Study of high-lying collective modes with AGATA

Fabio Crespi

Università degli Studi di Milano - INFN

Outline

- "Inelastic scattering as a tool to search for highly excited states up to the region of the Giant Quadrupole Resonance"

- Physics motivation

- Description of the experiment

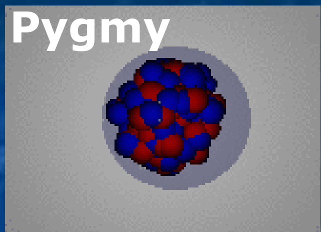
- An important experimental aspect:
  The Response of AGATA detectors to high energy gamma rays

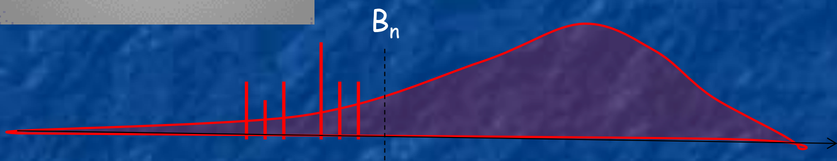
- Preliminary results

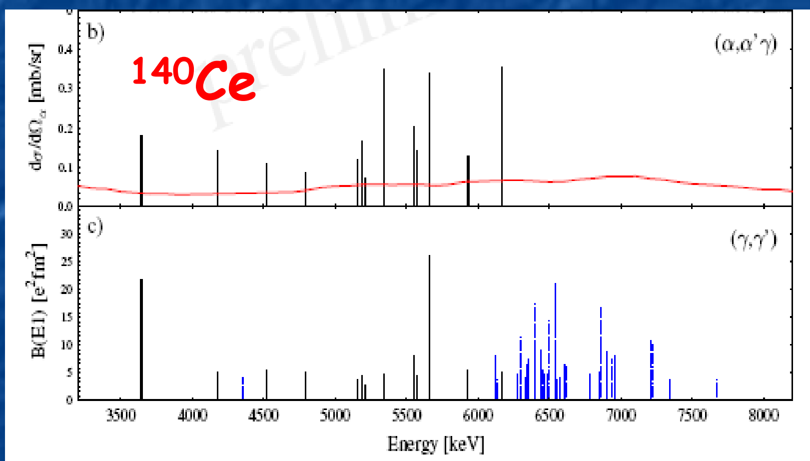
- Future Perspectives

Microscopic Structure of highly excited states

in STABLE nuclei



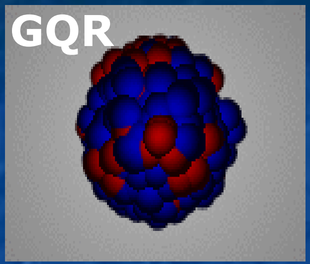


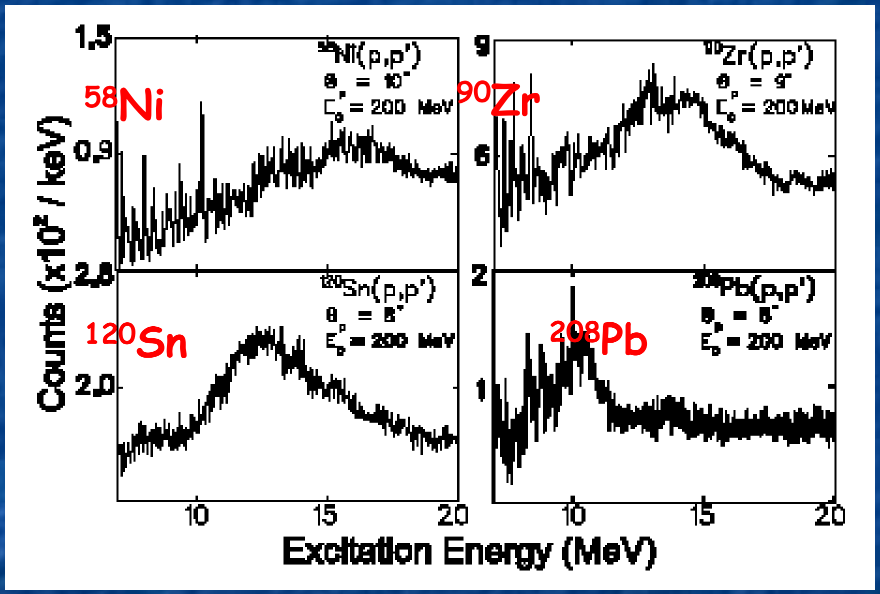


(γ,γ') experiments : A=50, A=140
$(\alpha,\alpha'\gamma)$ experiments @ 30 MeV/A

Selective Population

D. Savran et al., PRL97(2006)172502; T. Hartmann PRL85(2000)274



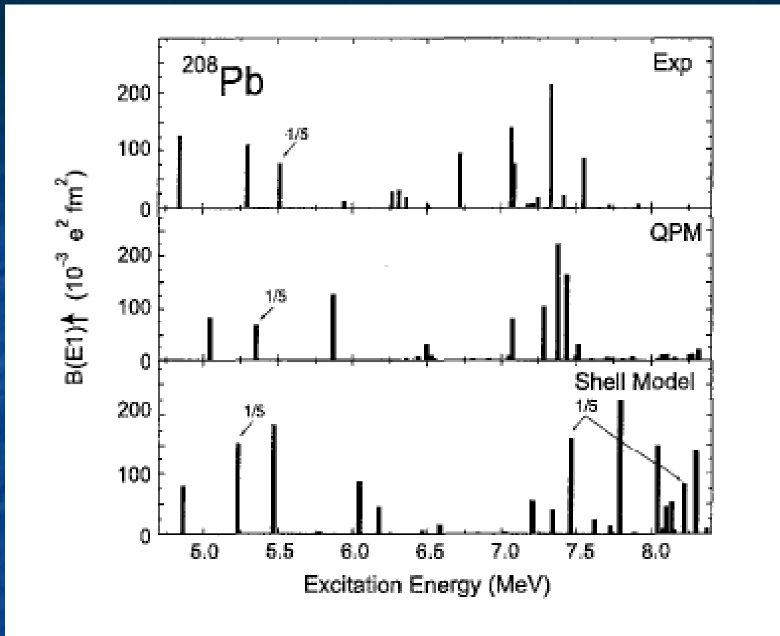


(p,p') and (e,e') experiments

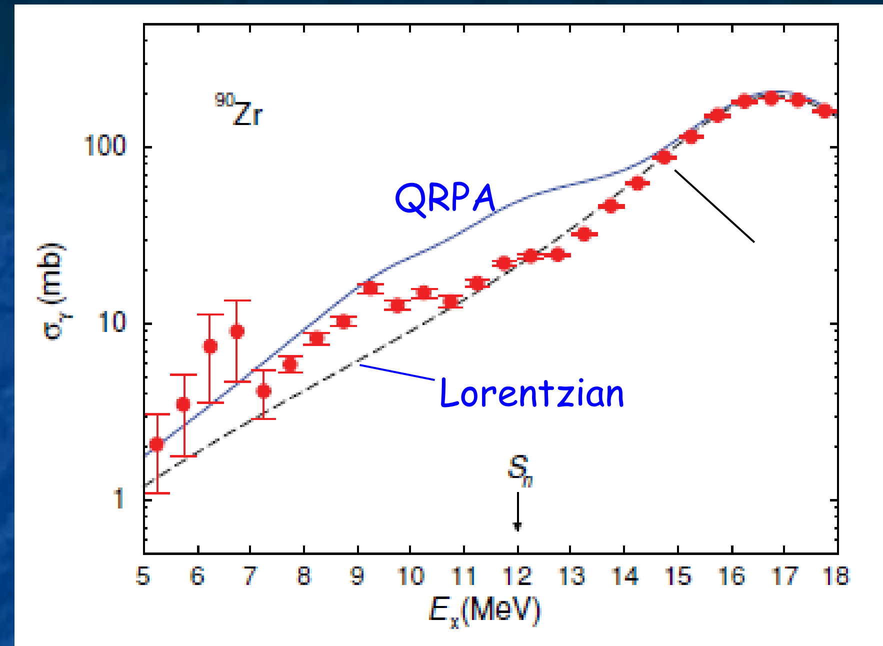
Fine Structures

Shevchenko PRL93(2004)122501-1

(γ,γ') – data (Richter et al.)



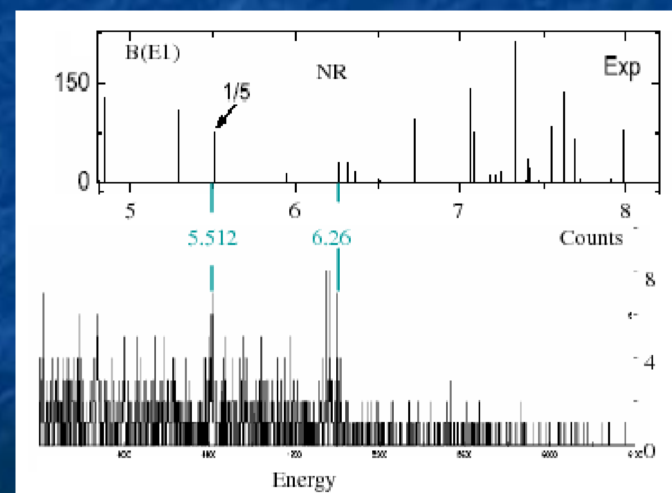
(γ,γ') – data (Schwengner et al.)



