CDS Milano:
Part of "GAMMA activity"
AGATA segmented HPGe tracking array and HECTOR+ large volume scintillator Array @ LNL, GSI,…

1. Introduction

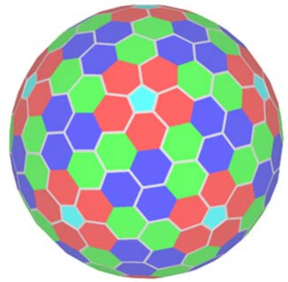
2. **PAST**:
   Highlight(s) from the performed experiments at LNL with STABLE BEAMS

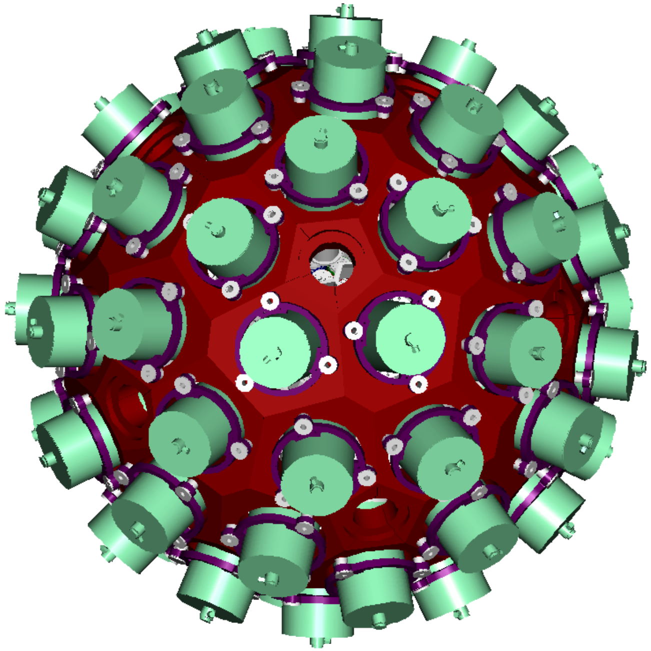
3. **PRESENT+FUTURE**:
   Preview from the campaign at GSI with EXOTIC BEAMS

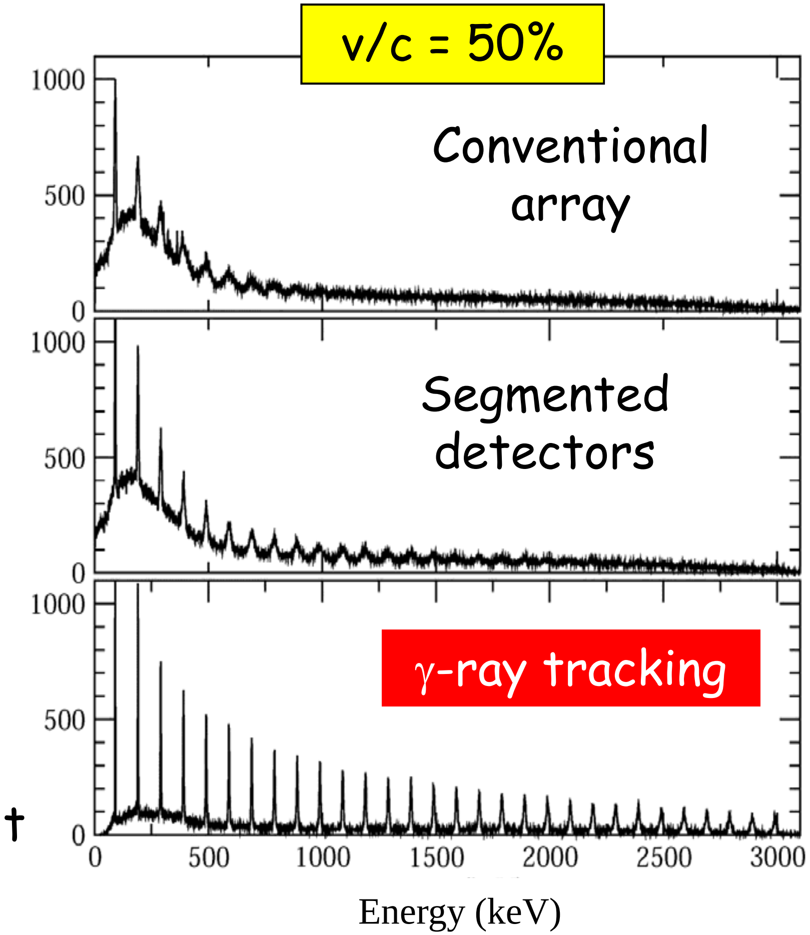
AGATA = Σ …

AGATA

(Advanced GAmma Tracking Array)





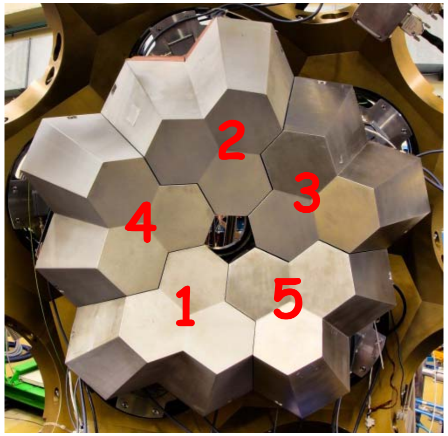


The innovative use of detectors in **position-sensitive mode** (combining digital DAQ, PSA (Pulse Shape Analysis), γ-ray tracking) will result in high efficiency (~40%), excellent energy resolution and sensitivity making AGATA the ideal device for spectroscopic studies of weak channels.

The effective **energy resolution** and **sensitivity** is maintained also at "extreme" v/c values

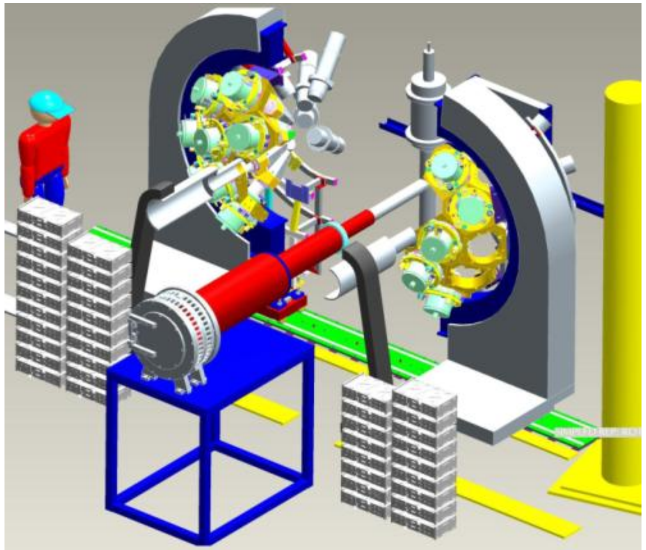
OVERVIEW AGATA+
Experimental Program

2010-2011 → LNL
5TC



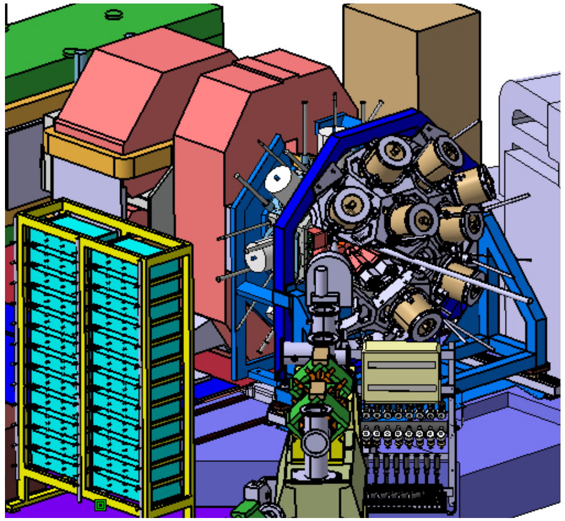
AGATA D.+PRISMA
+ HECTOR$^+$
Total Eff. ~6%+$^+$

