# Misura di pygmy dipole states in nuclei esotici

## CDS 7.2015

*A. Bracco, A. Giaz, A. Mentana, B. Million, F. Camera, F.C.L. Crespi, G. Benzoni, N. Blasi,* ***O. Wieland****, R. Avigo, S. Brambilla, S. Riboldi, A.I. Morales, G. Bocchi, S. Leoni, S. Ceruti et al.*

**OUTLINE**

- **Pygmy Dipole Resonance**

- Esperimenti a Legnaro **LNL** (Italia)
- Esperimenti a Darmstadt **GSI** (Germania)
- Esperimenti a Tokyo **RIKEN** (Giappone)
- Esperimenti a Osaka **RCNP** (Giappone)

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# Misura di pygmy dipole states in nuclei esotici

What We know

- Pygmy Dipole States are strongly correlated with the size of the neutron skin (or proton skin)
- Pygmy Dipole Resonance (PDR) is a collective excitation of the least bound neutrons (or proton
- PDR is mostly of Electric Dipole (E1) character

What we want to know: → GOAL

-Level of collectivity ?
-How (collective) properties change with neutron number ?
-How isospin changes mean field ?
-In exotic nuclei: does PDR strength exist also below neutron threshold ?
-No High resolution/statistics measurements available
-Present in all nuclei and mass regions ?
-Effect of deformation ?
-Proton Pygmy, still to proof
-"Picture" of PDR, toroidal mode
-from pygmy strength deduce dipole polarizability
-Isovector and Isoscalar mode

INFN-Milano activity

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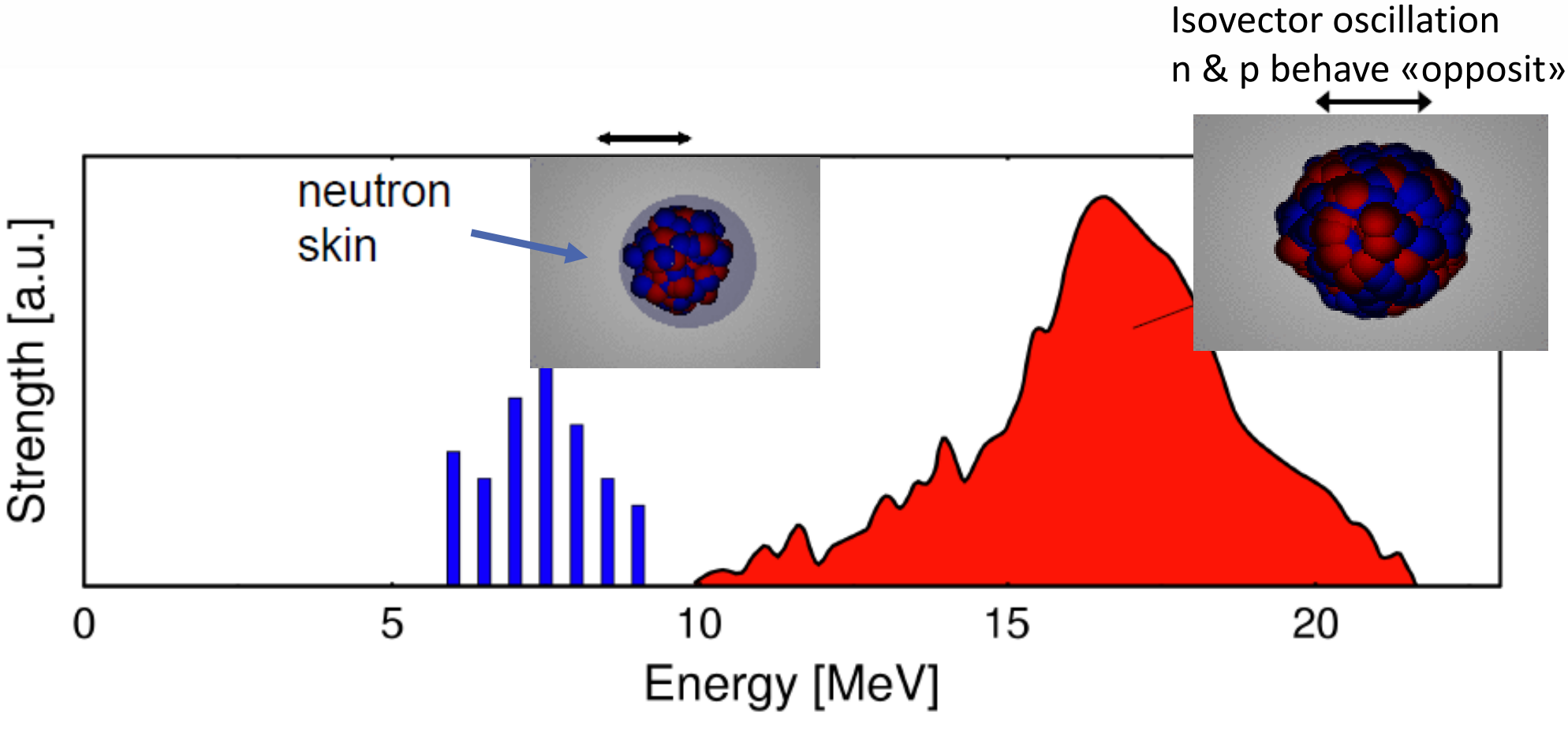
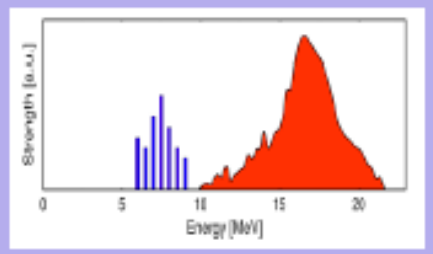
# E1 («dipole») strength distribution