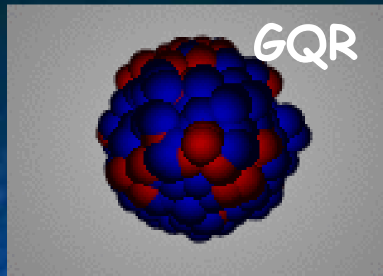
The **tail** of the GR is NOT a simple Lorentzian:

- evidence for enhanced E1/M1 structures in several nuclei
- importance for decay rates
- pronounced pygmy resonances in exotic nuclei

Inelastic scattering with ^{17}O can provide additional information on the nature of these states



M.A. Deleplanque et al., TEST exp. with 6 HpGe
Berkeley National Laboratories Ann. Rep., 2005

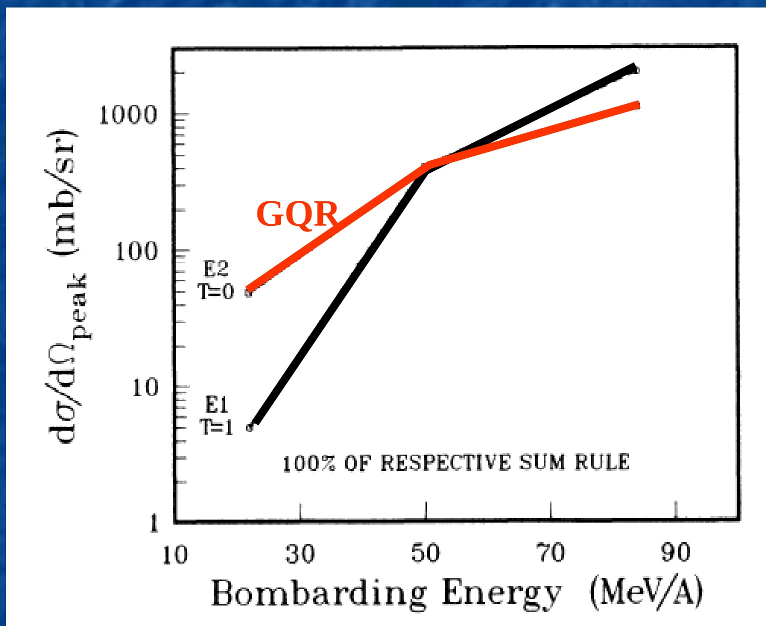


γ-decay from GQR: experiments in ORNL in '80s

Spin spectrometer
(72 NaI detectors) ➔ *poor resolution*

Silicon detector
(6 E-ΔE telescopes,
~900 keV resolution)

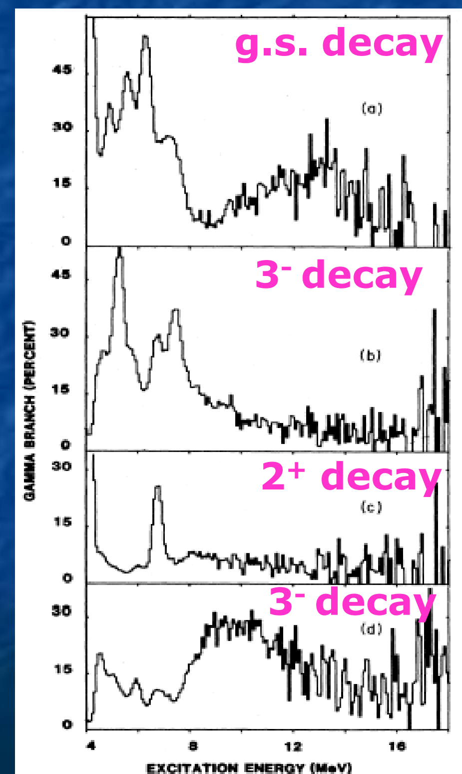
22 MeV/u ^{17}O on ^{208}Pb target

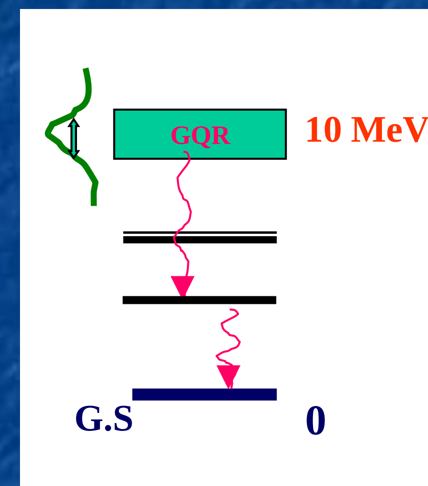


$$\frac{\sigma(GQR)}{\sigma(GDR)} \approx 20$$

$$\sigma(GQR) \approx 50\, mb/sr$$
$$@13^0$$

γ-ray gated spectra



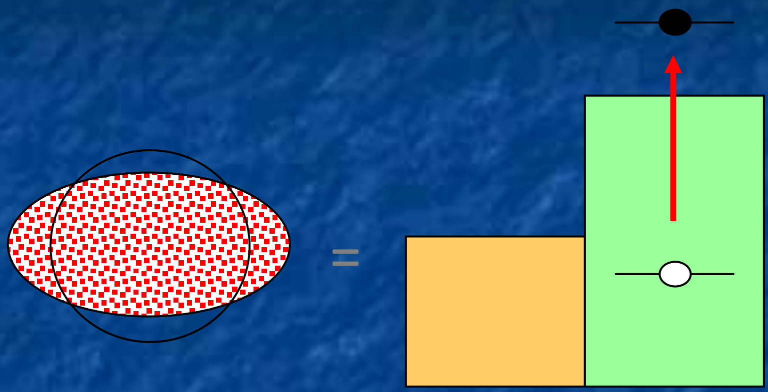


Branching to Excited states

J.Beene et al PRC39(1989)1307
J. Beene et al. PRC41(1990)929
F.E.Bertrand et al NPA 482(1988)287c

Theoretical Model for γ-decay of GQR

P.F. Bortignon, G. Colò, M. Brenna, Milano University



PARTICLE DECAY

GAMMA DECAY

branching

$$P_\gamma = P_{direct} + P_{CN} = \frac{\Gamma^{\gamma}_{GR}}{\Gamma^{\downarrow}} + \left< \frac{\Gamma^{\gamma}_{CN}}{\Gamma_{CN}} \right>$$

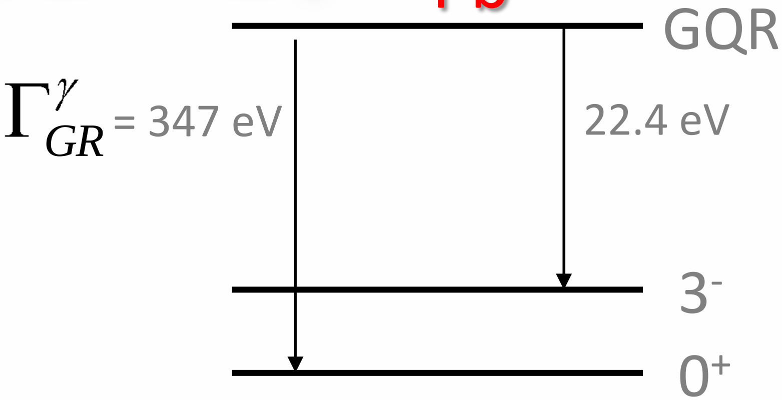
Damping into complex degrees of freedom 2p-2h, …

Beene, Bertch, Bortignon, Broglia, PLB164(1985)19
Wieland et al., PRL102(2009)092502.

$P_{direct} \sim P_{CN}$

preliminary

^{208}Pb



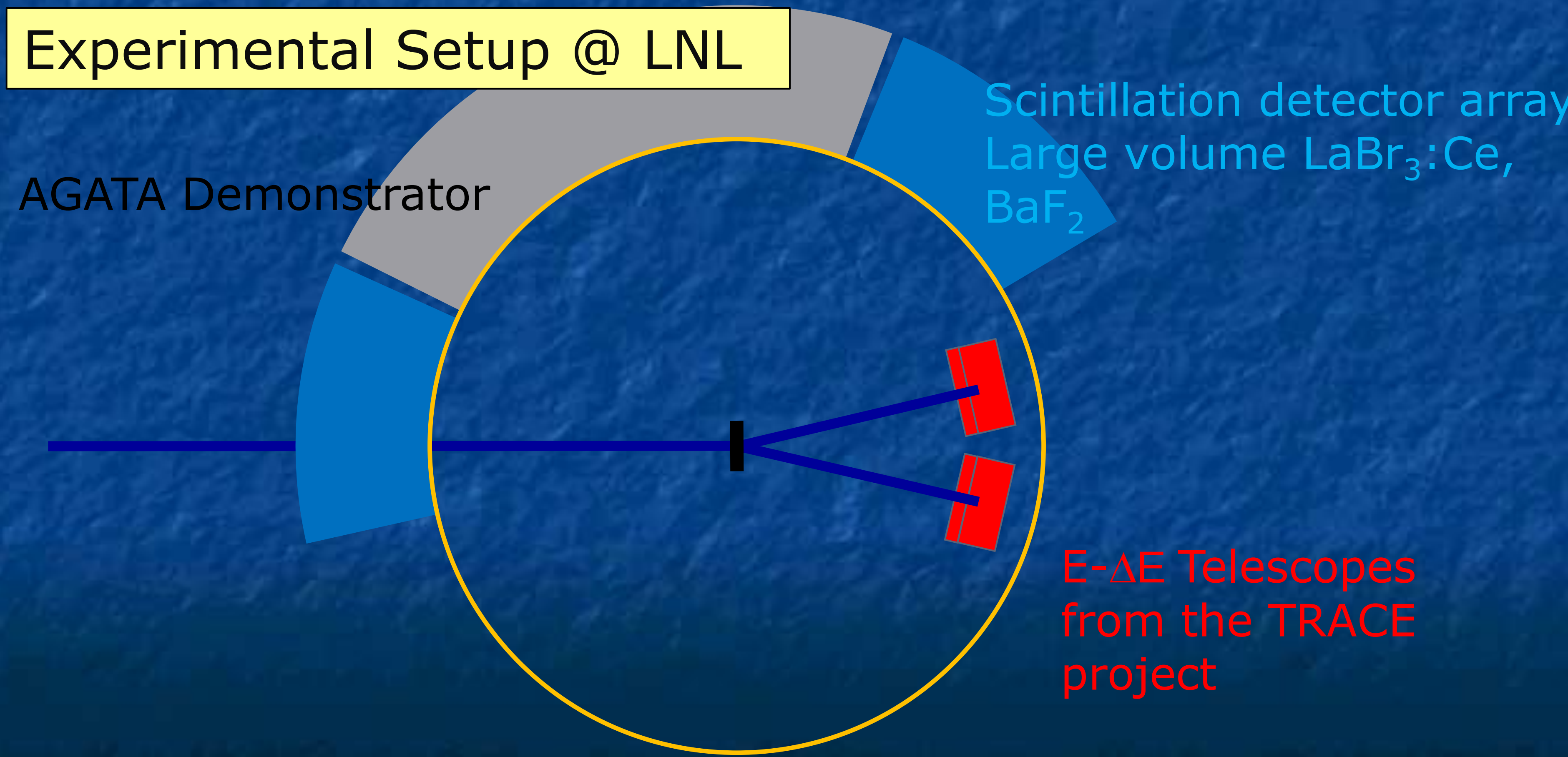
Microscopic methods to get wavefunctions of vibrational states (**RPA** based on Hamiltonian and Skyrme interaction):

- Exclusive esperiments are needed
- Future Applications to **Exotic Nuclei**
- **GDR, …**