2012 -2013→ GSI/FRS
≥5DC+5TC



AGATA @ FRS
+ HECTOR$^+$
Total Eff. > 10%+$^+$

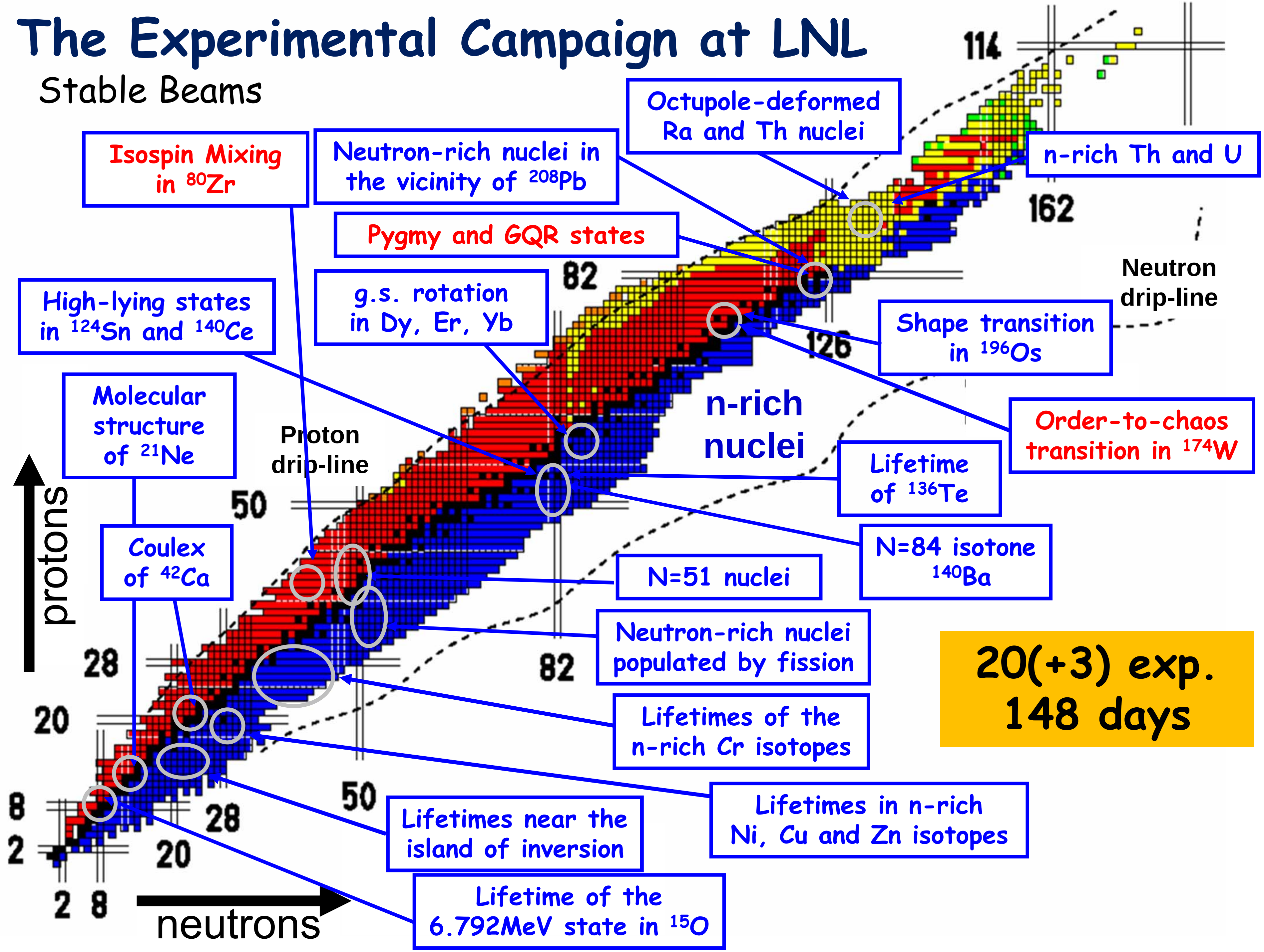
2014 → GANIL/SPIRAL2
~15TC



Total Eff. > 20%+$^+$

The Experimental Campaign at LNL

Stable Beams



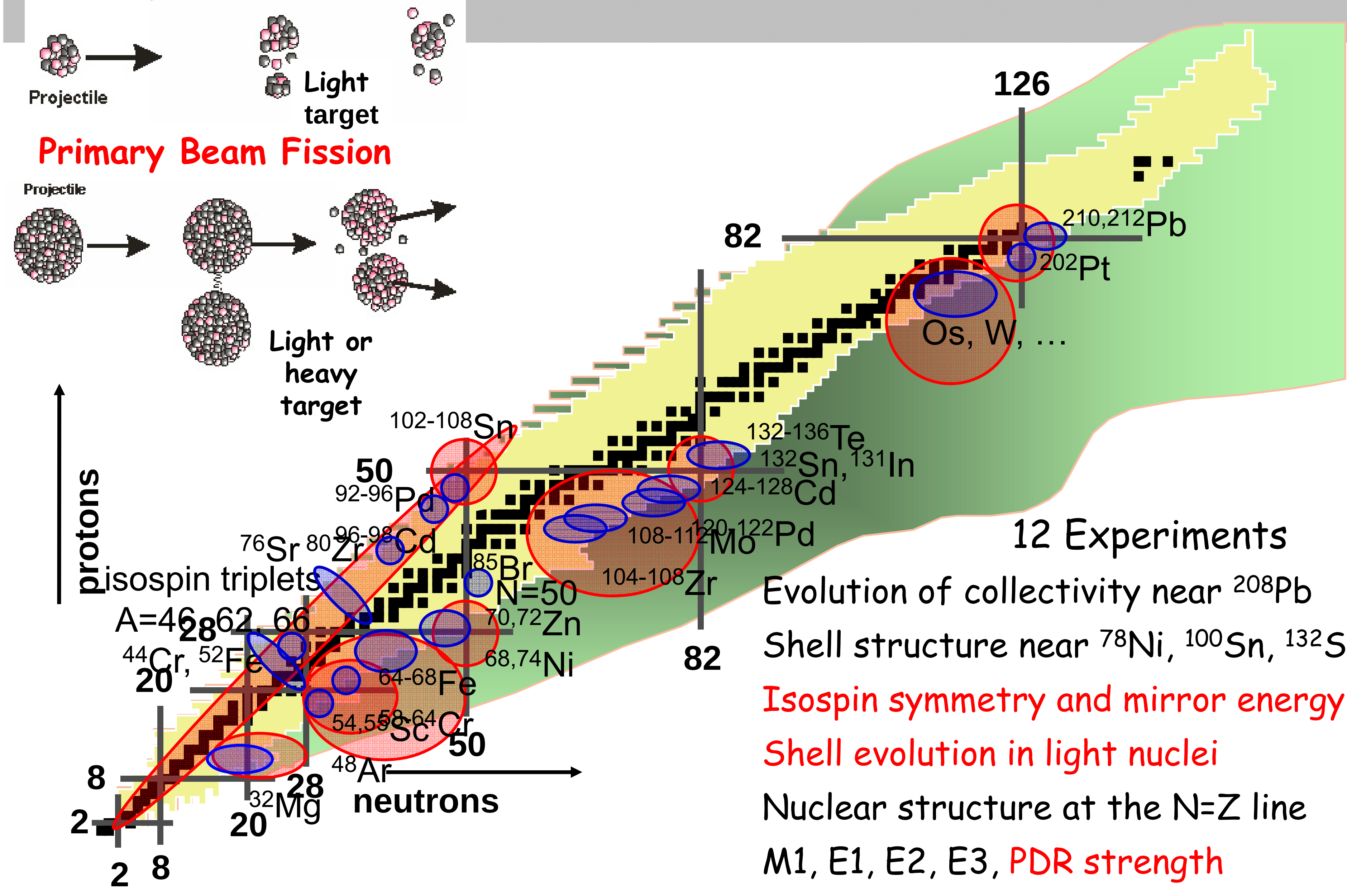
20(+3) exp.
148 days

AGATA@GSI-FRS Scientific Program

Exotic Beams and high AMeV

Primary Beam Fragmentation

Primary Beam Fission



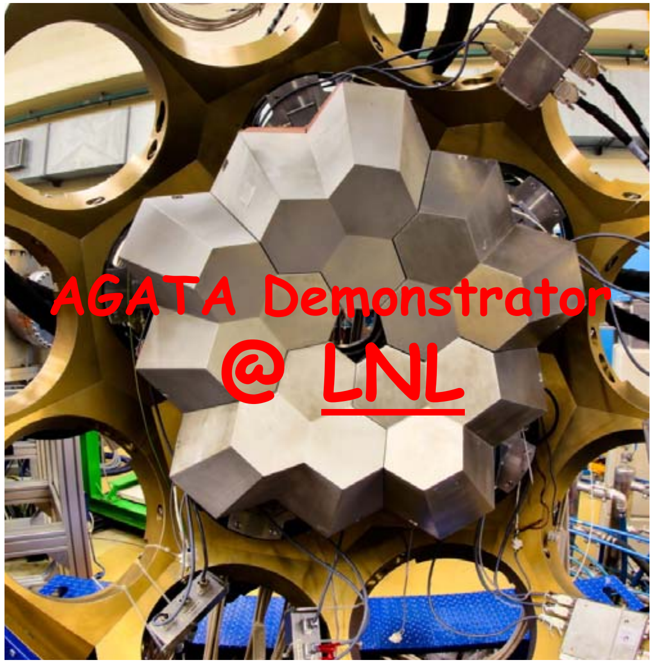
12 Experiments

- Evolution of collectivity near ^{208}Pb
- Shell structure near ^{78}Ni, ^{100}Sn, ^{132}Sn
- Isospin symmetry and mirror energy
- Shell evolution in light nuclei
- Nuclear structure at the N=Z line
- M1, E1, E2, E3, PDR strength

AGATA@LNL: First complete implementations of the γ-ray tracking array concept

Innovative use of HPGe detectors in position-sensitive mode

(combining digital DAQ, pulse shape analysis, γ-ray tracking)



15 crystals in 5 TC
Commissioned in 2009 (with 3 TC)
Experiments since 2010 (mostly with 4 TC)
Completed with the 5th TC, May 2011
Now moved to GSI!

Milano:

- Flange (Mi-Pd-LNL)
- Cameretta
- Telescopic beam line
- -New Beam Dump
- Ancillary Detector support (small BaF+ LaBr)
- -electronics (TRACE)
- DACQ (ancillary)
- -Preamp

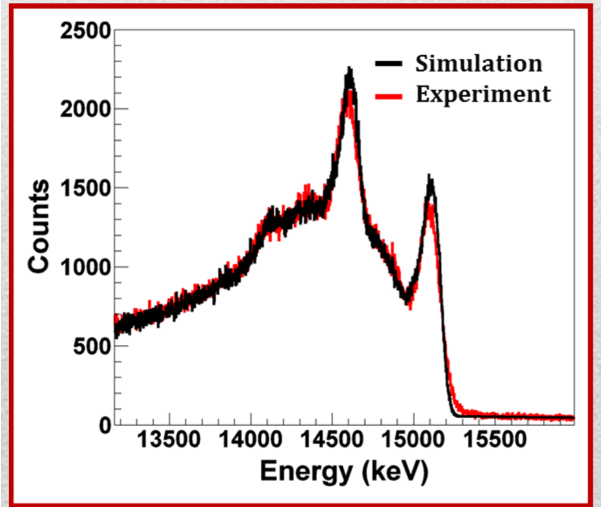
4 Examples of experiments from the Milano Nuclear Structure group @ LNL

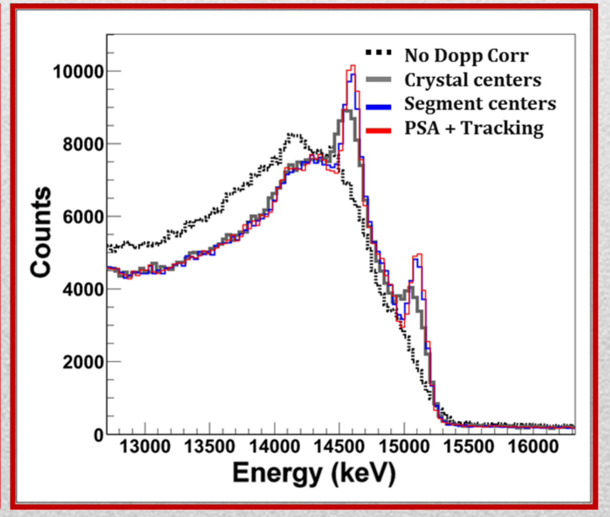
Tracking-Response of AGATA detectors to high-energy gamma rays (Fabio Crespi)	AGATA
Order-to-chaos in 174W (Valeria Vandone and Silvia Leoni)	AGATA+small BaFs
Isospin Mixing in the N=Z Nucleus ^{80}Zr at Medium Temperature (Agnese Giaz and Franco Camera)	AGATA+LaBr
High lying nuclear states via inelastic scattering of 17O (Luna Pellegri and Fabio Crespi)	AGATA+LaBr+BeamDump