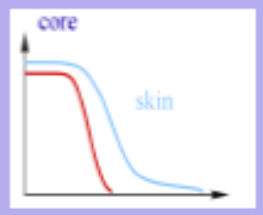

- Giant Dipole Resonance (GDR)
- Pygmy Dipole Resonance (PDR)

# Pygmy dipole states in nuclei esotici are connected to the nuclear Equation of State neutron skin and therefore to n-stars

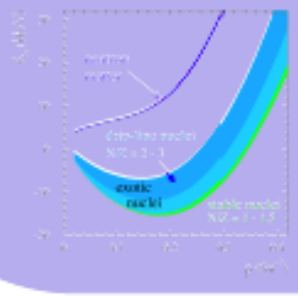
E1 response



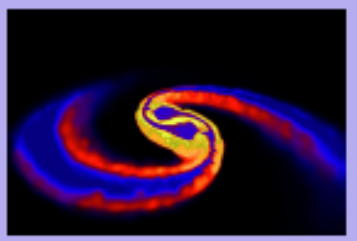

Neutron skin

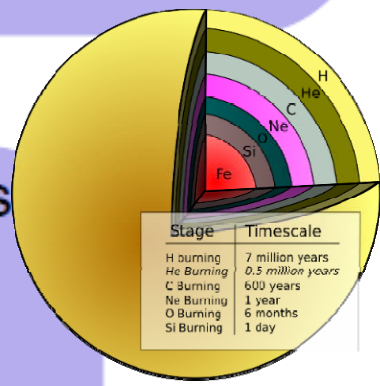



Equation of state

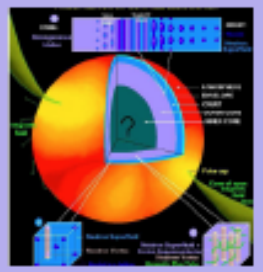


Nucleosynthesis



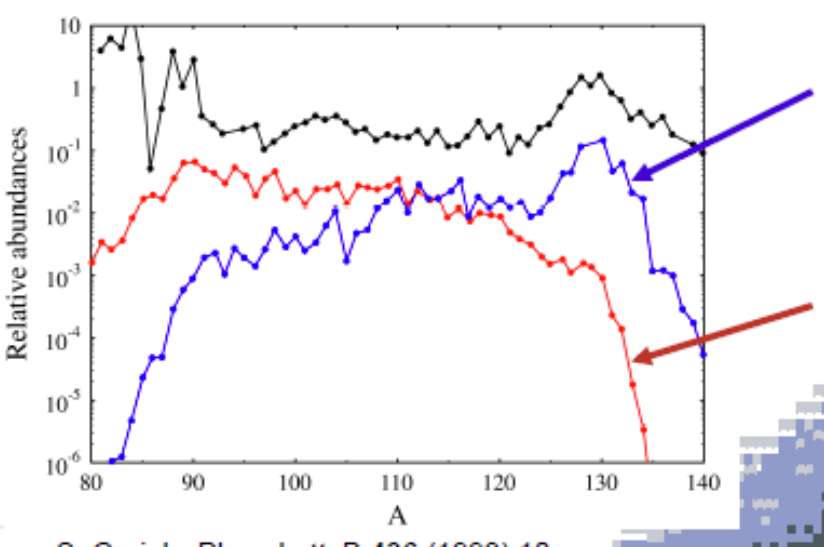



Neutron stars

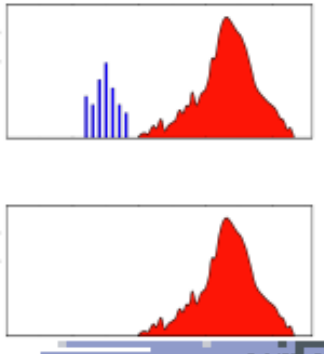


# Pygmy dipole states in nuclei esotici and Nuclear ASTROPHYSICS → GOAL

Possible influence on (γ,n) und (n,γ) reaction rates in astrophysical scenarios




S. Goriely, Phys. Lett. B 436 (1998) 10



r-process

