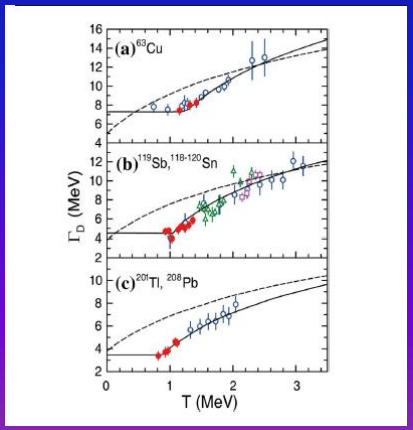
B.L. Berman and S.C. Fultz Rev.Mod.Phys. 47(1975)713

Brink and Axel independently hypothesized that the giant electric dipole resonance (GDR) stays at the same excitation energy relative to all initial states. This became known as the Brink–Axel hypothesis (BAH), which today is taken to mean that the Gamma Strenght Function (GSF) is independent of the energies, spins, and parities of the initial and final states and depends on the γ energy only.

The GDR intrinsic width does not change with excitation energy but temperature induces 'shape' and 'orientation' fluctuations. Namely, in a hot nucleus, there is not a fixed shape and orientation and the GDR cross section is a weighted average.

D.R. Chakrabarty, N. Dinh Dang and V.M. Datar Eur. Phys. J. A (2016) 52: 143





D.Santonocito and Y.Blumenfeld Eur. Phys. J. A(2020)56

M.Kmiecik et al Nucl. Phys. A674(2000)29

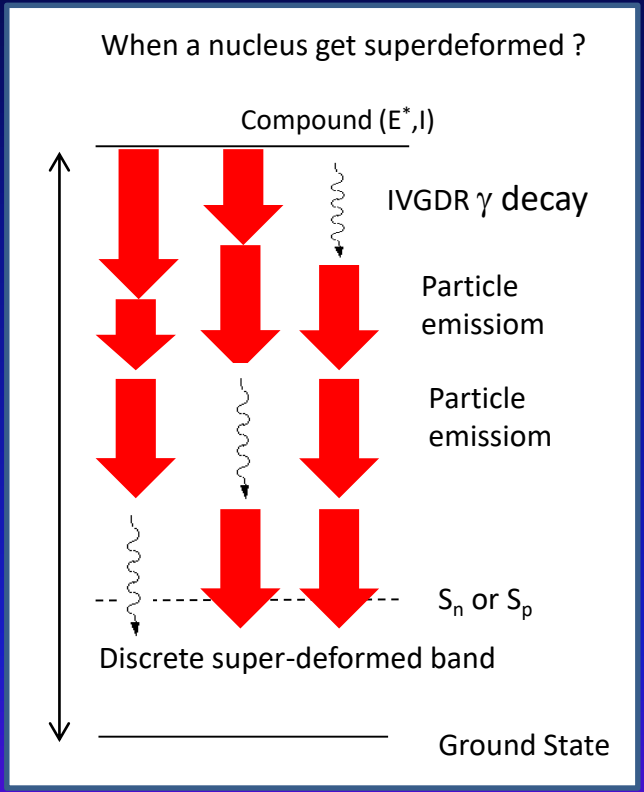
The HOT GDR cannot be considered a solved problem but, thanks to the work of several theoretician and experimentalists, it is not something unknown and not understood topic.