Response of AGATA detectors to high-energy gamma rays

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 are emitted by the $1^+ \to 0^+$ M1 transition in $^{12}C^*$ produced in the reaction:**

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





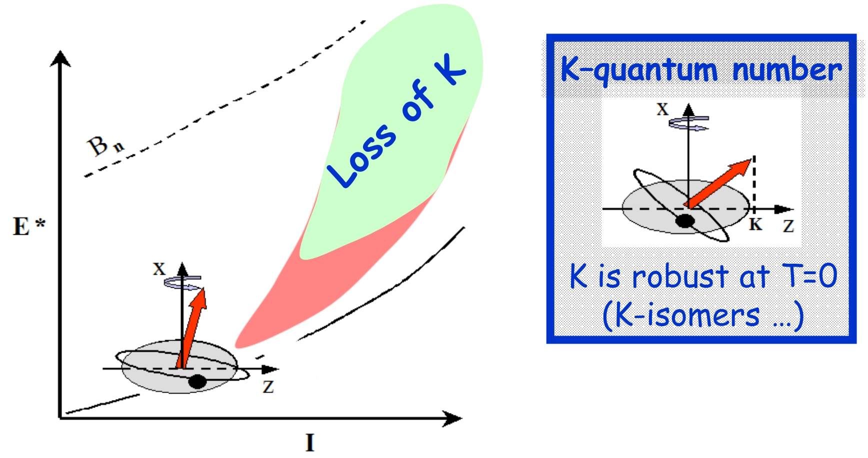
- ❑ Good agreement between simulated and experimental data
  → ***Unfolding of the gamma spectra***
- ❑ Great improvement in Doppler Correction quality using PSA+Tracking (also for high-energy gamma rays)

Order-to-chaos in ^{174}W

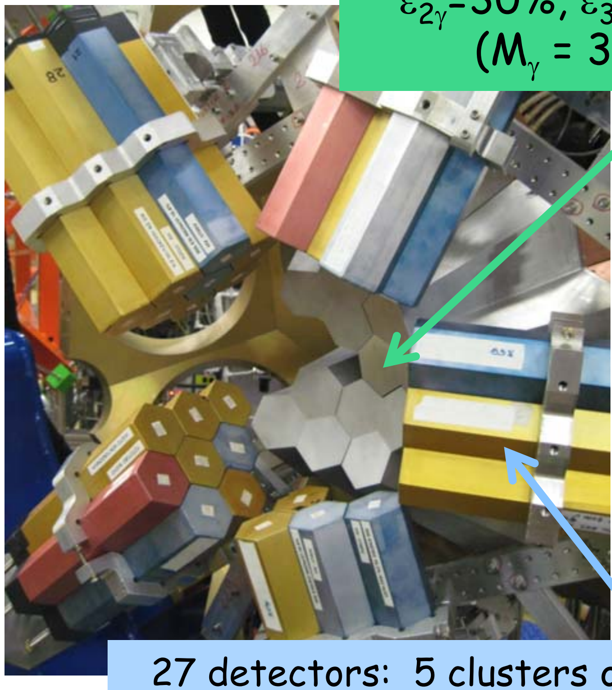
High-Spin Fusion Evaporation

^{50}Ti on ^{128}Te @ 217 MeV, $I \geq 60\hbar$

Loss of selection rules on K with temperature



K: projection of the total angular momentum on the symmetry axis

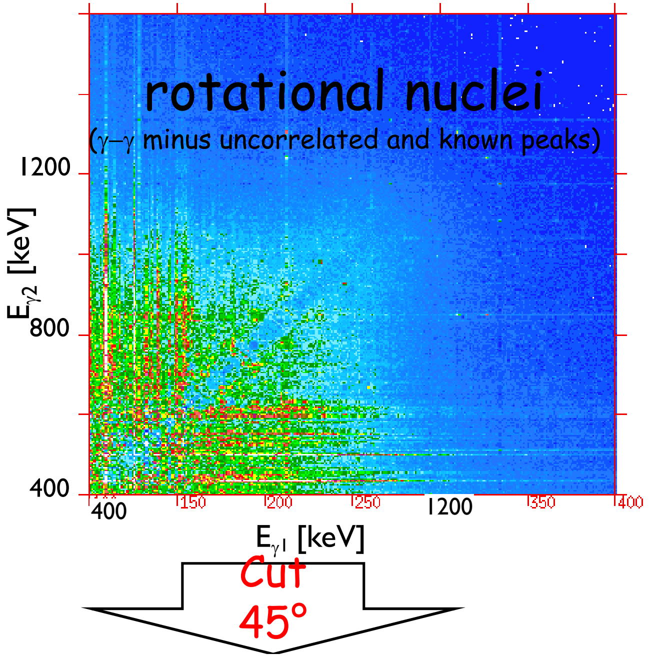


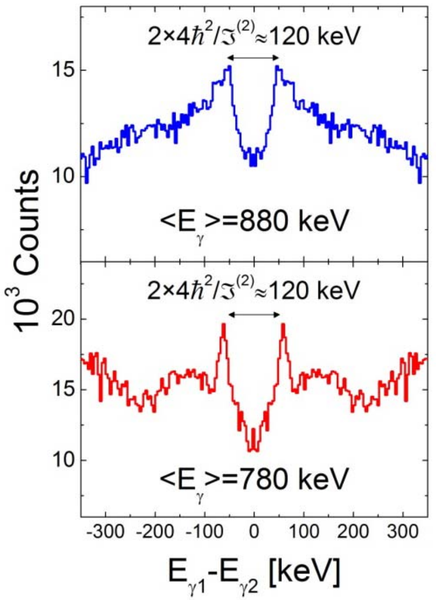
4 Triple Clusters
2 and 3 folds:
$\varepsilon_{2\gamma}$=30%, $\varepsilon_{3\gamma}$=10%
(M_γ = 30)

27 detectors: 5 clusters of BaF_2
(3"×3", exagonal)
Total solid angle: 25% of 4π
Total efficiency: 16% @ 500keV

Goal: populate ^{174}W at the **highest possible spins** (≥60ħ, selected in HELENA), in order to make the **statistical fluctuation analysis of the ridge-valley structures in the γ-γ matrices**, to estimate the number of low-*K* and high-*K* bands and their correlation

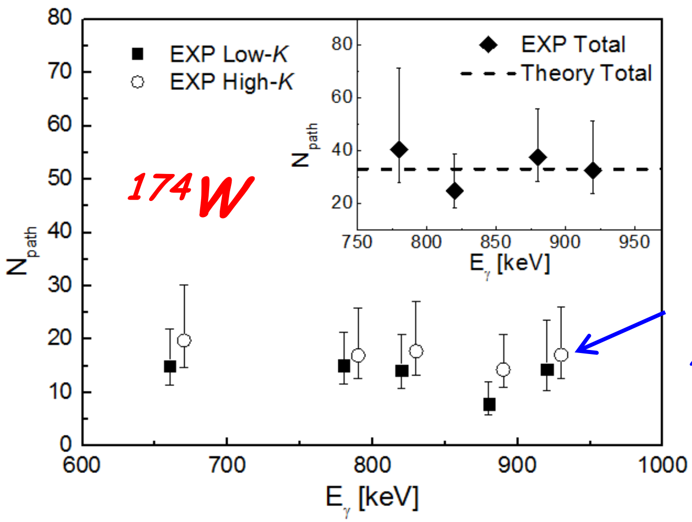
Quasi-Continuum γ-γ matrices





Statistical fluctuaction analysis of ridges:

Number of bands below 1 MeV



Similar number Low-K and High-K Bands

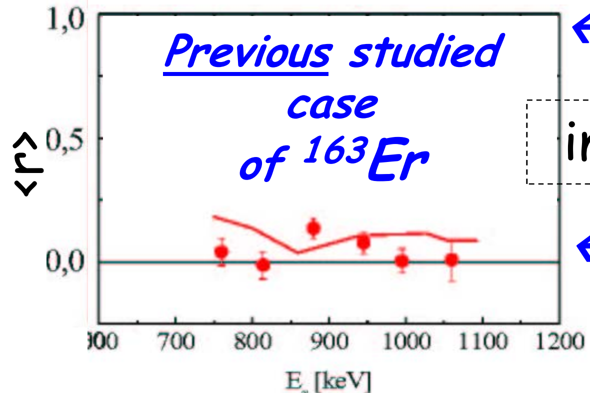
As in the only studied case of ^{163}Er

Perspectives:

Covariance Analysis between Low-K and High-K spectra →

similarity of different cascades, test of the selection rules

Is the K quantum number conserverd up to E*< 1 MeV ?



← CHAOS

in ^{174}W ?

← ORDER

Statistical analysis shows: K conserved up to 1 MeV

Isospin Mixing in ^{80}Zr

$^{40}Ca + ^{40}Ca = ^{80}Zr$ & $^{37}Cl + ^{44}Ca = ^{81}Rb$

AGATA sensitivity power selects CN

The Ground State of most of nuclei has Isospin $I=I_z=(N-Z)/2$

Isospin is an almost good quantum number

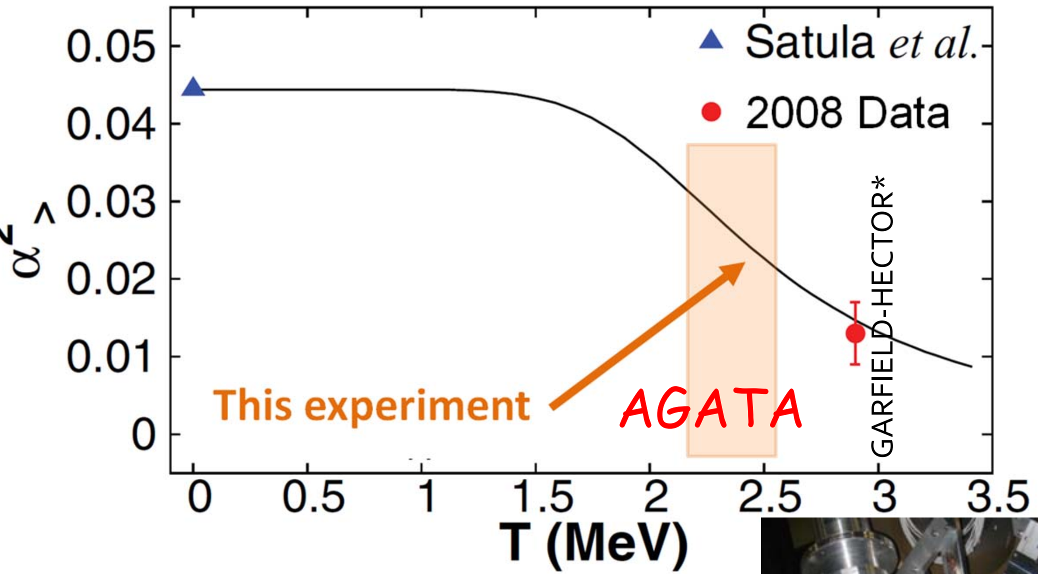
Isospin symmetry in nuclei is broken by Coulomb interaction (V_c)