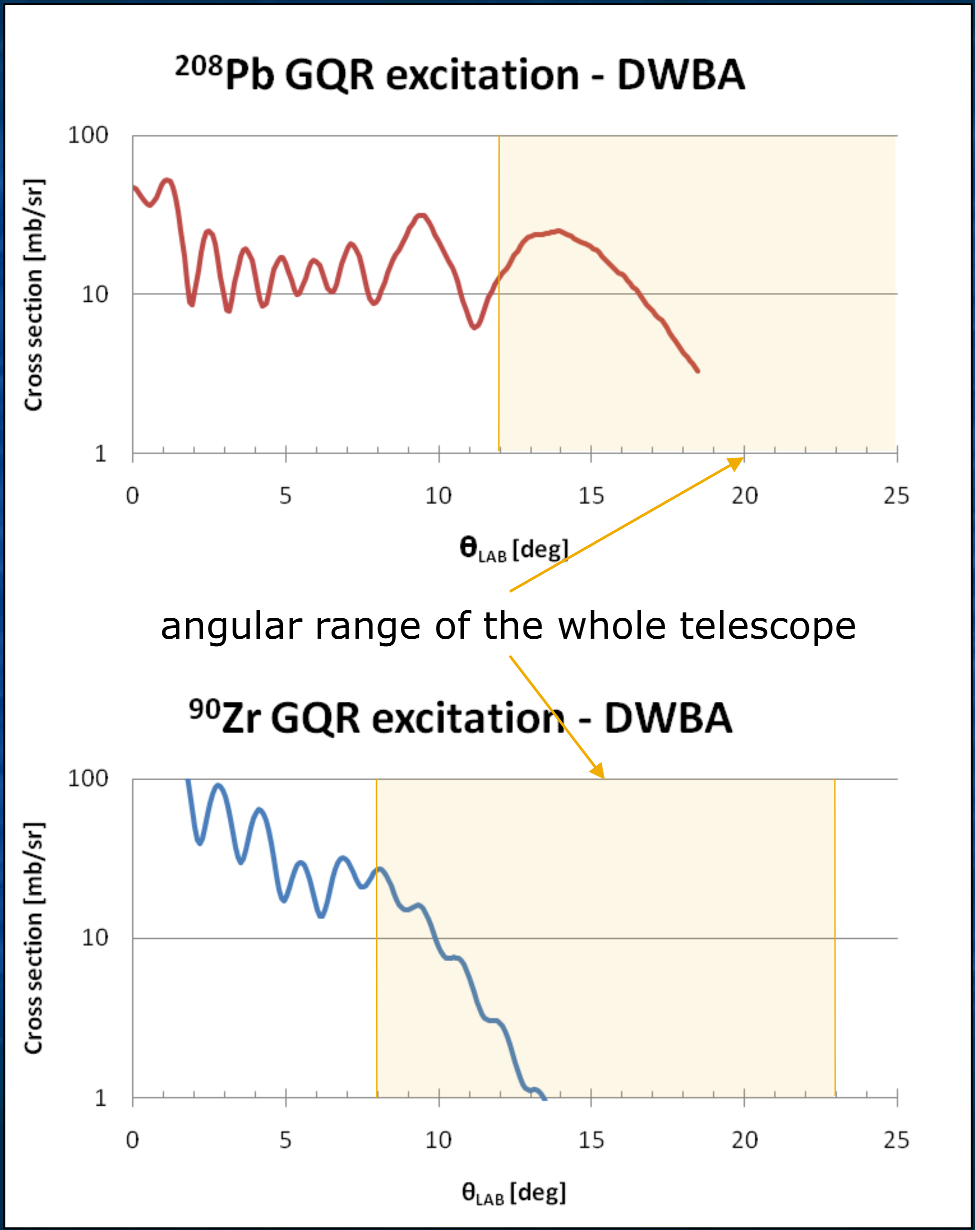
Experimental Technique

Inelastic scattering ^{17}O @ 20 MeV/u on ^{90}Zr, ^{208}Pb targets
+ γ-ray coincidence measurement

Heavy-ion scattering can populate giant resonances with large cross-sections ,
^{17}O is loosely bound (S_n = 4.1 MeV) → we can eliminate projectile excitation above 4 MeV



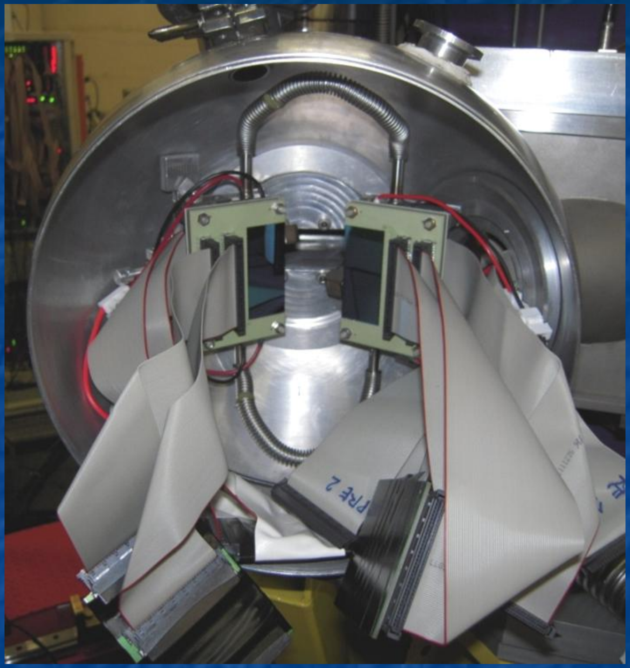
Cross-section estimates



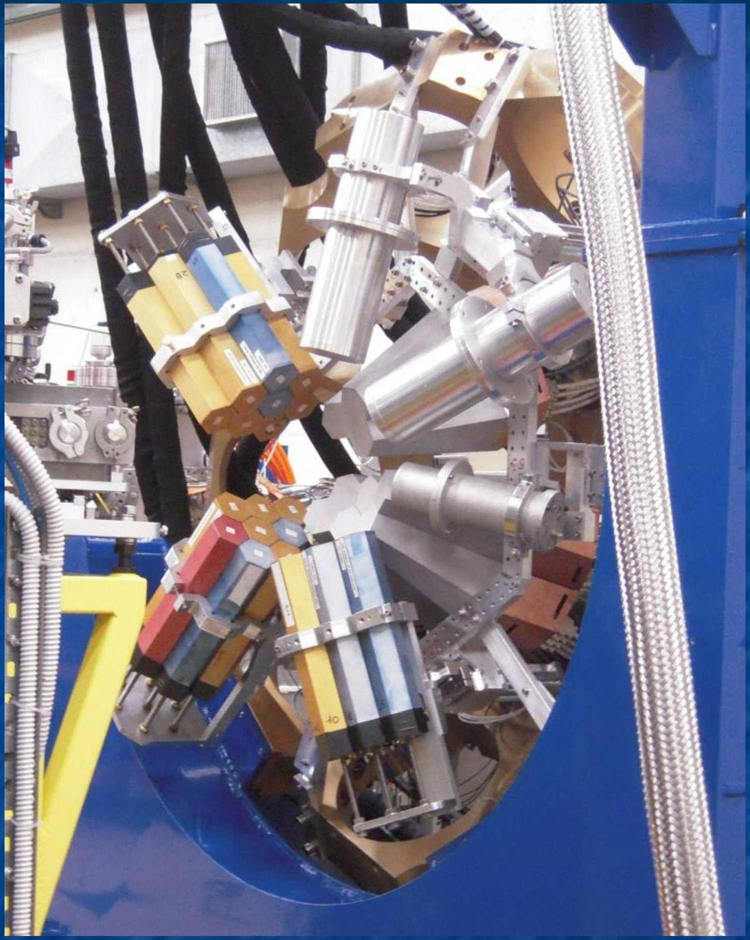
Sizable cross-section within ~6°
The detector covers a much larger angle ($\Delta\theta$ = 15°)

The different kinematics for the ^{208}Pb and ^{90}Zr targets require different detector positions

Silicon Telescopes and Scintillator Array in AGATA



- Si-pad technology: 60 (5x12) pixels
- Active area of 20x50 mm^2
- Pixel area of 4x4 mm^2
- Cooled to -30 °C
- E detector: 1 mm thick
- ΔE detector: 200 μm thick



- $LaBr_3$:Ce detectors
- Large volume (up to 9x20 cm)
- 20 Helena BaF_2 clusters

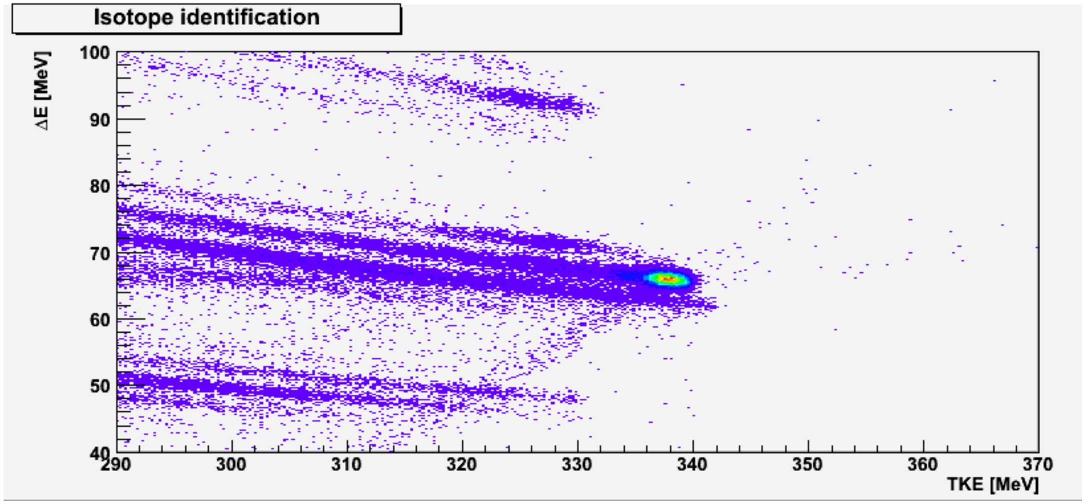
Ejectile detection

Constraints on $E^*-E_{\gamma tot}$ allow to greatly suppress background and select decay branches to g.s. or excited states