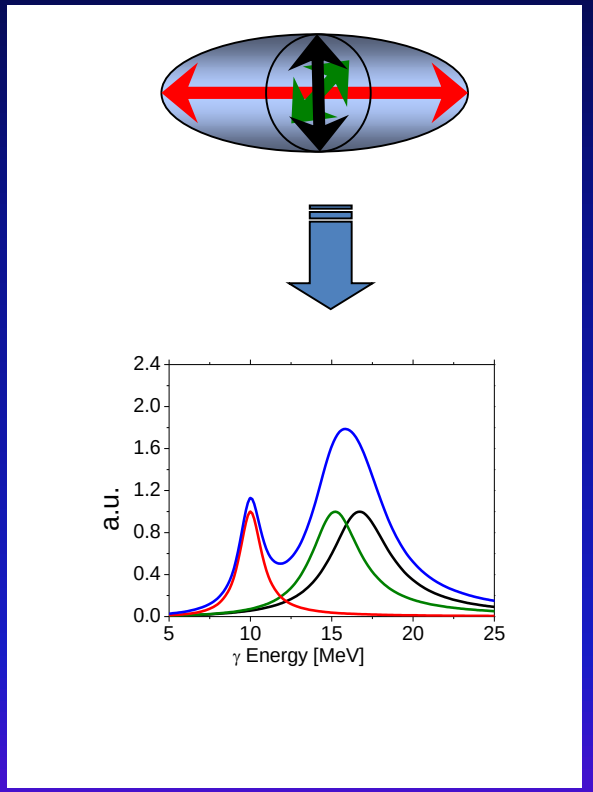
The HOT Giant Dipole Resonance (GDR) can be used as a probe to study new phenomena

HOT GDR in super-deformed nuclei

One use the feature that GDR couples to nuclear shape-deformation

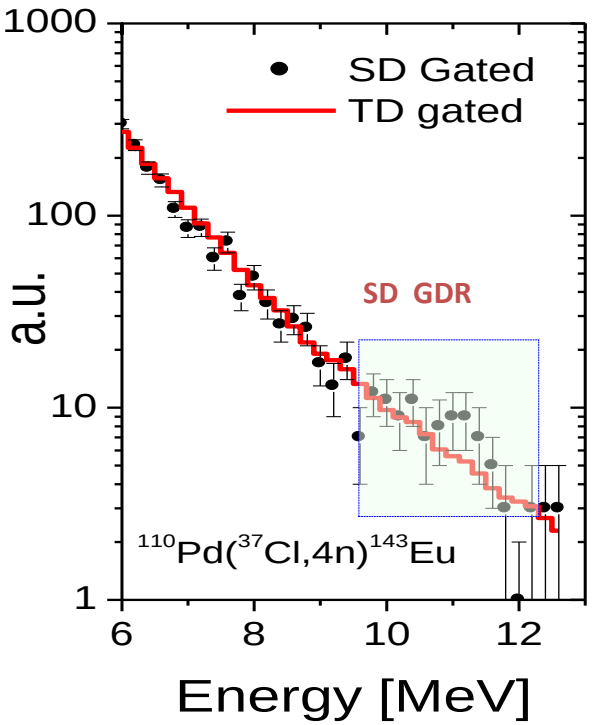
A GDR built on a normal deformed nucleus will be moderately splitted.
A GDR built on a super deformed nucleus is expected to highy splitted

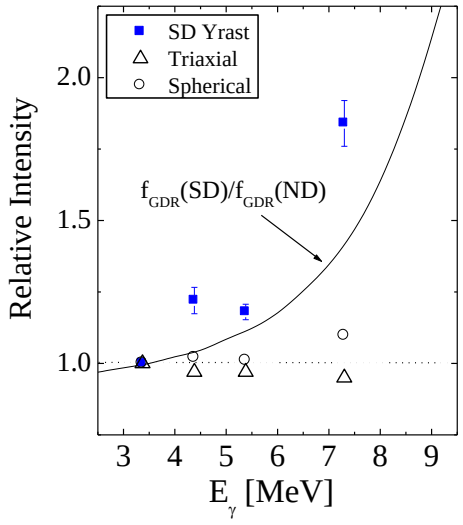




" … The large increase in E1 transition probability T(E1;U;) needed to explain the population of the 60 $\hbar$ member of the super-deformed band arises from the product of two effects. The GDR built on a super-deformed state splits into two major components, the lower expected around 8 MeV of excitation, and leads to an increase of T(E1;U;) by a large factor. The second effect is connected with the low level density expected in the super-deformed minimum, … " … R.Broglia … PRL 59(1987)2416