GDR is a tool to measure the isospin mixing

GDR decay is inhibited

(I=0 to I=0 E1 transitions are forbidden)

Experiment to measure the Isospin mixing in N=Z nucleus ^{80}Zr at medium temperature



*Corsi, Wieland Bracco Camera et al Phys.Rev C 84 (2011) 041304(R)

Isospin mixing at T=0 depends on the nuclear interaction assumptions → Strong test of theory

Our objectives:

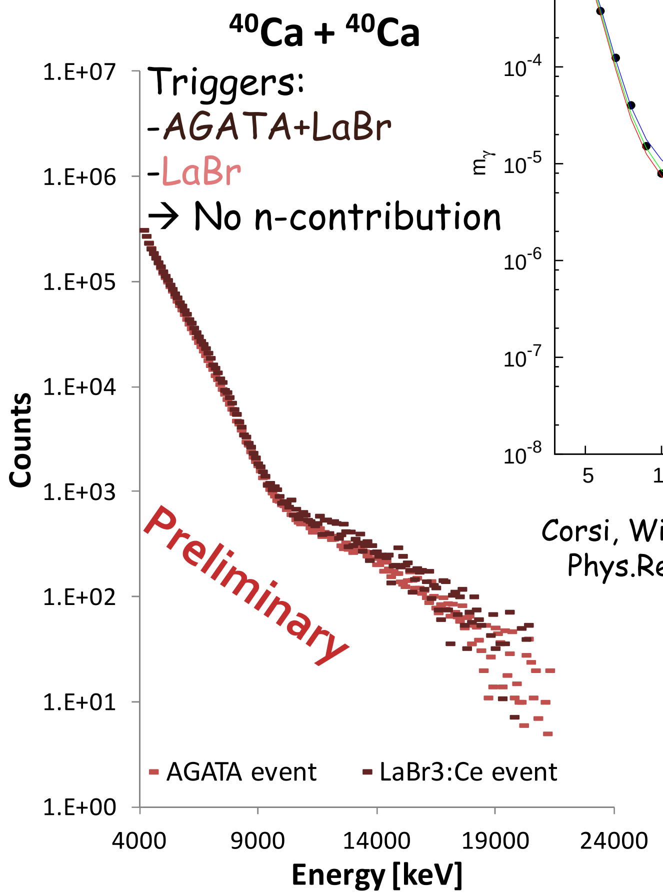
- **measure the temperature dependence of isospin mixing in ^{80}Zr**
- extract the value of Isospin mixing at zero temperature
- validate the theoretical calculations to extract the T=0 mixing value from the T≠0 one
- measure the Coulomb Spreading Width

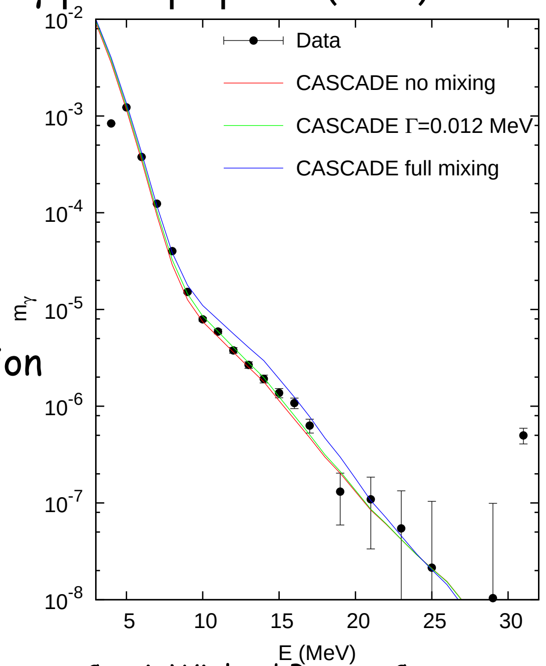
H.L. Harney et al rev. Mod. Phys. 58(1986)607 - M.N. Harakeh et al. Phys. Lett. B 176(1986)297 - A.Behr et al. Phys. Rev. Lett. 70(1993)3201

^{40}Ca + ^{40}Ca high energy γ-spectra

$LaBr_3$:Ce detectors

$Labr_3$:Ce event gated on γ prompt peak (**2** ns)

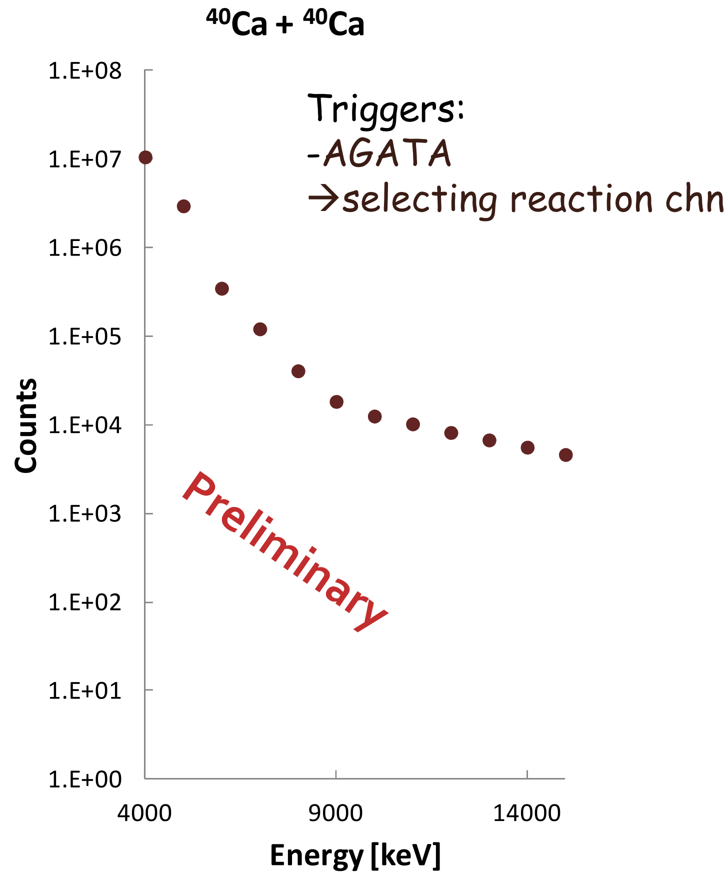




Corsi, Wieland Bracco Camera et al
Phys.Rev C 84 (2011) 041304(R)

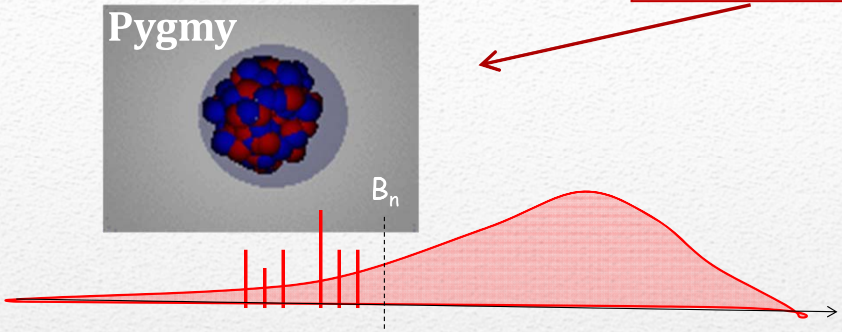
AGATA demonstrator

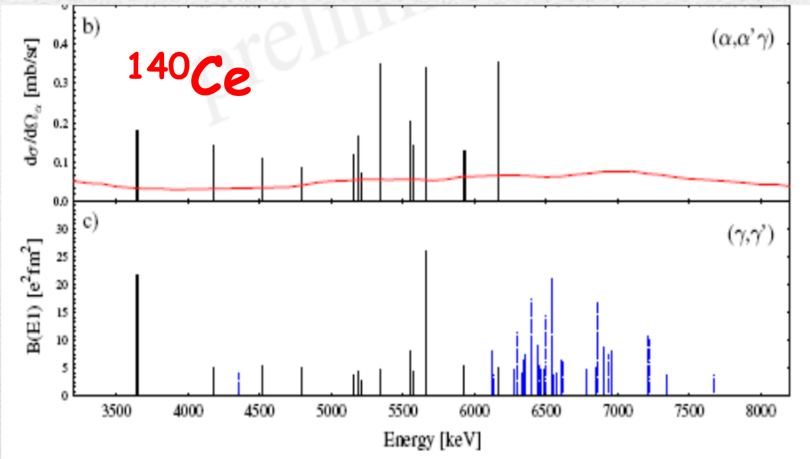
High energy spectrum for AGATA event gate about **30** ns



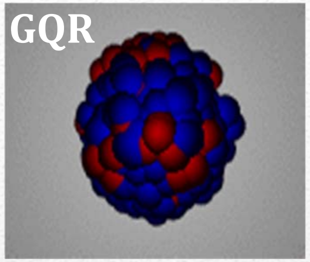
High lying nuclear states via inelastic scattering of 17O

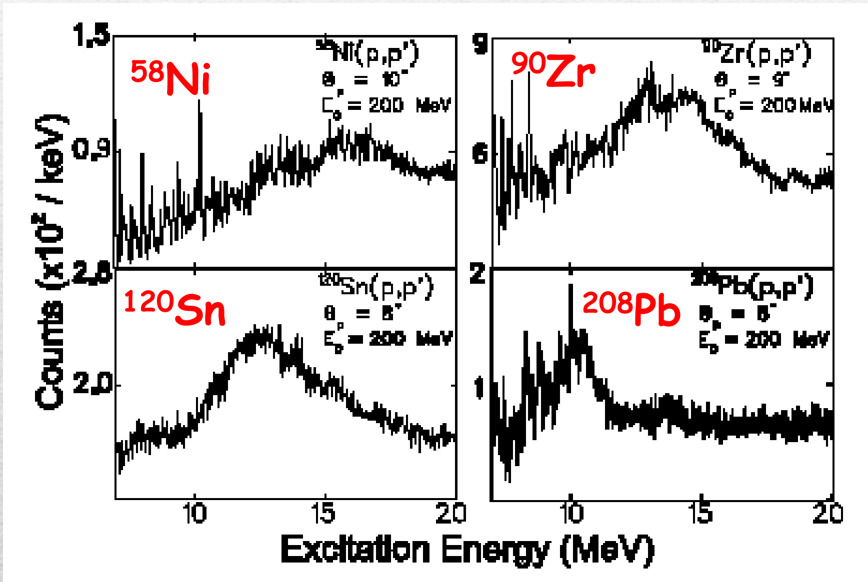
In Stable Nuclei





?