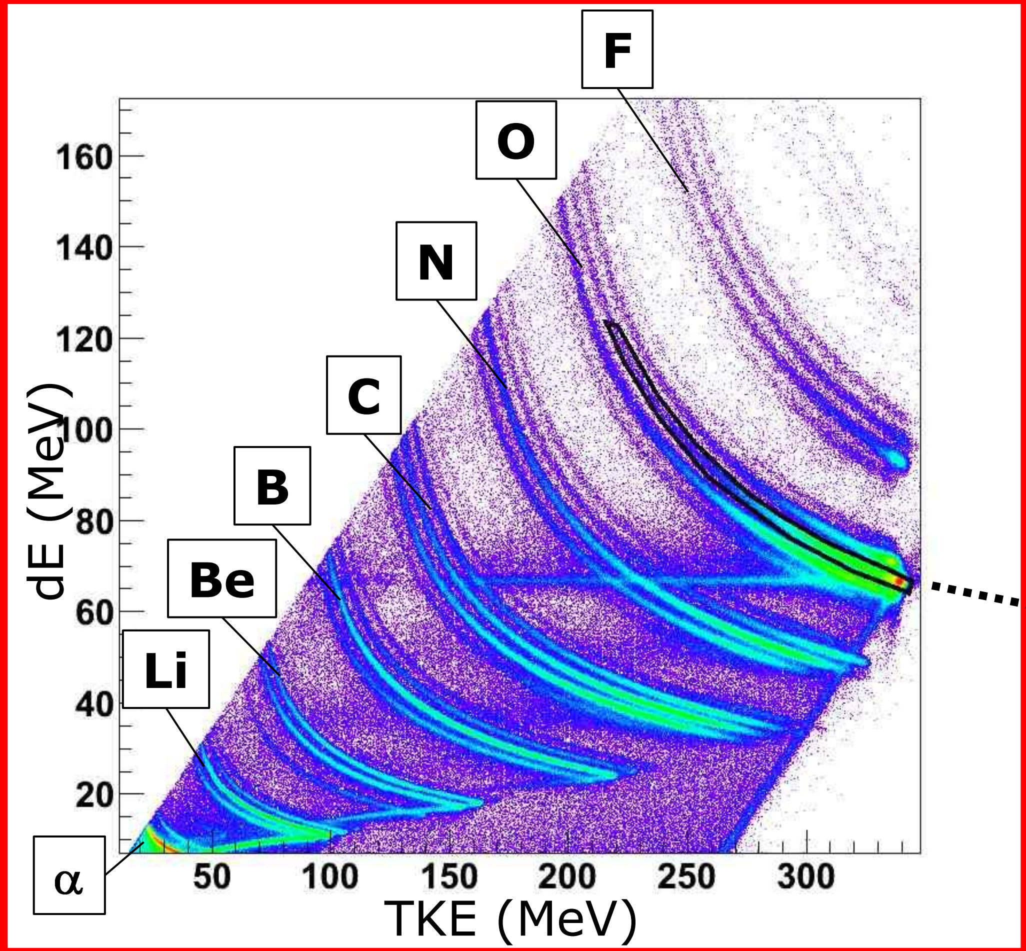
E-ΔE detector must have a high energy resolution for selection of excitation energy (<1%) but also a large solid angle to increase efficiency

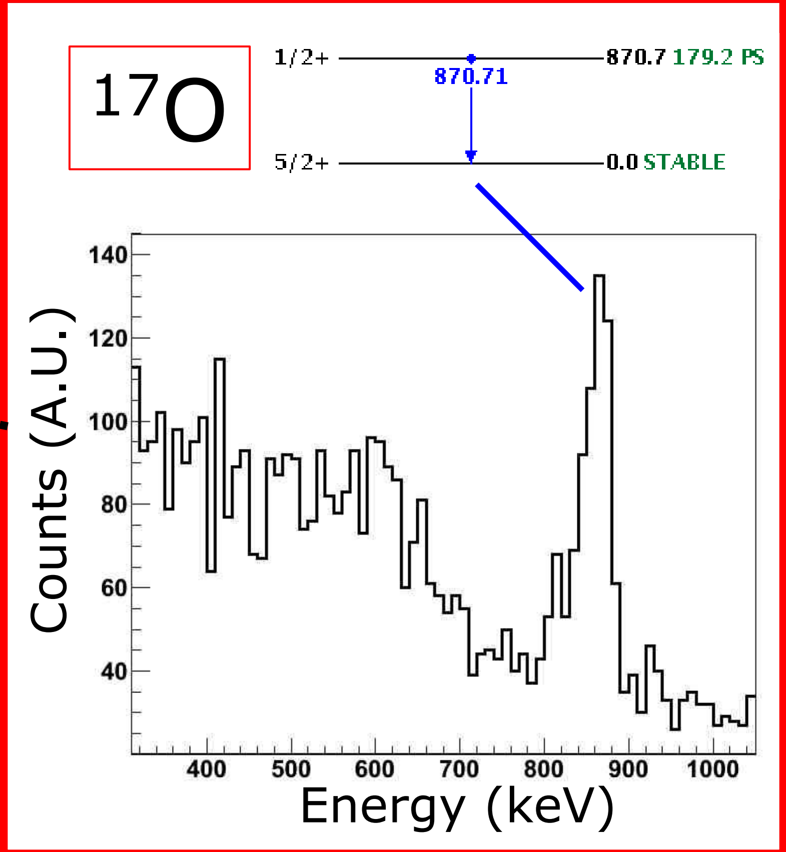
Segmented E-ΔE detector

- Si-pad technology, 60 (5x12) pixels
- Large number of channels
- Active area of 20x50 mm^2
- Pixel area of 4x4 mm^2
- Cooled to -30 °C
- E detector: 1 mm thick
- ΔE detector: 200 μm thick

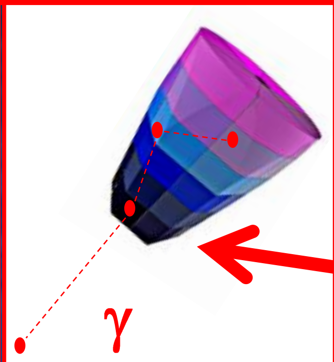


^{17}O @ 20 MeV/u → v/c ~ 0.2

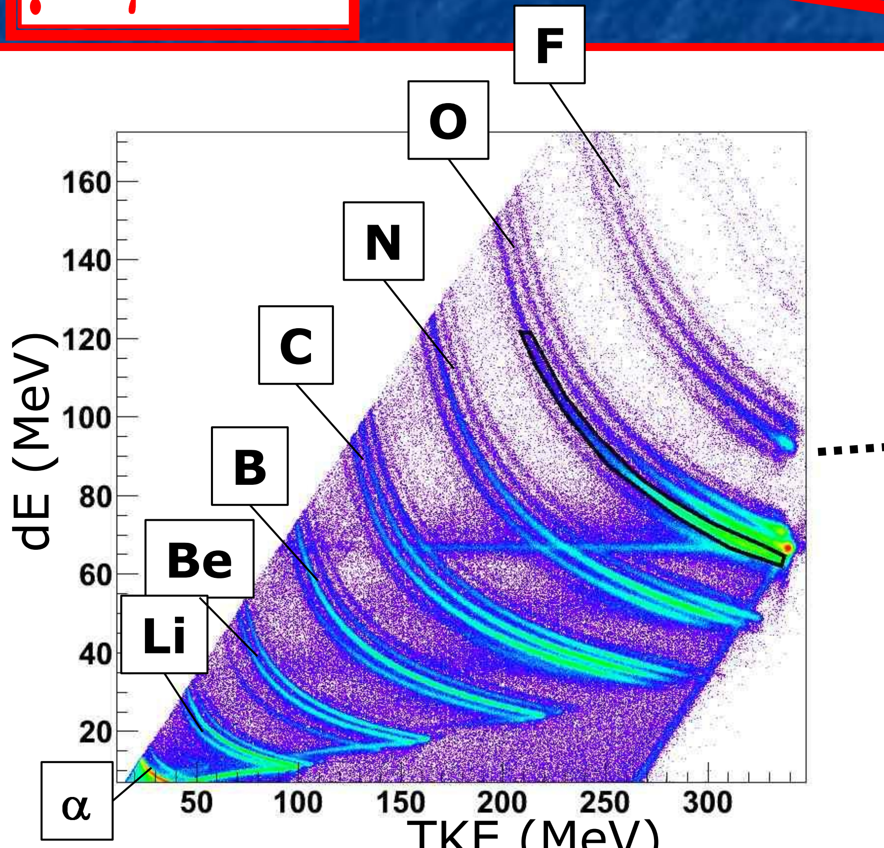




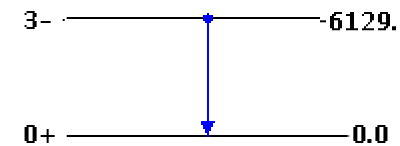
Detection of gamma rays emitted in-flight – Doppler Correction