A measurement was performed several years ago





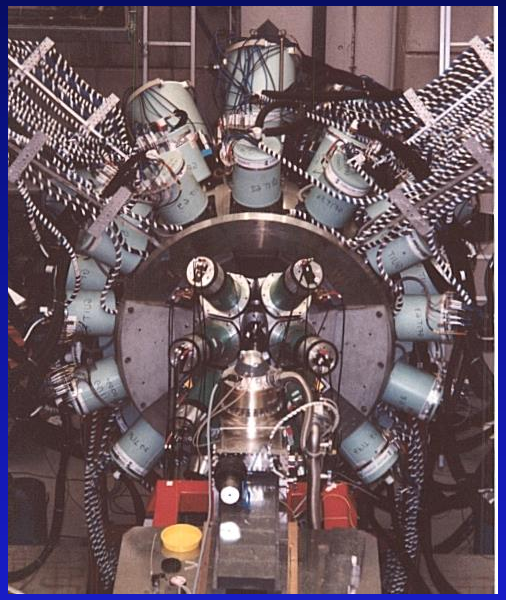
A.Bracco et al., Nucl. Phys. A 682(2001)449c
F.Camera et al., Eur. Phys. A 2(1998)1
G.Benzoni et al., Physics Letters B 540 (2002) 199
B.Million et al., Eur. Phys. J. A 20, 157–162 (2004)

… but the acquired statistics was too low.
Based on very low statistics it was concluded that super-deformation survives only few MeV above yrast.

A new experiment is now going to be proposed coupling the AGATA and the PARIS arrays.
In this experiment ten time more statistics is expected.

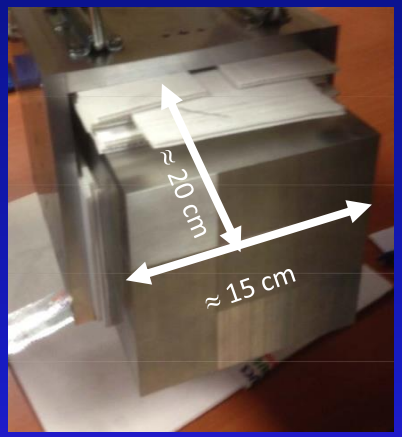
PAST

FUTURE



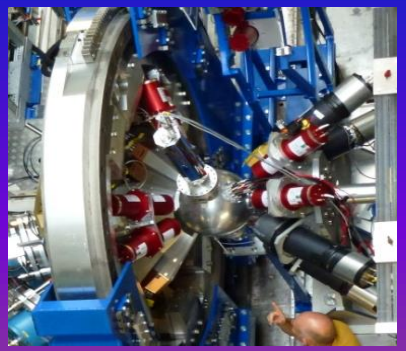
EUROBALL
+
HECTOR

AGATA



X 10

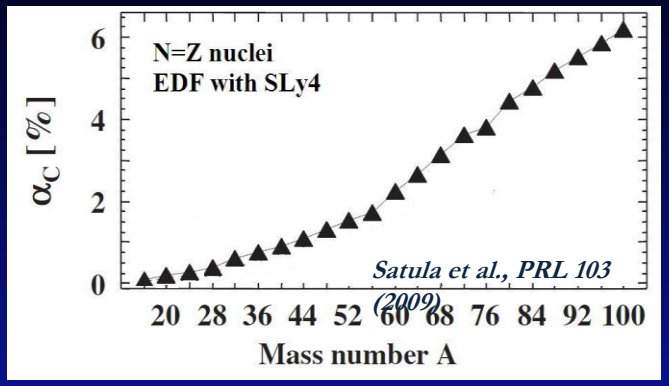
PARIS



HECTOR+

Isospin Mixing

One use the evidence that the γ-decay of the 'hot' GDR is composed only by E1 photons



Nuclear Hamiltonian does not commute with the elctromagnetic interaction therefore Isospin is not conserved.