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

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

Selective Population

Fine Structures

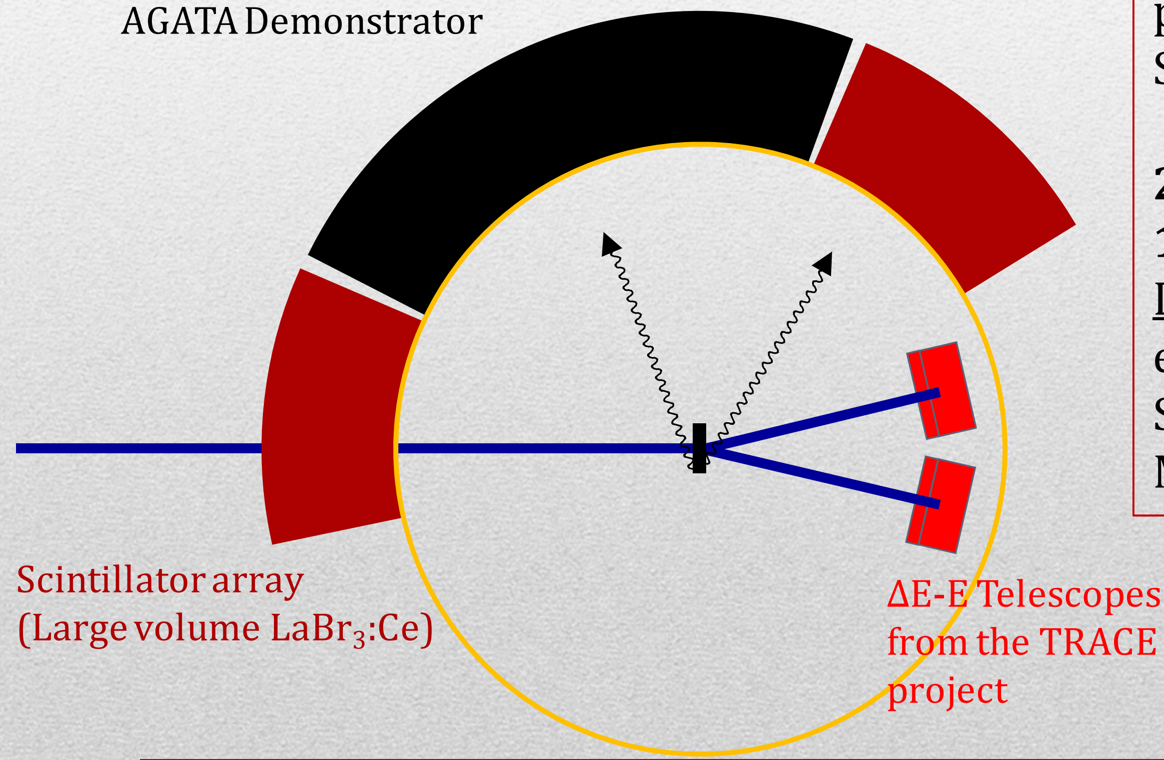
D. Savran et al., PRL97(2006)172502; T. Hartmann PRL85(2000)274

Shevchenko PRL93(2004)122501-1

Experimental Technique

Inelastic scattering of ^{17}O @ 20 MeV/u on different targets + γ-rays in coincidence

- Large cross-section for the population of the giant resonance region
- ^{17}O is loosely bound (S_n = 4.1 MeV)
- → **Clean removal of projectile excitation**

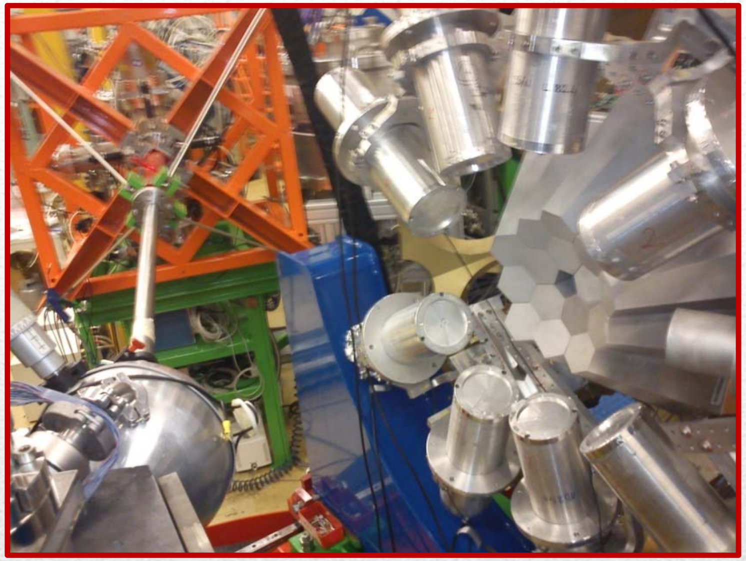


Two experiments performed at LNL:

1) Studied Nuclei: **208Pb 90Zr**, performed in May 2010, Spokesperson: R. Nicolini

2) Studied nuclei: **208Pb, 124Sn,140Ce**, performed in December 2011 (with improved experimental setup), Spokespersons:
M. Kmiecik, F. Crespi

Detection

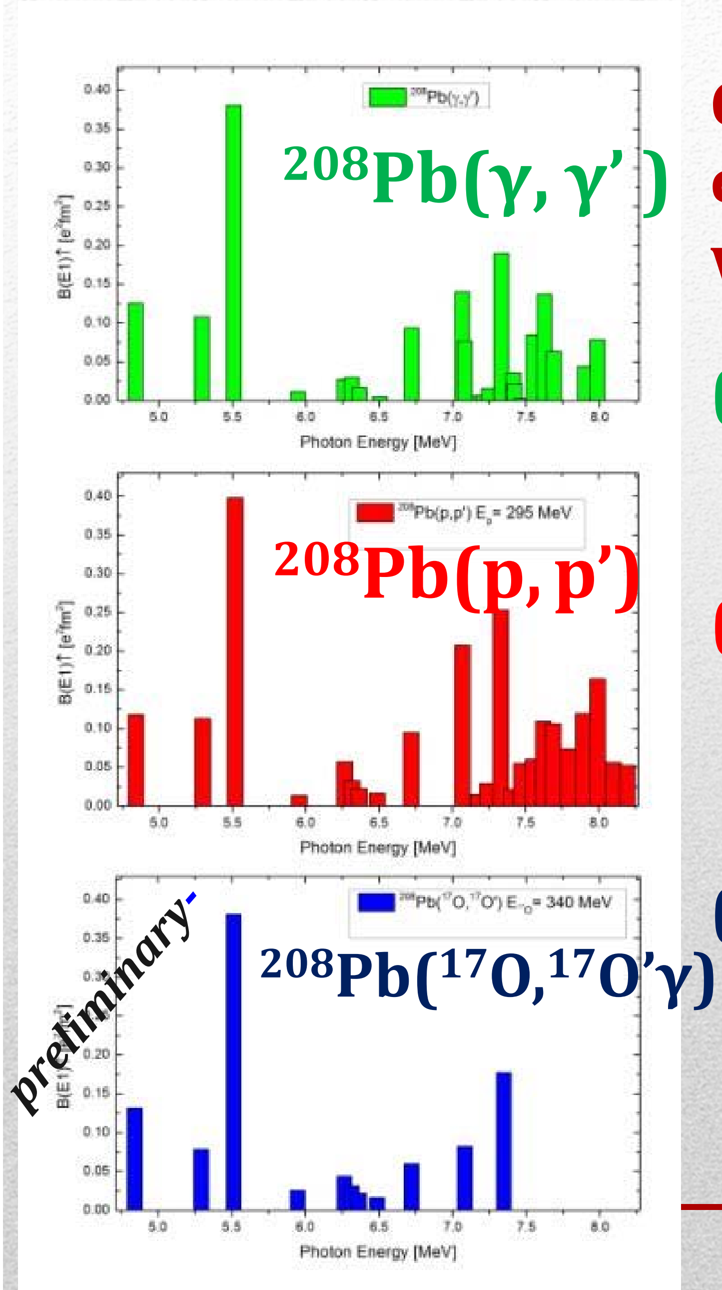


AGATA Dem. + 9 $LaBr_3$:Ce

- Higly segmented HPGe detectors
- Digital electronics
- Pulse Shape Analysis
- Tracking algorithms
- High efficiency (30% higher than HPGe)
- Large volume (up to 9x20 cm)
- Good time resolution (< 1ns)
- Good energy resolution (the best of all scintillators ~20 keV FWHM at 662 keV)

- 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

- Selection of reaction channel
- Correlation between E* and E_γ
- Good energy resolution (< 1%)
- Large solid angle coverage



Comparison with the results of the excitation of the pygmy states with 3 probes :

(γ, γ') - probing the entire nuclear volume

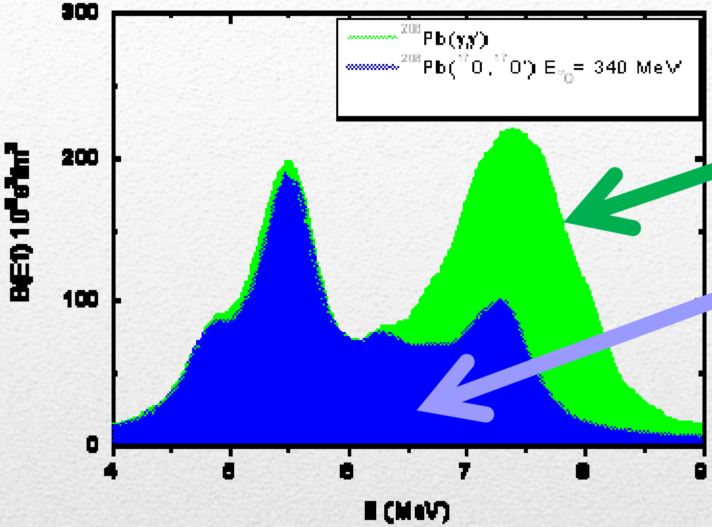
N. Ryezayeva et al., Phys. Rev. Lett. 89, 272502 (2002)