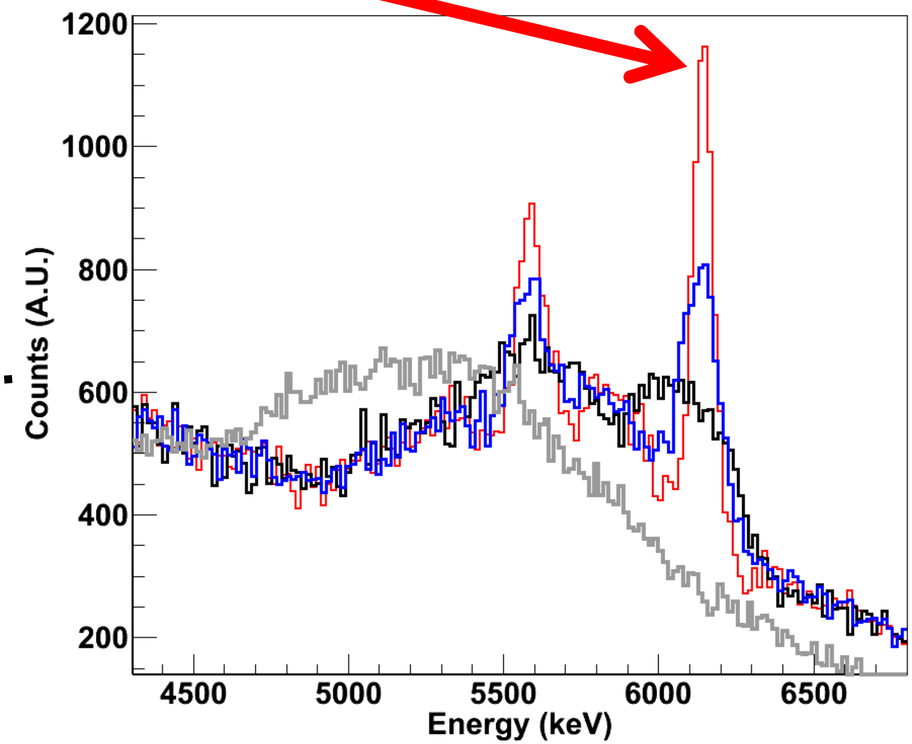
v/c ~ 0.2



^{16}O

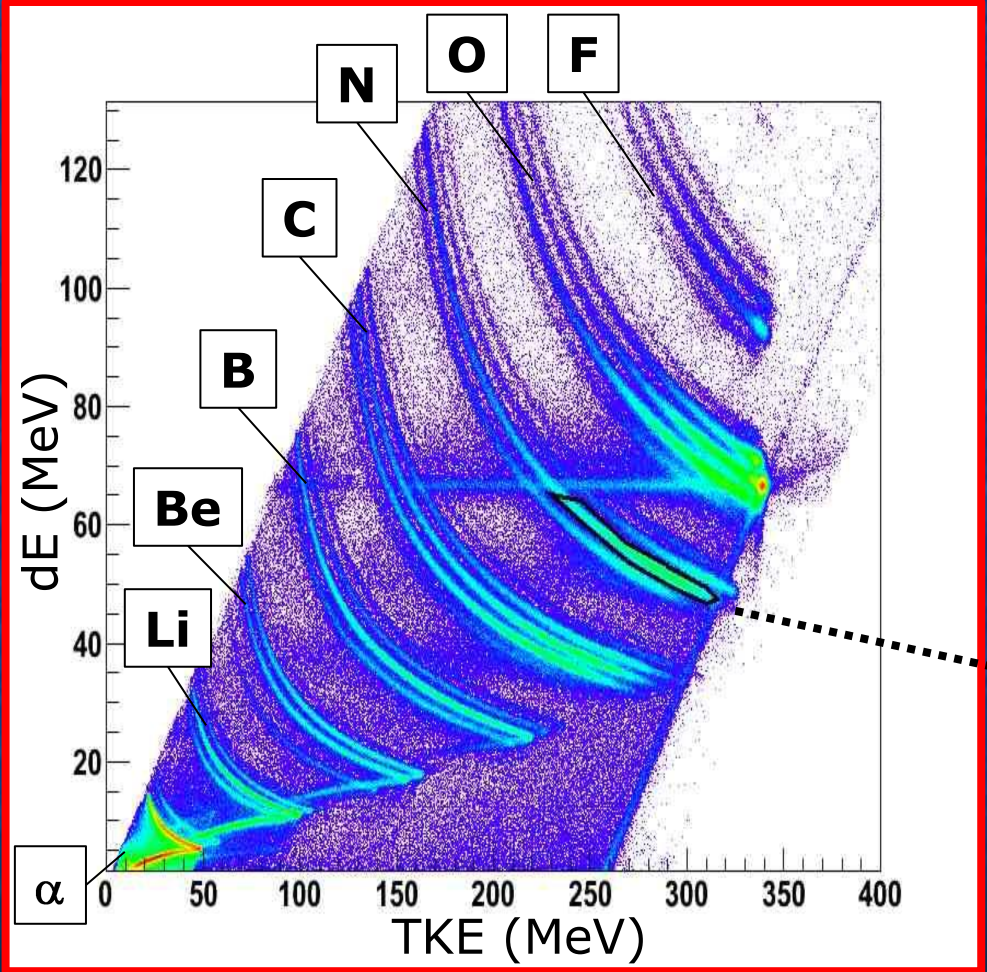


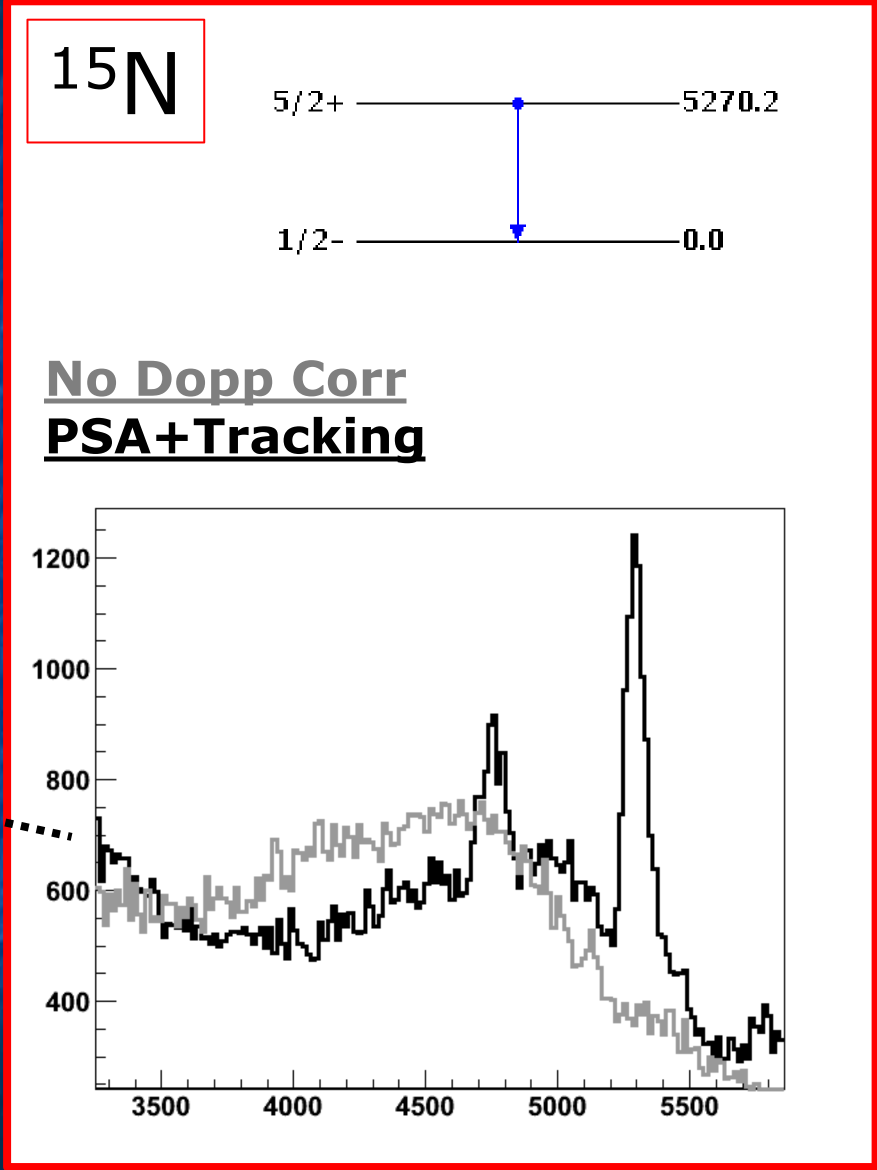
No Dopp Corr
Crystal Centers
Segment Centers
PSA+Tracking



Detection of gamma rays emitted in-flight – Doppler Correction

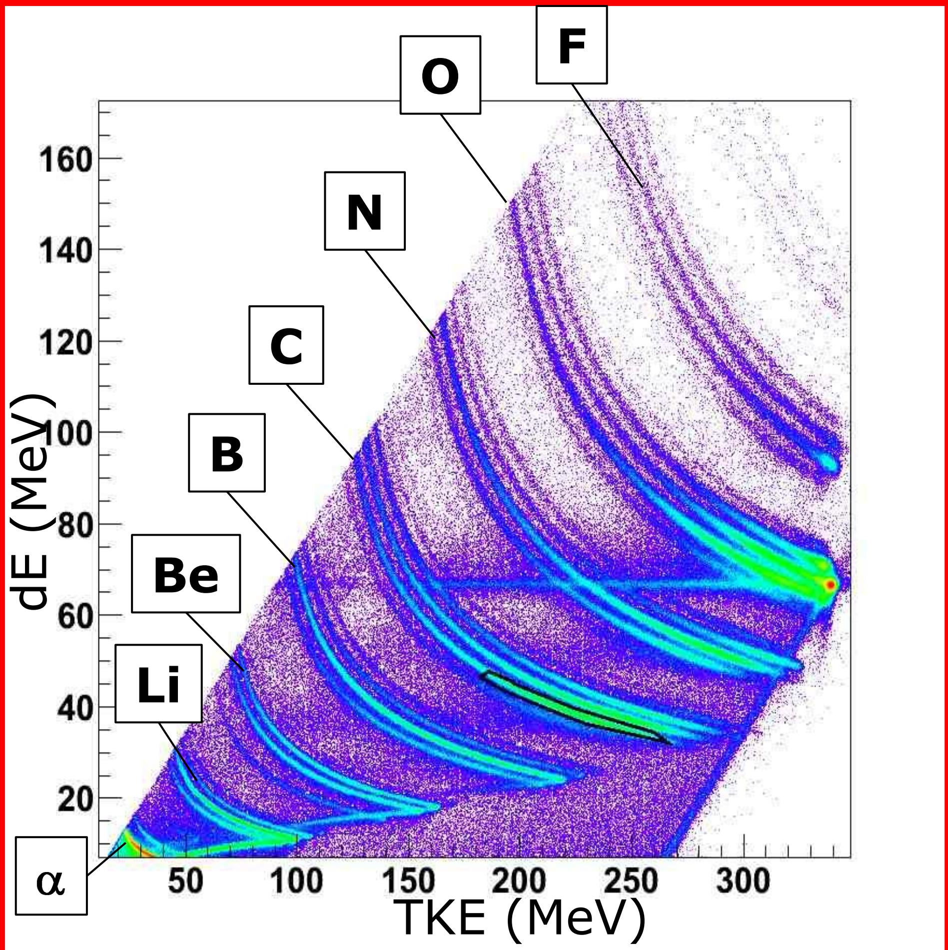
v/c ~ 0.2

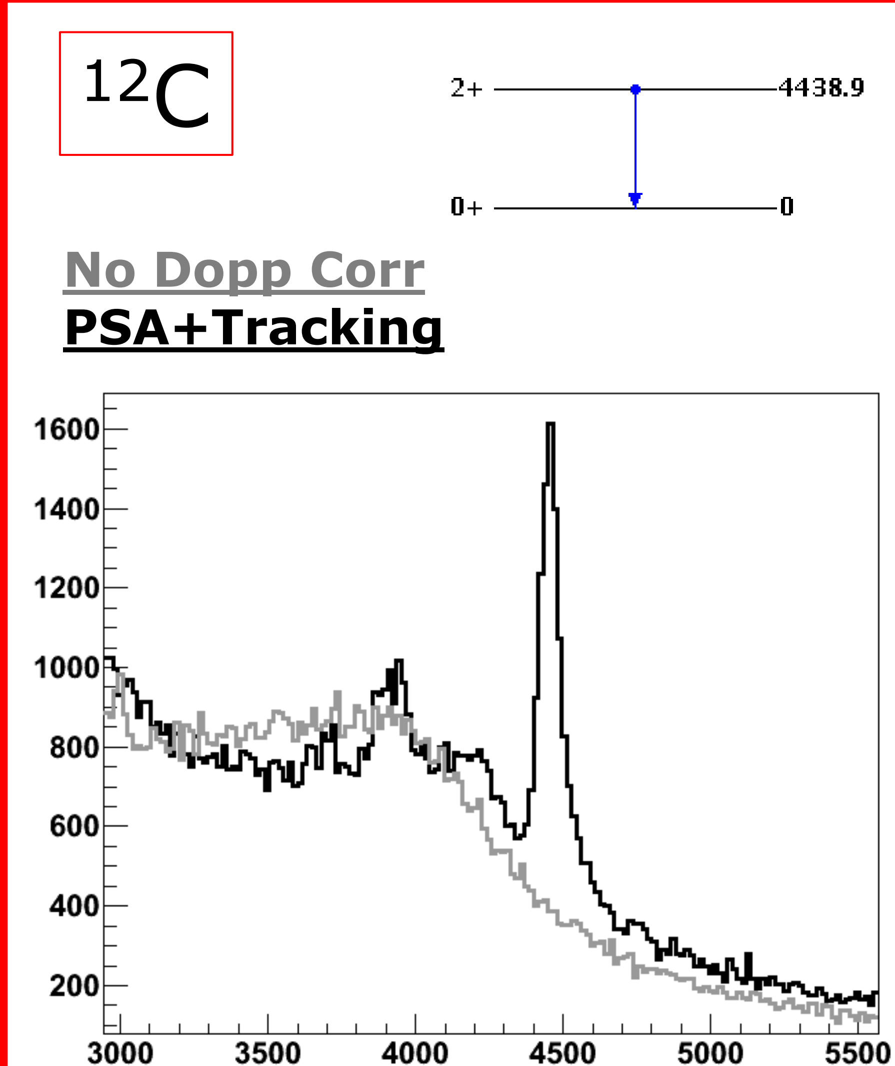




Detection of gamma rays emitted in-flight – Doppler Correction

v/c ~ 0.2





Response of AGATA detectors to high-energy gamma rays

In many in-beam gamma spectroscopy experiments the detection of high-energy gamma rays in the range up to 10-20 MeV is of primary importance, e.g.:

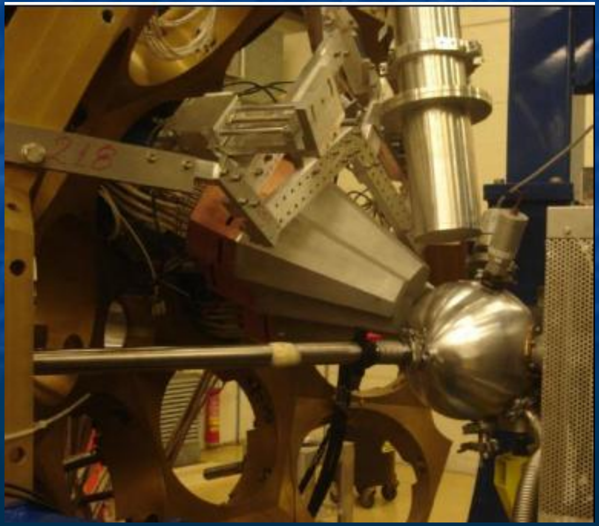
Measurement of ISOSPIN MIXING AT FINITE TEMPERATURE

AGATA+LaBr experiment performed in may 2011 (last week) @ LNL:

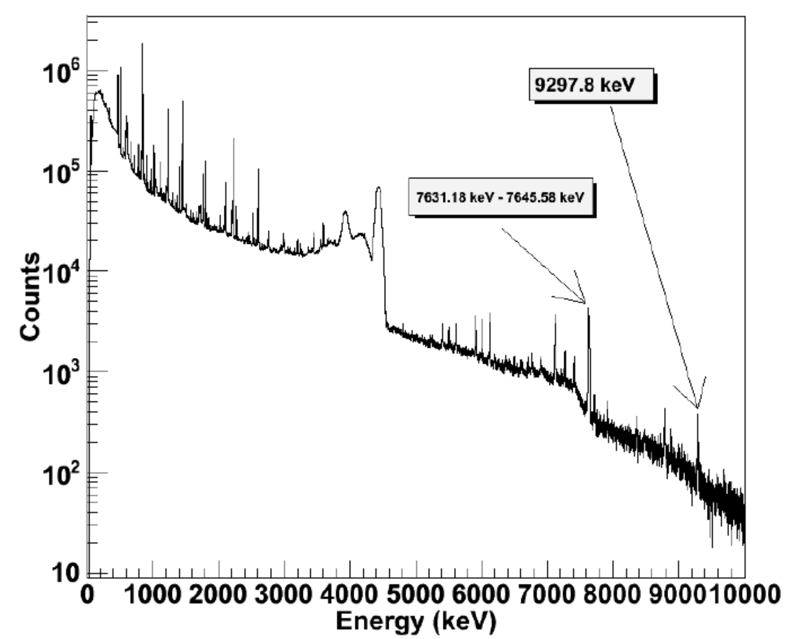
"ISOSPIN MIXING IN THE N=Z NUCLEUS
80Zr AT MEDIUM TEMPERATURE"

A measurement of the response to 15.1 MeV gamma rays has been performed using two HPGe triple clusters of the AGATA Demonstrator array, operating at LNL. **15.1 MeV gamma rays that are emitted by the $1^+ \rightarrow 0^+$ M1 transition in $^{12}C^*$ produced in the reaction:**

$$D(^{11}B,\gamma)^{12}C + n \ @ \ E_{beam} = 19.1 \text{ MeV}$$

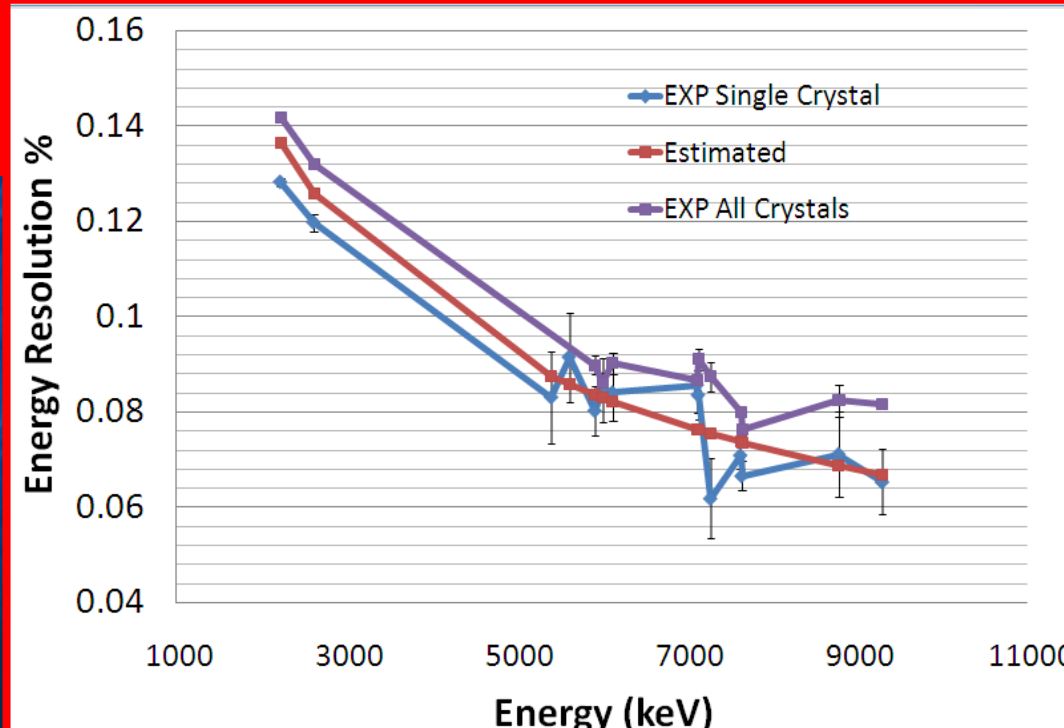


Response of AGATA detectors to high-energy gamma rays



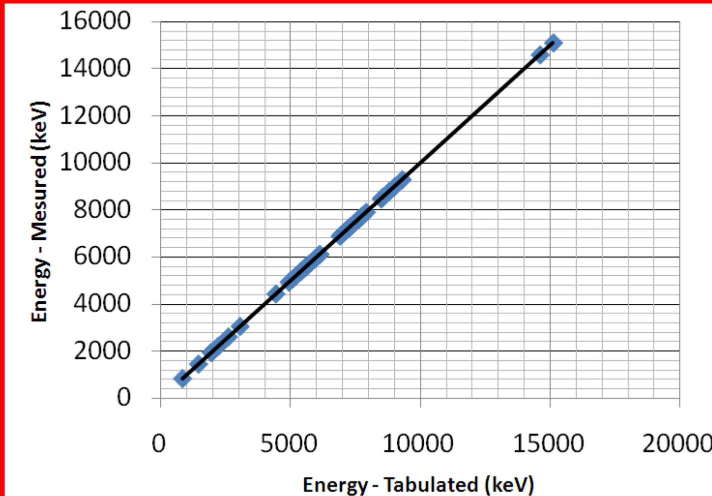
Calibration measurements with an **Am-Be-Fe source** were carried out.
The three high energy gamma-ray lines at **7631.18 keV, 7645.58 keV** (emitted in the 56Fe(n,γ)57Fe reaction) and **9297.8 keV** (emitted in the 54Fe(n,γ)55Fe reaction) are indicated.

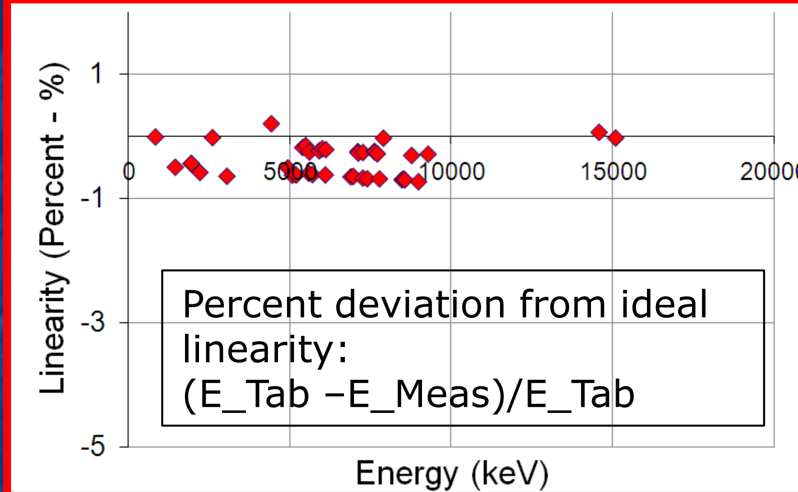
These data allowed a high-energy calibration of the detectors to be made and to **check the linearity and the energy resolution** of the AGATA detectors up to 9 MeV.