Isospin is not a good quantum number. The wavefunction of a 'generic' nuclear state is a linear combination of wave fuctions with different Isospin, in other words, a nuclear state has not a fixed value of isospin.

$$A = \beta^2 \mid I > + \alpha^2 \mid I+1 > + \ldots.$$

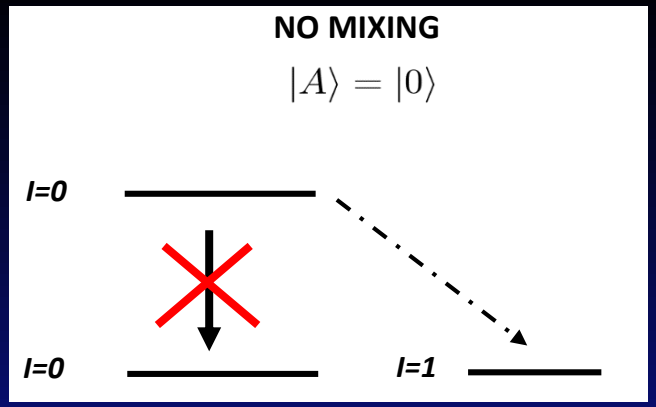
The nuclear interaction is stronger than the electromagnetic interaction. Therefore, the electromagnetic interaction induced effects are 'small' if compared with the strong nuclear interaction induced effects. Therefore, for each nuclear configuration, there is a dominant isospin value ($\beta >> \alpha$).

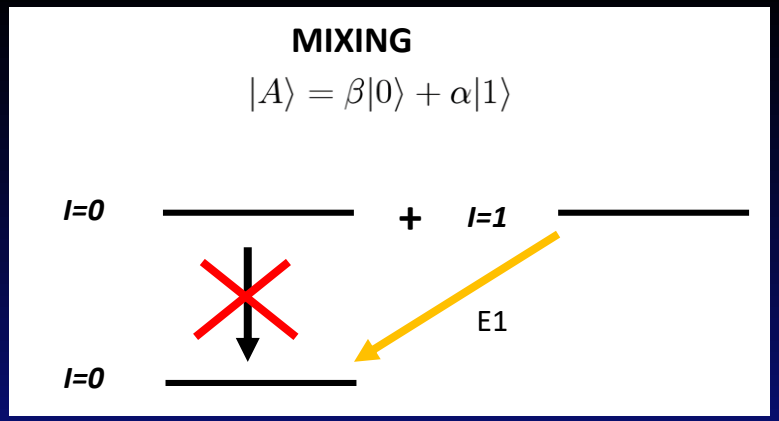
General trend of the mixing

$$\alpha^2 \simeq \frac{\Gamma^{\downarrow}}{\Gamma_{CN}} \simeq \frac{\tau_{CN}}{\tau_{MIX}}$$

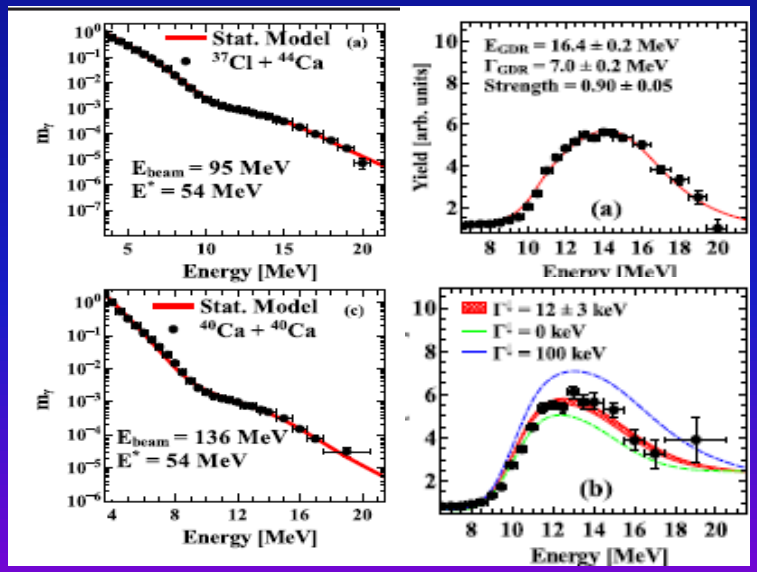
Coulomb Spreading width → To be obtained from measurements