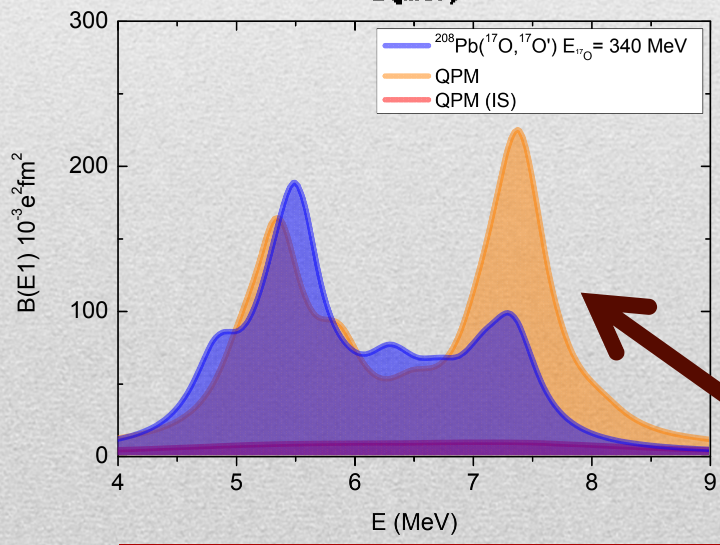
(p,p') - at 295 MeV isovector probe possible branching at excited states

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

(^{17}O , ^{17}O' γ) strong isoscalar character– similar behavior of (α, α' γ) in other nuclei

Comparison of the strength from:





(γ, γ') - and this (^{17}O , ^{17}O' γ) experiments

Some missing strength in case of (^{17}O , ^{17}O' γ) above 7 MeV

(^{17}O , ^{17}O' γ) experiment
Below 7 MeV good agreement exp-theory

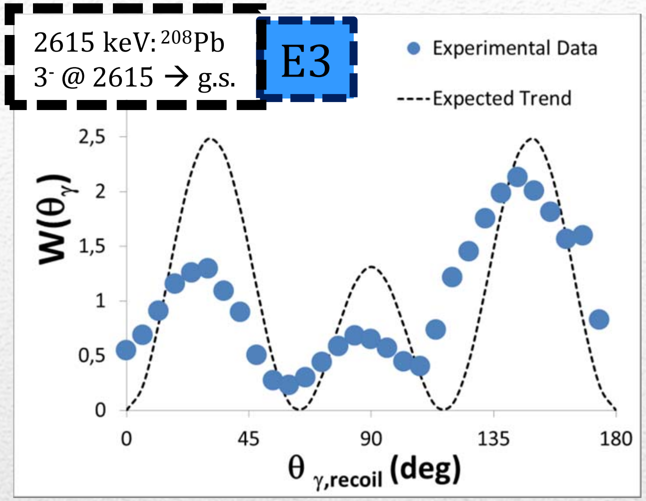
and theoretical prediction
From N. Ryezayeva et al. PRL89 272502(2002)

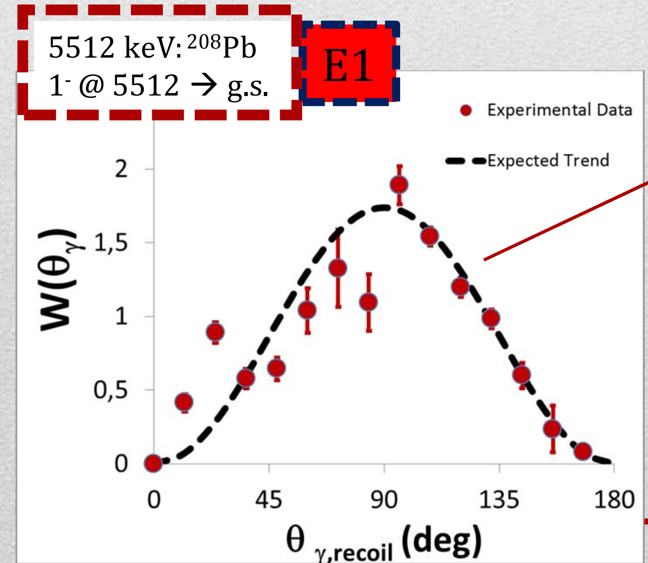
Angular Distributions

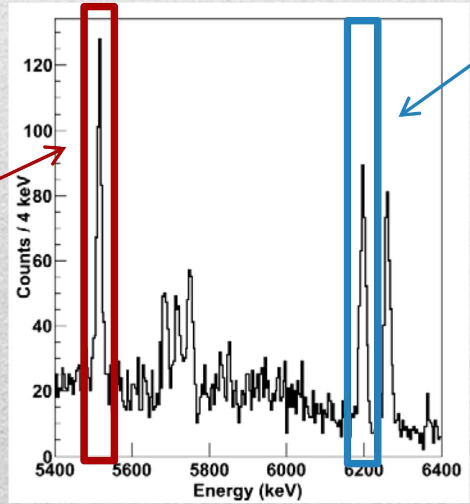
Data from new (December 2011) Experiment: *Very Preliminary*

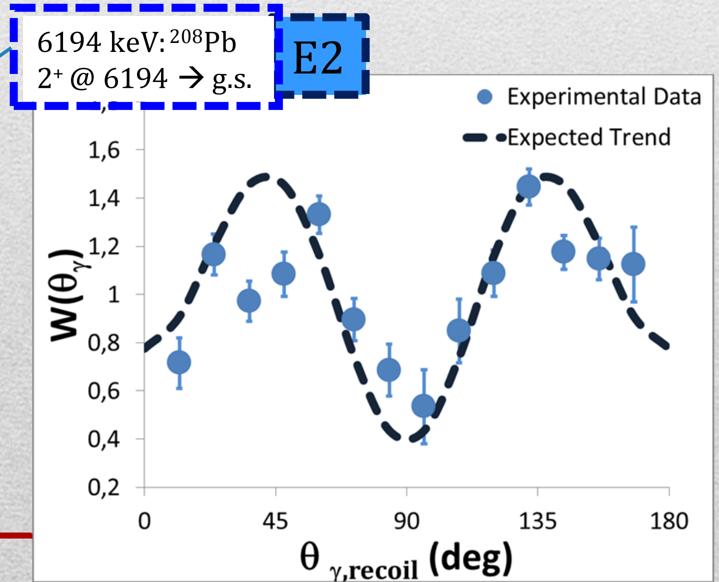
- Angular Distribution of gamma rays obtained exploiting position sensitivity of Germanium (Agata) and Silicon detectors
- Angles are defined with respect to the Z axis along the direction of ^{208}Pb nucleus
- Calibration for the Agata detectors angular efficiency was accomplished by means of Geant4 simulation

→ still to be tuned (...plots extracted just few days ago)