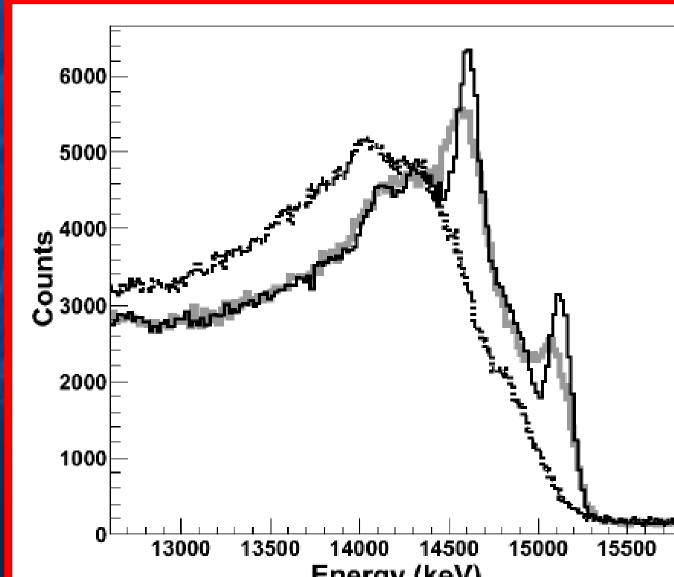
Response of AGATA detectors to high-energy gamma rays

Linearity of AGATA detectors checked up to 15 MeV, using both Am-Be-Fe calibration data and the 15.1 MeV gamma (+S.E.) from the in-beam test



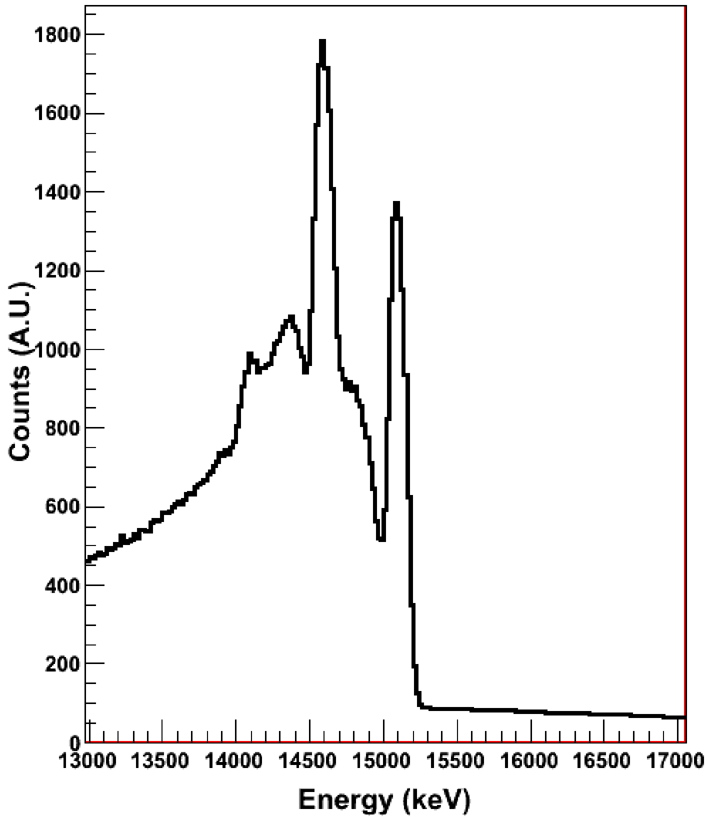


The spectrum obtained **without Doppler correction** (dotted black line) is compared to the one obtained by applying a Doppler correction using only the **central position of the HPGe crystal** with the largest energy deposit (thick gray line) and to the one obtained by using the full information provided by the **PSA and Tracking** (thin black line).

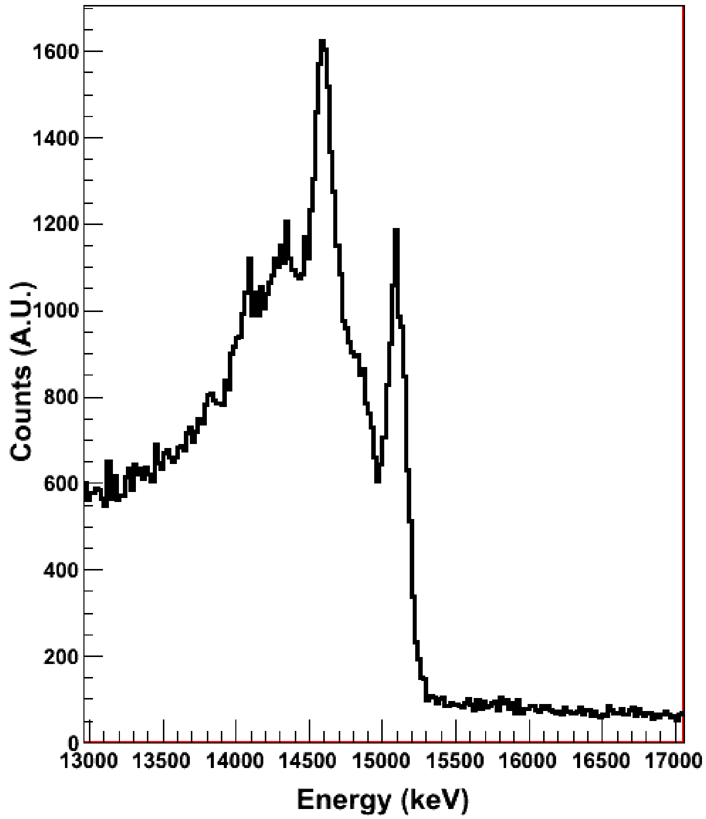


Response of AGATA detectors to high-energy gamma rays

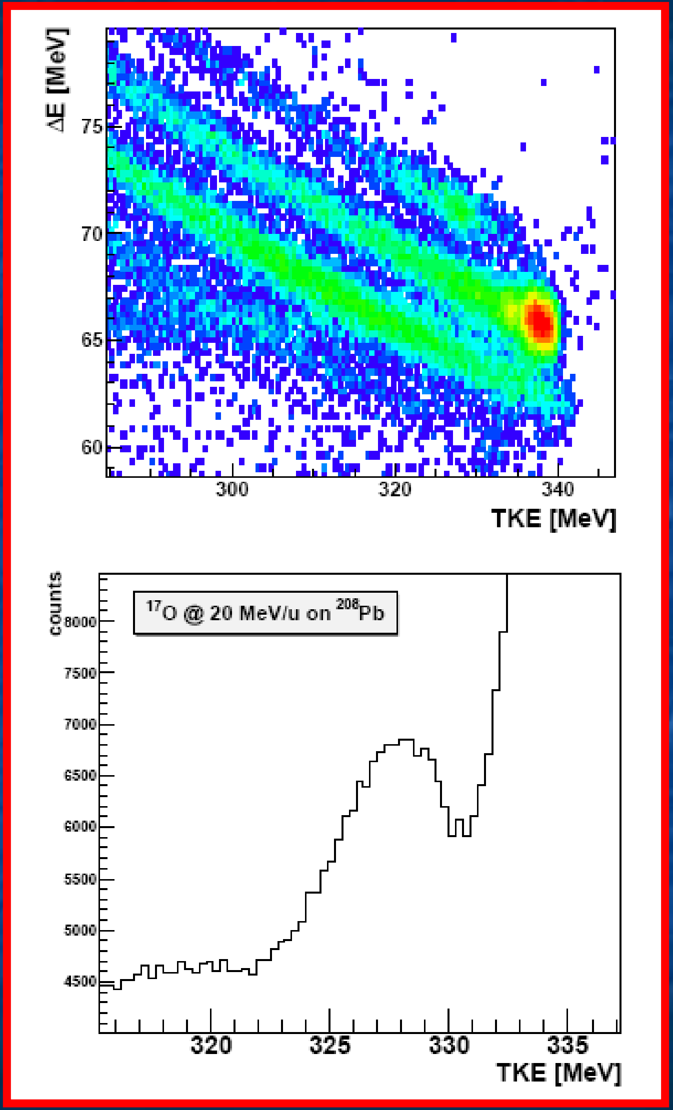
Simulation



Experiment



Preliminary Results for ^{208}Pb

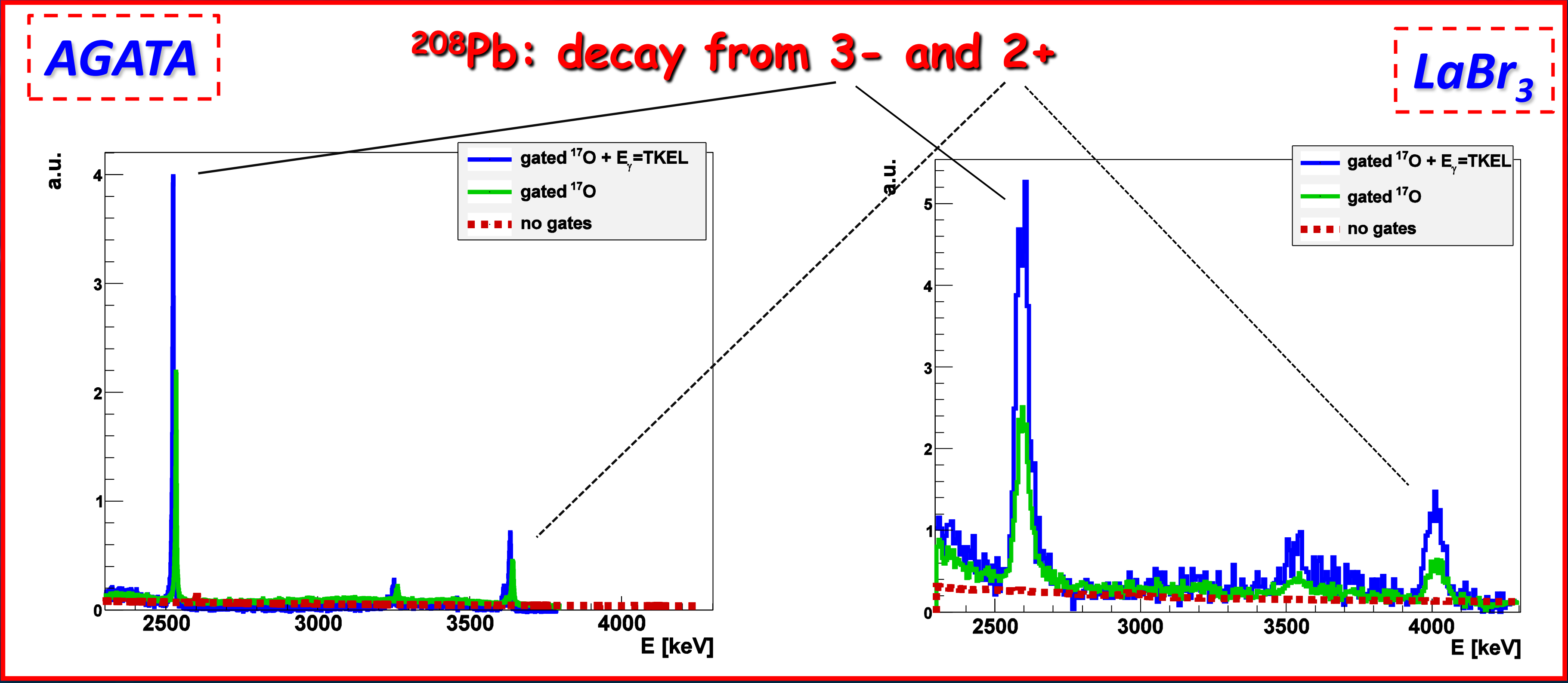


The Total Kinetic Energy (TKE) of the ion was obtained by summing the E and DE detectors signal, pixel by pixel.
The DE -TKE correlation is displayed (top panel) showing a good separation of the O isotopes.