Compound nucleus decay width → Known from the particle decay width

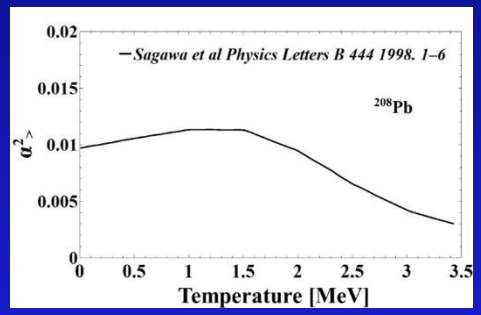




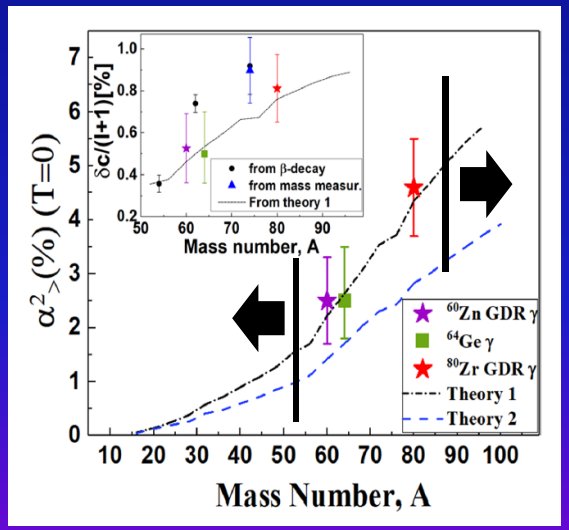
The E1 γ-decay of the GDR is sensitive to Isospin. If Isospin is conserved, the γ-decay of the GDR, in self conjugate nuclei produced in a zero isospin state, is forbidden between states with Isospin zero. The amount of the first step GDR γ-decay, in self conjugate nuclei produced in a zero isospin state, provides a quantitatively estimate on the degree of conservation of Isospin.



S.Ceruti et al. Phys.Rev.Lett. 115(2015)222502



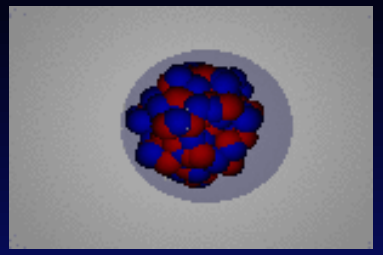
Theoretical Predictions



G.Gosta et al. PRC 103(2021)L041302

New measurements A.Giaz to be submitted

The PDR (Pygmy Dipole Resonance) is, probably, what was, several years ago, the GDR.



Some PDR excitation states have an Iso-scalar and some an Iso-vector nature.
PDR is predicted and was always observed around particle binding energy.

Does the PDR collective states survive to excitation energy?
How is PDR in deformed nuclei?

A very important point associated to the study of the PDR states is the need of a systematic study to learn about the dependence of the PDR on mass and neutron excess and the investigation of the isospin character using complementary approaches. It extremely important the use of different probes to excite and measure the decay of the PDR. These data also help theoretical models.

IFIN – ELI – Search of the 'hot' PDR

$^{32}S + {}^{24}Mg \rightarrow {}^{56}Ni$
$^{34}S + {}^{26}Mg \rightarrow {}^{60}Ni$
$^{36}S + {}^{26}Mg \rightarrow {}^{62}Ni$
$^{16}O + {}^{48}Ca \rightarrow {}^{64}Ni$
$^{18}O + {}^{48}Ca \rightarrow {}^{66}Ni$

Krakow – Study of the γ decay of the PDR built on the ground state $p + {}^{58, 62, 64}Ni$

ELI-NP

GAMMA BEAM:

- Energy: 0 - 19.5 MeV
- Bandwidth: 0.5%
- Time averaged spectral density: 5000 photons/s/eV