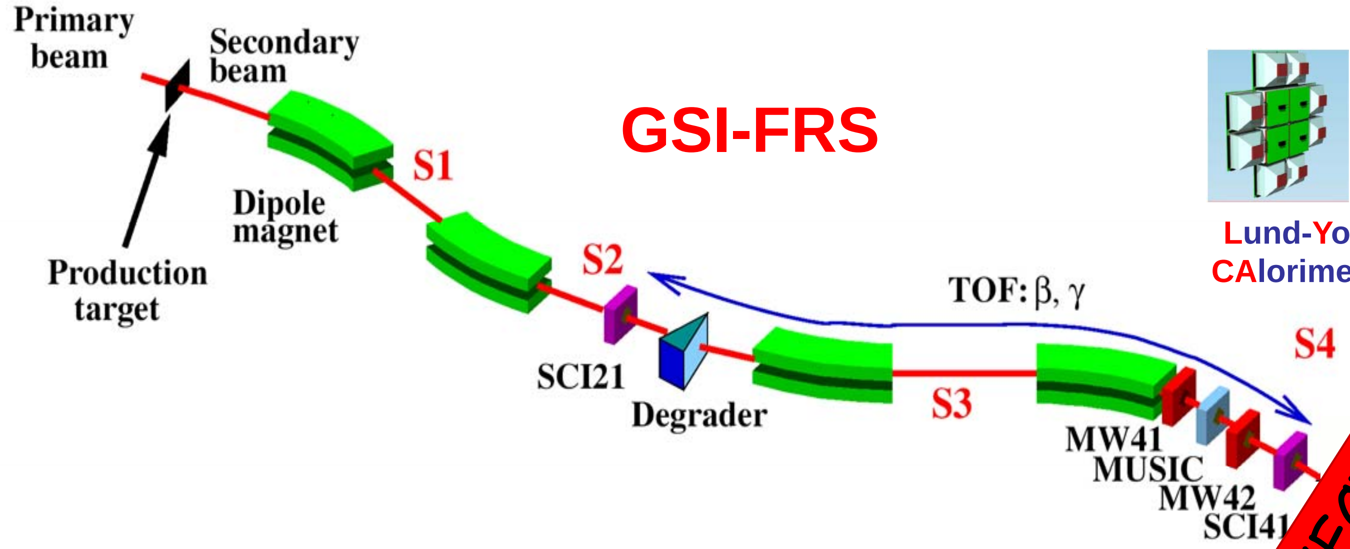


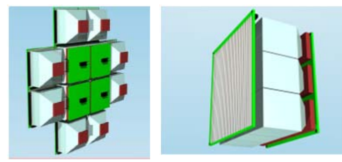




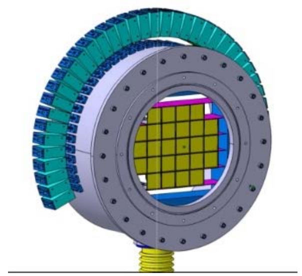


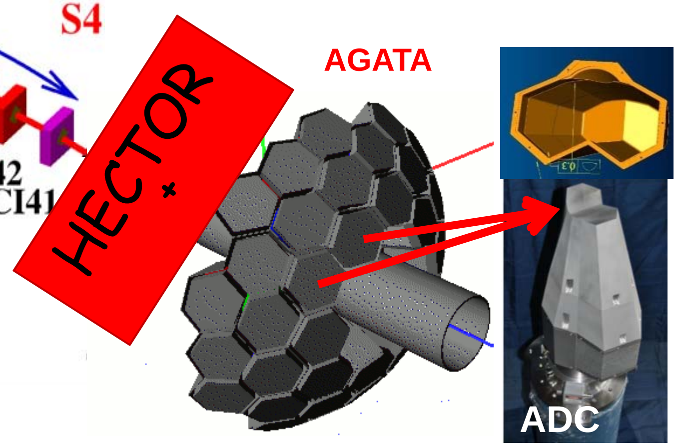
AGATA at the GSI-FRS in-flight RIB

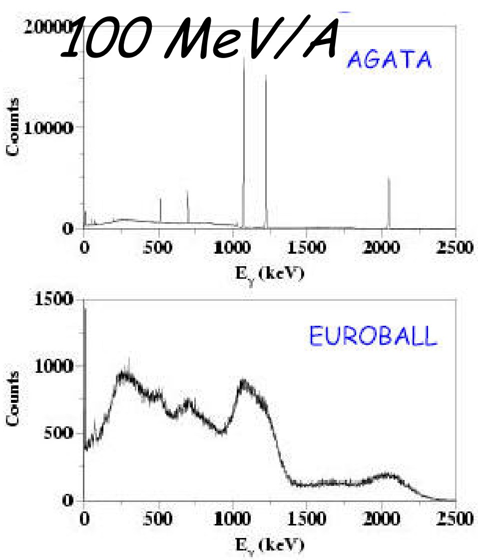


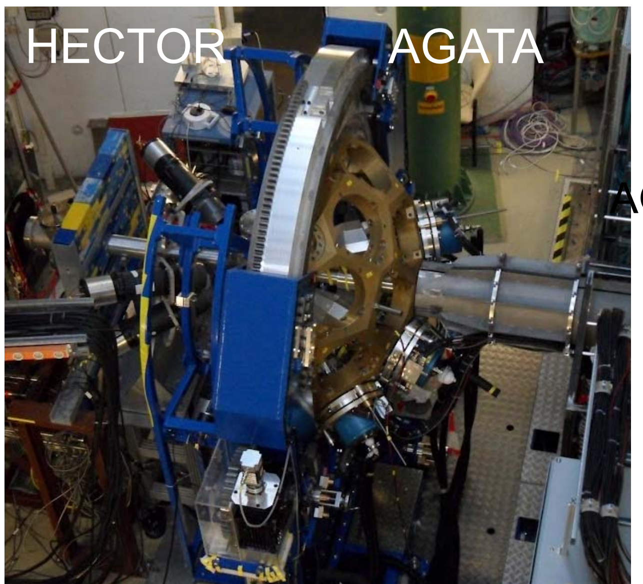


Lund-York-Cologne CAlorimeter (LYCCA)









Ancillary integration: S. Brambilla,
AGATA DIGIT PREAMP A. Pullia Milano
Target detector distance:10-23.5 cm
Energy resolution (FWHM):4–8keV
Starting configuration (5 double Cluster 5 triple Cluster)
γ-efficiency (β~0.5): 10%$^{++}$
γγ-efficiency : 1 %
+ HECTOR+ (INFN-Milano)

AGATA at the GSI-FRS in-flight RIB

Milano:

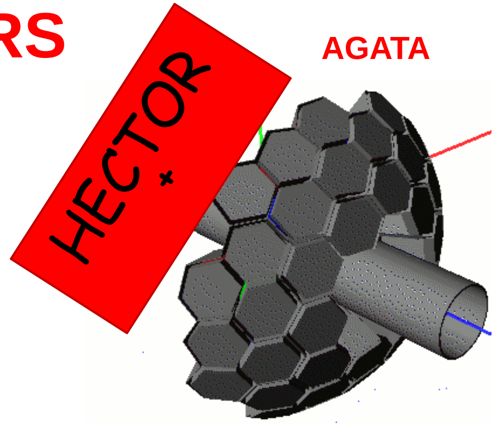
- Supporti Hector BaF
- Table

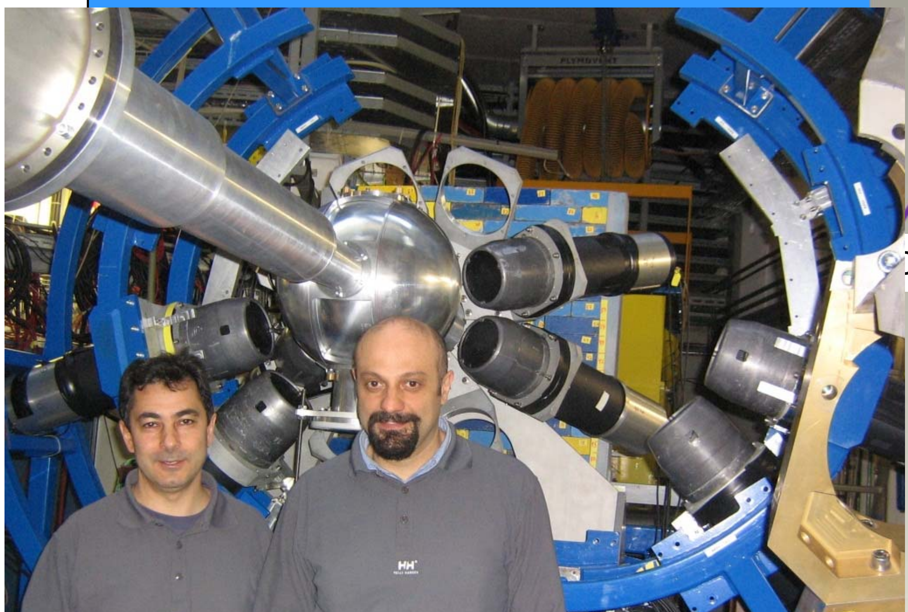
for Detectors

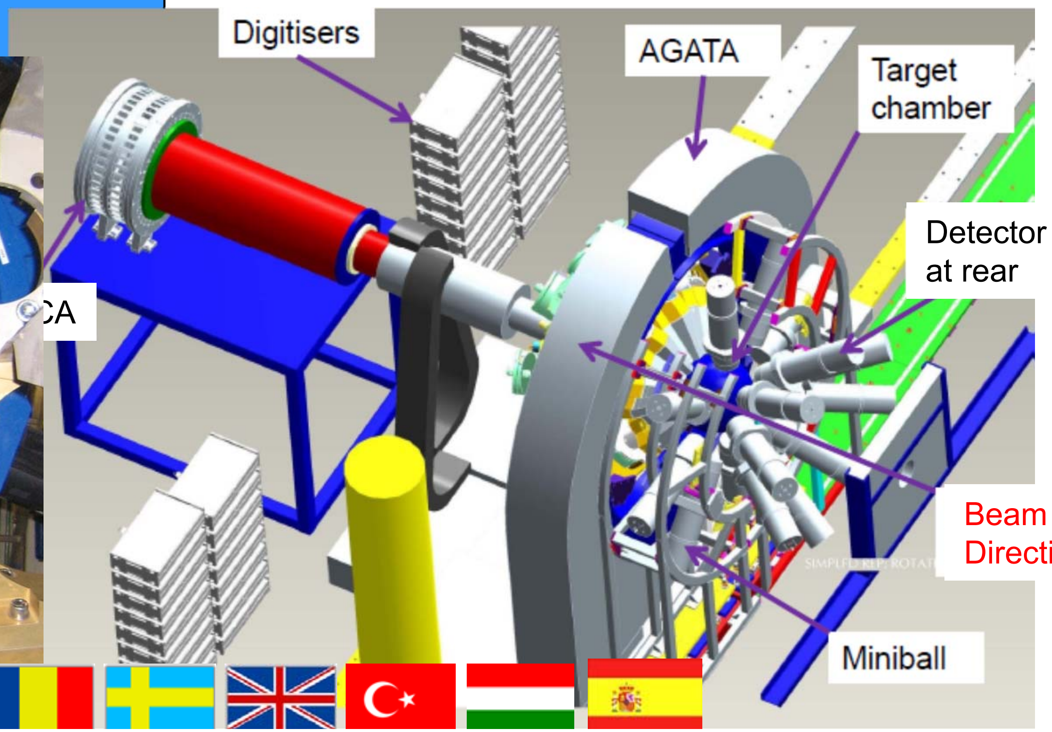
and GSI-Beam line support

- Supporti LaBr su AGATA
- Ancillary DACQ + elecronics

GSI-FRS





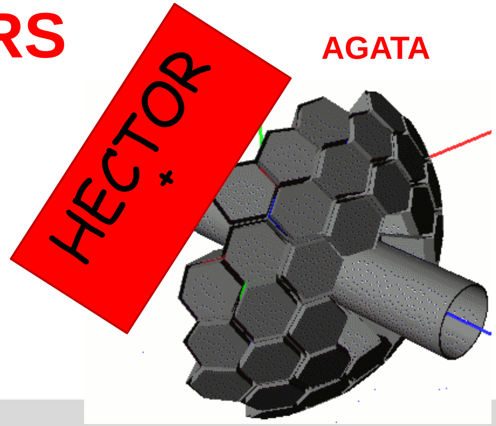


AGATA at the GSI-FRS in-flight RIB

Experiments at GSI 2012,2013:
Involved directly in 3(2012) +2(2013) experiments as spokes/coauthors persons, Indirectly through AGATA and HECTOR+ in all 12 experiments

Example
→**EXPERIMENT in Oktober 2012: The Pygmy Dipole Resonance (PDR) in ^{64}Fe and the properties of neutron skin with RELATIVISTIC COULOMB EXCITATION at 400AMeV**

GSI-FRS



ADC

MILANO

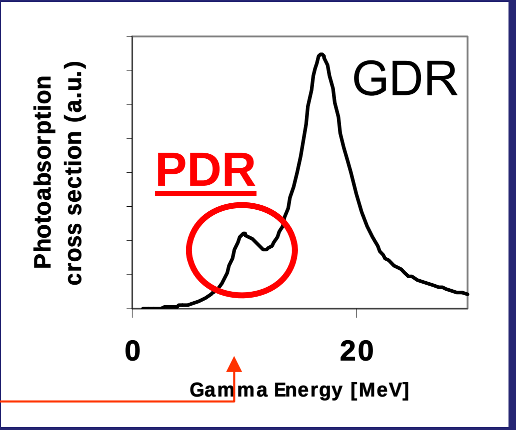
Nives	**Blasi**	Fabio	**Crespi**
Angela	**Bracco**	Agnese	**Giaz**
Franco	**Camera**	Luna	**Pellegri**
Bénédicte	**Million**	Valeria	**Vandone**
Oliver	**Wieland**	Simone	**Bottoni**
Silvia	**Leoni**		
Giovanna	**Benzoni**		
Alberto	**Pullia**		
Ciro	**Boiano**		
Sergio	**Brambilla**		
Stefano	**Riboldi**		
Simone	**Coelli**		
Fabio	**Tomasi**		
Ennio	**Viscione**		
Andrea	**Capsoni**		