A portion of the energy spectrum of the inelastically scattered 17O is shown in the bottom panel ;
the large bump centered around the energy of 329 MeV (E* ~ 11 MeV) is known to be dominated by the Giant Quadrupole Resonance

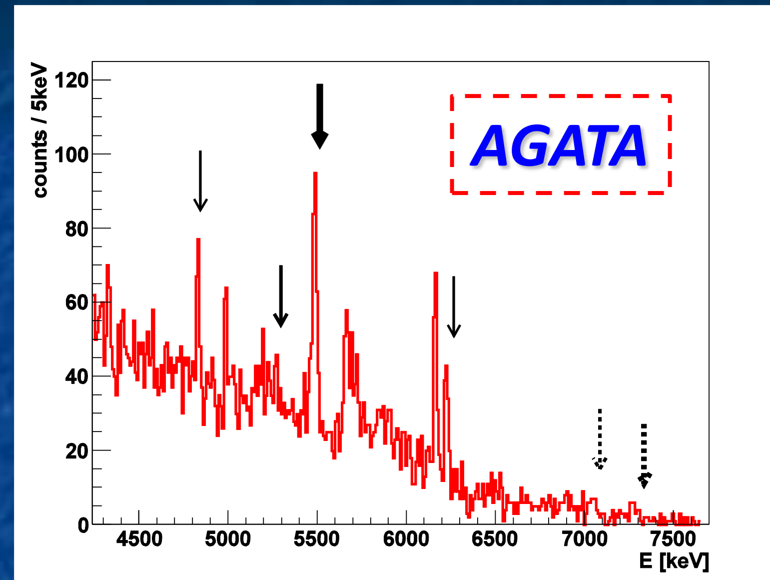
Preliminary Results for ^{208}Pb

The energy spectrum of γ-rays obtained after selecting the inelastically scattered ^{17}O is shown (in green) together with the spectrum obtained without any gating condition (in red). It is evident that this condition enhances the intensity of the 208Pb γ-ray transitions, in particular those at 2615 keV and at 4085 keV, corresponding to the ground-state decay from the first two excited levels (3− and 2+).

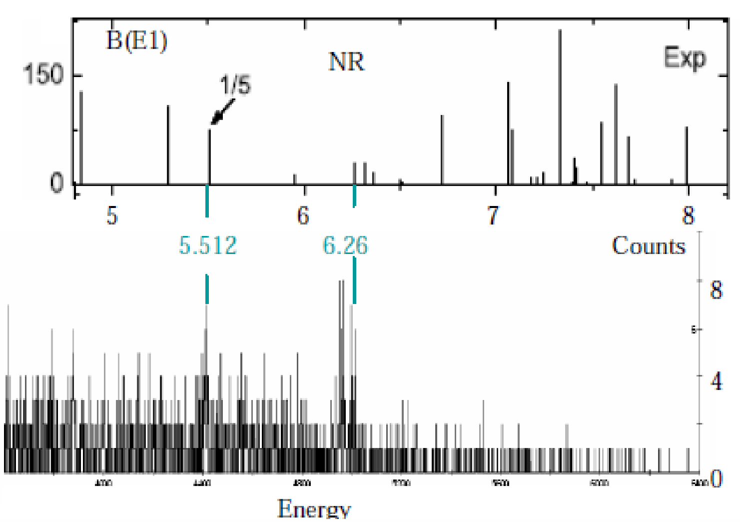


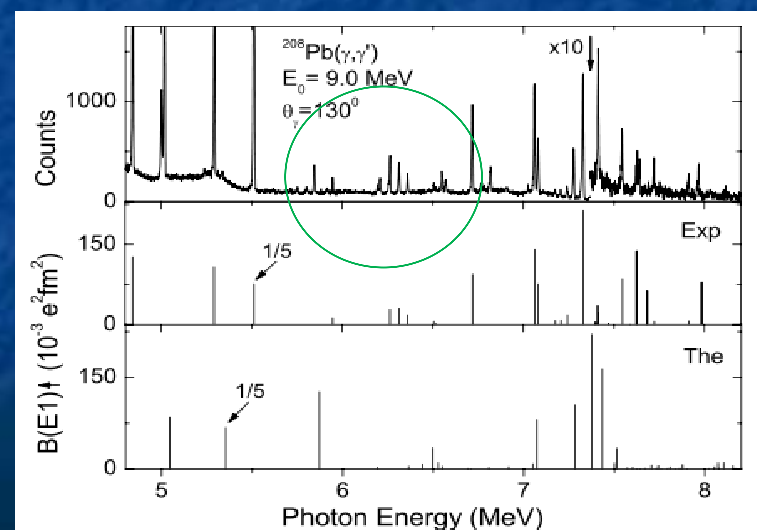
Preliminary Results for ^{208}Pb

Structures appear in γ-spectra after gating on ^{17}O With E= 5-10 MeV*



Berkley-A.Rep.: Deleplanque et al.





N. Ryezayeva et al., PRL 89, 27 (2002)

Conclusions and Perspectives

❑ **Preliminary results were shown for the experiment "Inelastic scattering as a tool to search for highly excited states up to the region of the Giant Quadrupole Resonance"**

➢ *An important part of the work is devoted to technical issues (new gamma detector technology - AGATA)*

➢ *Doppler corrected gamma spectra have been shown for different selection of outgoing nuclei (Improved Doppler Correction capability provided by AGATA detectors is fundamental* **^{17}O @ 20 MeV/u → v/c ~ 0.2** *)*

➢ *Preliminary results for ^{208}Pb show that the resonance has been populated.*

➢ Using Heavy Ions as a probe, interesting results on the population of the pygmy resonance are found, for which further analyses will be carried out. Experiments performed with different probes (e.g. purely isoscalar in the case of alpha particles or other N = Z nuclei, and both isoscalar and isovector for N ≠Z nuclei) are complementary, altering the relative population of the different states. *With the planned work we expect to make another step toward a better understanding of the underlying structure of giant resonances.*

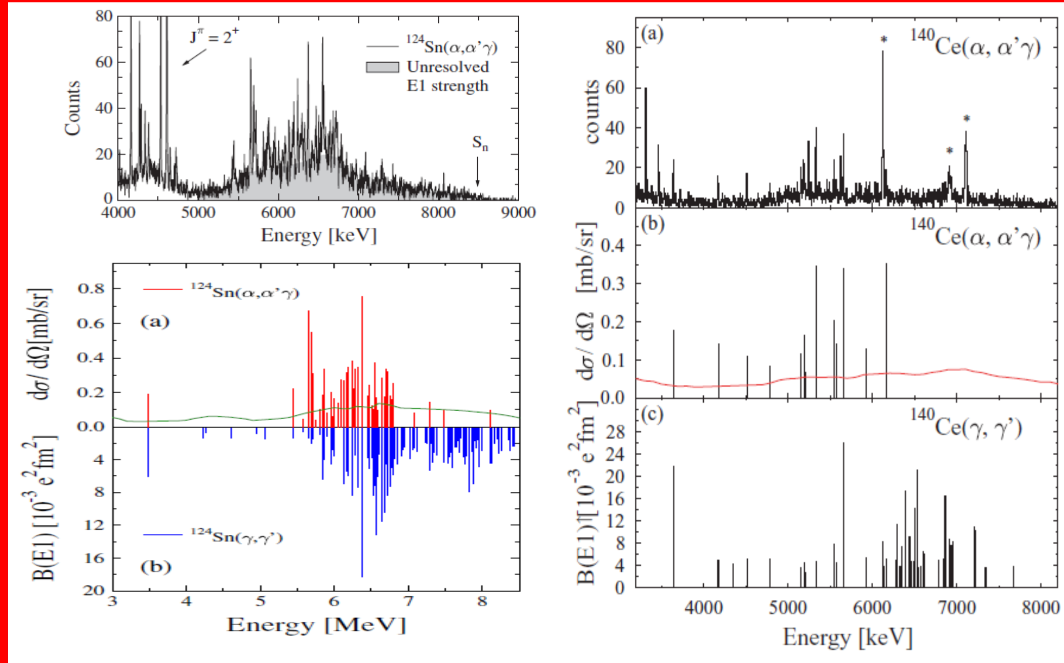
➢ *^{90}Zr data analysis still work in progress*

Conclusions and Perspectives

We intend to continue this research program by studying highly excited states in ^{124}Sn and ^{140}Ce nuclei, making use of inelastic scattering with ^{17}O heavy ions.

A deeper understanding of the nuclear structure properties of the Giant Quadrupole Resonance and of the pygmy dipole resonance requires in fact systematic studies in different region of masses, with different probes.

[Left Panel] J. Endres et al., Phys. Rev. Lett. **105**, 212503 (2010).
[Right Panel] J. Endres et al., Phys. Rev. C**80**, 034302 (2009).



→ Proposal in preparation:
"Study of high-lying bound and unbound states in ^{124}Sn and ^{140}Ce via inelastic scattering of ^{17}O ions"
Spokespersons: M. Kmiecik, F. Crespi

Collaboration

"Inelastic scattering as a tool to search for highly excited states up to the region of the Giant Quadrupole Resonance"

Contact Person: Angela Bracco - University of Milan and INFN

Spokespersons:

R. Nicolini[a], D. Mengoni[c,h], A. Bracco[a], G. Benzoni[a], F. Birocchi[a], N. Blasi[a], C. Boiano[a], S. Brambilla[a], F. Camera[a], A. Camplani[a], A. Corsi[a], F.C.L. Crespi[a], A. Giaz[a], S. Leoni[a], B. Million[a], L. Pellegri[a], S. Riboldi[a], V. Vandone[a], O. Wieland[a], G. De Angelis[b], A. Gadea[b,d], P. Molini[b], D. R. Napoli[b], F. Recchia[b], E. Sahin[b], J.J. Valiente-Dobon[b], D. Bazzacco[c], E. Farnea[c], A. Gottardo[c], C. Michelagnoli[c], D. Montanari[c], C. Ur[c], A. Maj[e], M. Kimiecik[e], M. Ciemala[e], R. Kempley[f], A. Bürger[g]

[a] Università degli Studi e INFN sezione di Milano, Via Celoria 16, 20133, Milano.
[b] INFN, Laboratori Nazionali di Legnaro, Legnaro, Italy.
[c] Università di Padova e INFN, sezione di Padova, Padova, Italy.
[d] IFIC, Valencia, Spain.
[e] The Niewodniczanski Institute of Nuclear Physics, Polish Academy of Sciences, Krakow, Poland
[f] University of Surrey, Guildford, UK
[g] University of Oslo, Norway
[h] School of Engineering and Science, University of the West of Scotland, Paisley, Scotland-U.K.