- Repetition Rate: 72 MHz (14 ns)
- Photons per bunch: 1-5

- OK for γ-rays
- Too short for neutrons (decrease in intensity --> reduction of repetition rate)

https://www.eli-np.ro/

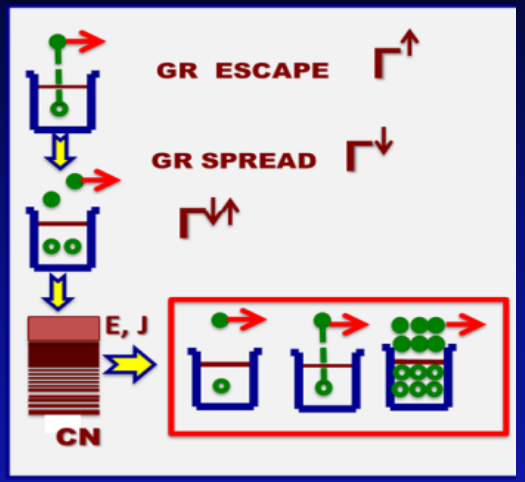
As described in the TDR:

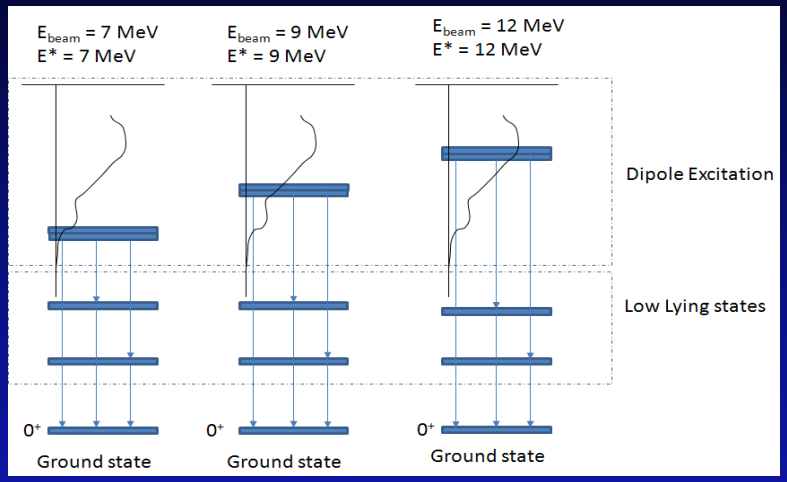
ELIGANT-GN
15 $LaBr_3$(Ce) + 19 $CeBr_3$ (size 3x3 inches)
33 BC501A + 22 GS20.

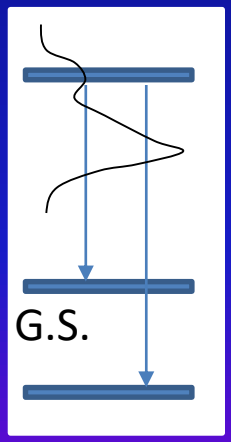
ELIGANT-TN
28 tubes with ^{3}He embedded in a polyethilene cube.

ELIGANT is the most effective choice for measurements when the energy of the gamma beam is higher than the particle binding energy

Measurement of the absolute values of B(E1) and B(M1) for $E^* \geq E_B$
Measurement of the absolute values of the neutron and γ branching ratio







Theory ⇒ PDR ⇒ single-particle (non-collective) excitations or collective with mixed isoscalar/isovector

Experiments ⇒ At the moment experiments cannot pin down PDR microscopic structure

Experiments @ELI-NP ⇒ - Very similar γ-decays branch are measured in nearby nuclei provide indication of a PDR collective character

⇒ Tunes theories for PDR in the *r*-process nucleosynthesis.

⇒ Polarization provides a very clean identification of E1/M1 decay as a function of E*

ELI-NP LOI

Physics Case ($E\gamma > S_n$ or S_p)

Statement of Research Intent to ELI-NP

GDR decay in ^{208}Pb

Collaboration presenting the LoI

- *Franco Camera (1,2)*
- *Angela Bracco (1,2)*
- *Oliver Wieland (2)*
- *Fabio Crespi (1,2)*
- *Benedicte Million (2)*
- *Silvia Leoni(1,2)*
- *Giovanna Benzoni(2)*
- *Gainluca Colo (1,2)*
- *Enrico Vigezzi (2)*
- *Javier Rioca Maza (1,2)*
- *Adam Maj (3)*
- *Maria Kmiecik (3)*
- *Michal Ciemala (3)*
- *Atzushi Tamii (4)*
- *Nobuyuki Kobayashi (4)*
- *Takashi Sudo (4)*