Pygmy Dipole Resonance

Collective* oscillation of neutron skin against the core

*RQRPA

FEW Theory Available
Very few Experiments



E1 strength shifted towards low energy

Nupecc long range plan 2004

"Giant resonances are of paramount importantce for nuclear astrophysics. …

Nupecc long range plan 2010 Fig.5 (PDR in ^{68}Ni measured with RISING@GSI)

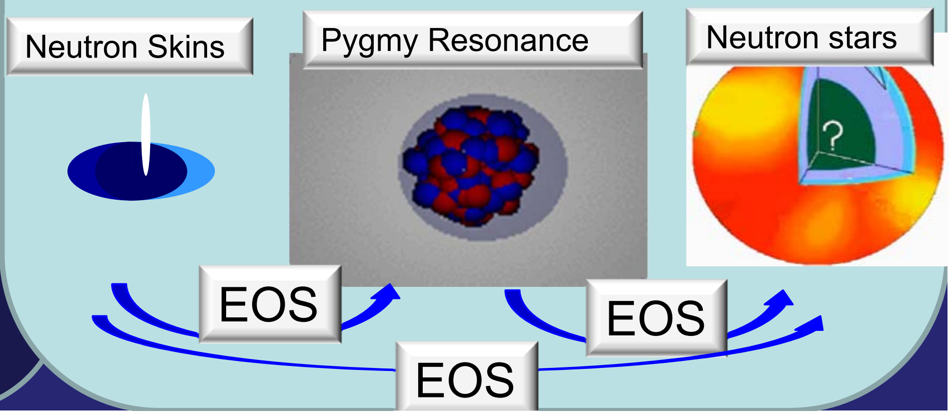
"A very interesting aspect is the relation of the dipole strength to the density-dependence of the symmetry energy and the neutron-skin thickness.

We want to study with the PDR:

-Level of collectivity & strength related to GDR
-How (collective) properties change with N
-How deformation acts
-Impact on r-process
→ Different theoretical approaches give different predictions in terms of collectivity, strength, line-shape and astrophysical impact of the PDR

Additionally from the pygmy dipole resonance one can derive:
-Neutron skin thickness
-Nulear symmetry energy

Note that:
Relation between neutron skin and neutron stars: both are built on neutron rich nuclear matter so that one-to-one correlations can be drawn

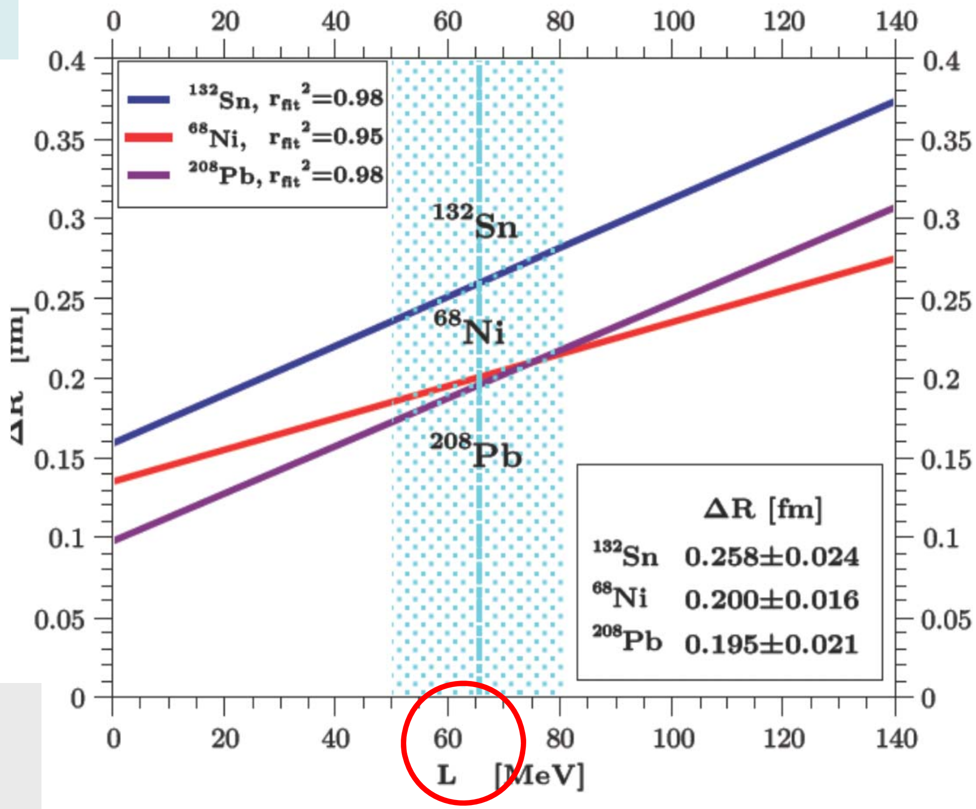


PDR→ Extract the neutron radius

Strong correlations between L, PDR STRENGTH and ΔR (the neutron skin thickness) have been noticed previously.

B.A. Brown, PRL 85, 5296 (2000);
S. Typel and B.A. Brown, PRC 64, 027302(R) (2001).
R.J. Furnstahl, NPA 706, 85 (2002);
S. Yoshida and H. Sagawa, PRC 69, 024318 (2004).

L is in direct relation to PDR strenght through nuclear (skyrme, meson) forces



Using the value of L deduced from ^{68}Ni and ^{132}Sn for ^{208}Pb one obtains

R_n-R_p = 0.195+/- 0.021 for ^{208}Pb

Analysis using theory.......
A.Carbone, P.F. Bortignon, A. Bracco, F. Camera, G. Colò, O. Wieland
(University of Milano and INFN)
Phys. Rev. C 81 (2010) 041301(R

→EXPERIMENT in Oktober 2012: The Pygmy Dipole Resonance in ^{64}Fe and the properties of neutron skin with RELATIVISTIC COULOMB EXCITATION at 400AMeV

(N-Z)@^{68}Ni=12

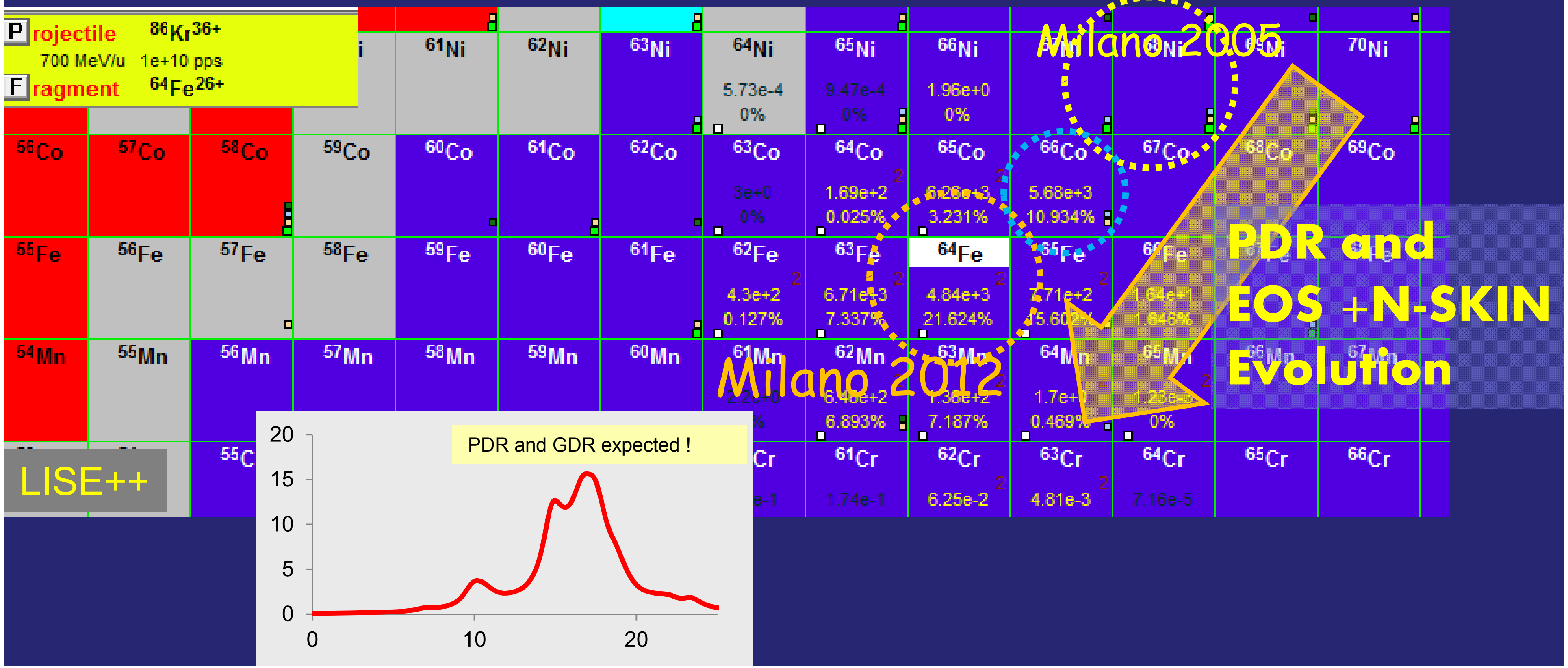
=(N-Z)@^{64}Fe=12

N/Z@^{68}Ni=1.43

N/Z@^{64}Fe=1.46

(N-Z)^2/A^2@^{68}Ni=0.031

(N-Z)^2/A^2@^{64}Fe=0.035



MEASUREMENTS OF THE γ DECAY OF THE PYGMY DIPOLE RESONANCE in ^{64}Fe

The plan is to study the PDR, presence, parameters in the nucleus ^{64}Fe AND to infer the size of **neutron skin** by improving the technique used for ^{68}Ni.

GSI + AGATA + HECTOR+ is (THE) unique possibible place and set-up combination to do this relativistic coulomb excitation experimen

To disentangle clearly the presence of a PDR DOPPLER correction with AGATA and Theta information in scintillators is needed.

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Conclusion

GRAZIE

AGATA with stable Beams at LNL:
-proof of tracking concept to do physics
-very successfull physics campain

AGATA with exotic Beams at GSI:
-most advanced Gamma arrays in the world : HPGe and LaBr
meets highest intensity*AMeV Beam in the world to
Measure exotic very new physics phenomena

Crucial Contribution In physics and technology from Milano physics, electronics, dacq, mechanics groups

>12 Countries
>40 Institutions