1) *University of Milano, Physics Department, Via Celoria 16, 20133 Milano*
2) *INFN section of Milano, Via Celoria 16, 20133 Milano*
3) *The Niewodniczan'ski InstituteofNuclearPhysics,PolishAcademyofSciences,ul.Radzikowskiego152,31-342Krako'w,Poland*
4) Research Center for Nuclear Physics, Osaka University, Ibaraki, Osaka 567-0047, Japan

Local contact – (ELI-GANT Team – P.A.Soderstrom)

Scientific case

Gamma and Neutron decay of the PDR-GDR in ^{208}Pb

This physics case was already widely discussed in the TDR "gamma above neutron threshold" [1] and in references [2-4].

It is important to stress that, in this LOI, we concentrate in the energy region above the neutron threshold (S_n). In this energy region, the competition with neutron decay and the small two-steps decay branching ratio make the experiments very difficult and the signal very weak. Only the use of the ELI-NP 'clean' and almost 'monochromatic' gamma beam and the very efficient ELI-GANT arrays would make possible to perform successfully these measurements.

GDR decay in ^{208}Pb

ELIGANT-TN

Measurement of photo-neutron cross section vs the energy of the gamma beam. The results of this measurement must be compared with what already present in literature.

ELIGANT-GN

Measurement of PDR-GDR γ-decay to the Ground State
Measurement of two steps γ-decay to the Ground State
Measurement of n plus γ-decay
Measurement of n-decay to the Ground State
Measurement of the neutron/γ decay branching ratio.

There will be the choice (depending on the time needed to change the energy of the γ beam) to study different isotopes using few beam energies or one isotope using several beam energies

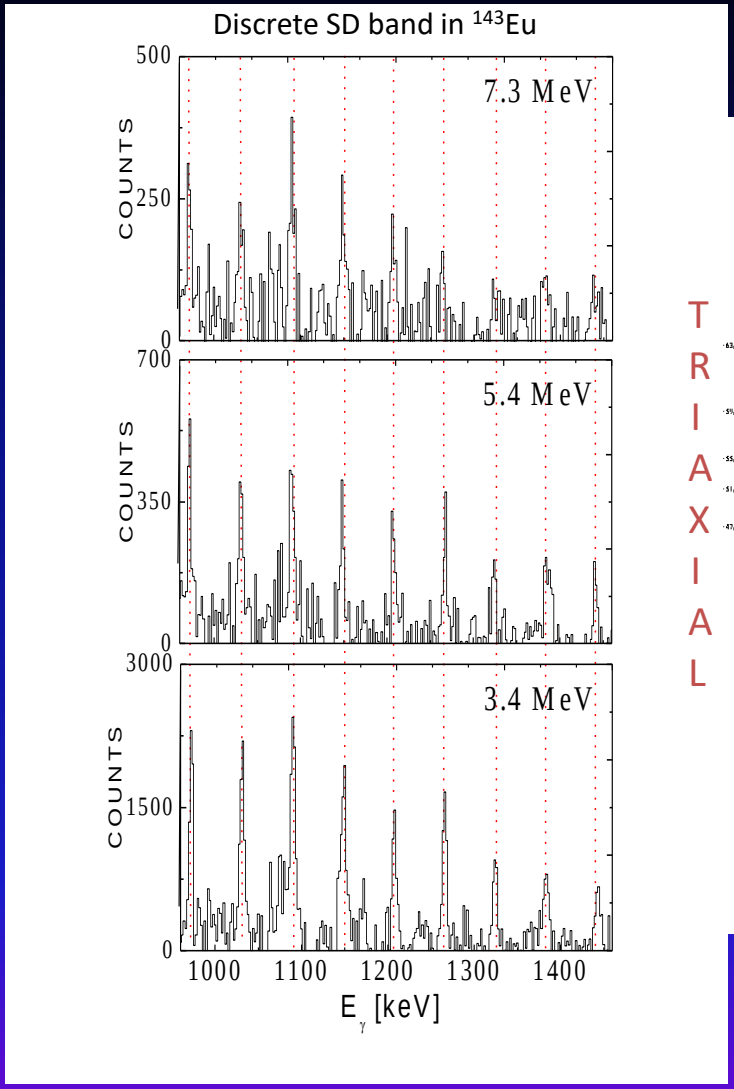
Conclusions

The Giant Dipole Resonance generali features

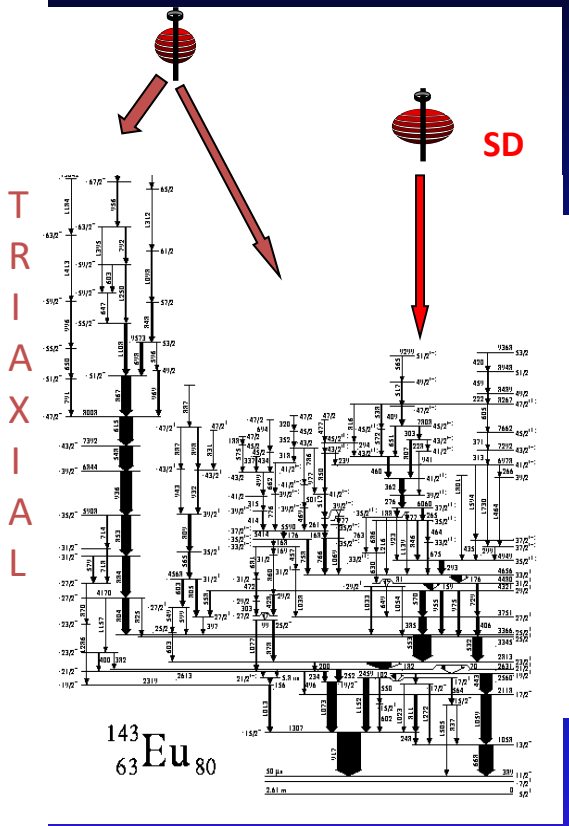
The study of the GDR in hot nuclei $\Rightarrow$ The use of the GDR in hot nuclei
Super-Deformed Bands and Isospin Mixing
PDR
ELI-NP

Thank you for the attention

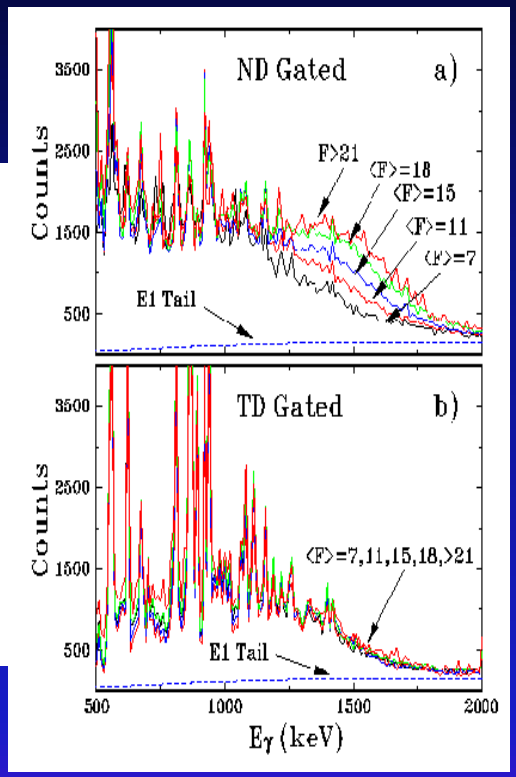
Why ^{143}Eu



Literature shows that the discrete super-deformed band in ^{143}Eu feeds only the normal deformed (ND) quasi spherical transitions



SPHERICAL



A.Atac et al PRL 70(1993)1069
M.Piiparinen et al ZPA 343(1992)
S.Leoni et al. PRL 76(1996)3281