**Reliable extrapolation needed !**

→ understanding of the nature of the PDR

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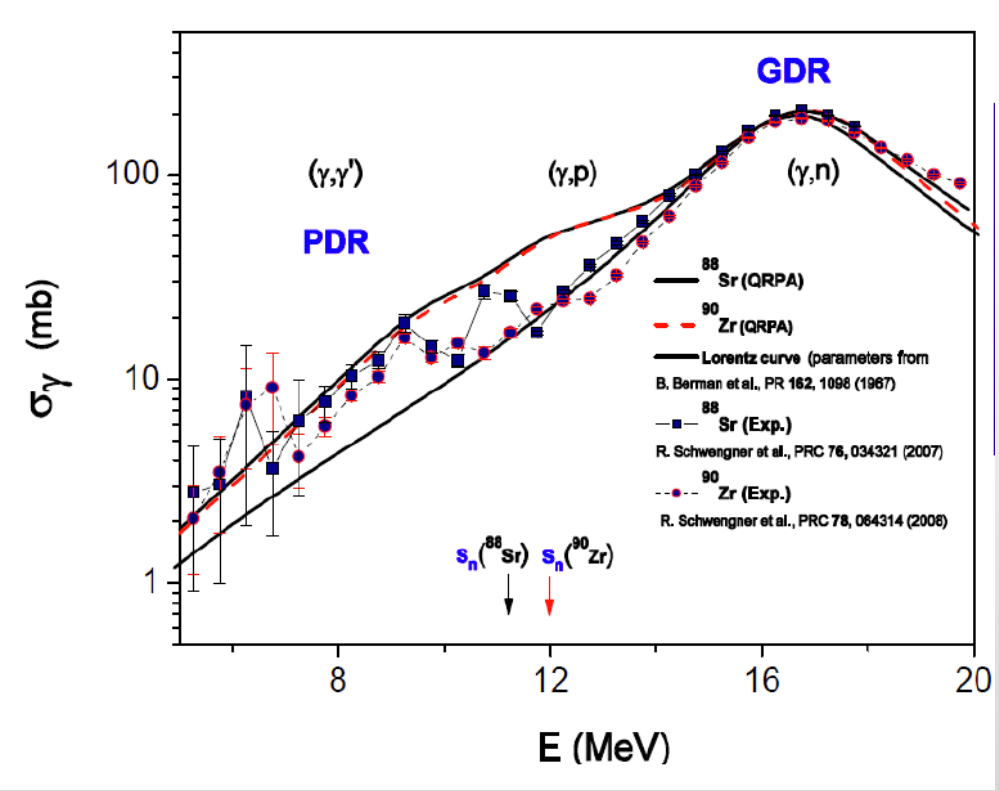
# The astrophysical importance of the Pygmy Resonances → GOAL

The present knowledge shows that standard strength functions curently used for the calculation of cross sections do not describe the dipole strength distribution below and above the (γ,n) threshold correctly




**Nupecc long range plan 2004-2010**

"Giant resonances are of paramount importantce for nuclear astrophysics" …"It is of particular interest to study the collective strength in short-lived nuclei…"

**INPC 2013** – Nucl. Astrophysics session:

"..whole E1 strenght, below and above threshold, from comparable experiments, is urgently needed for exotic nuclei…"

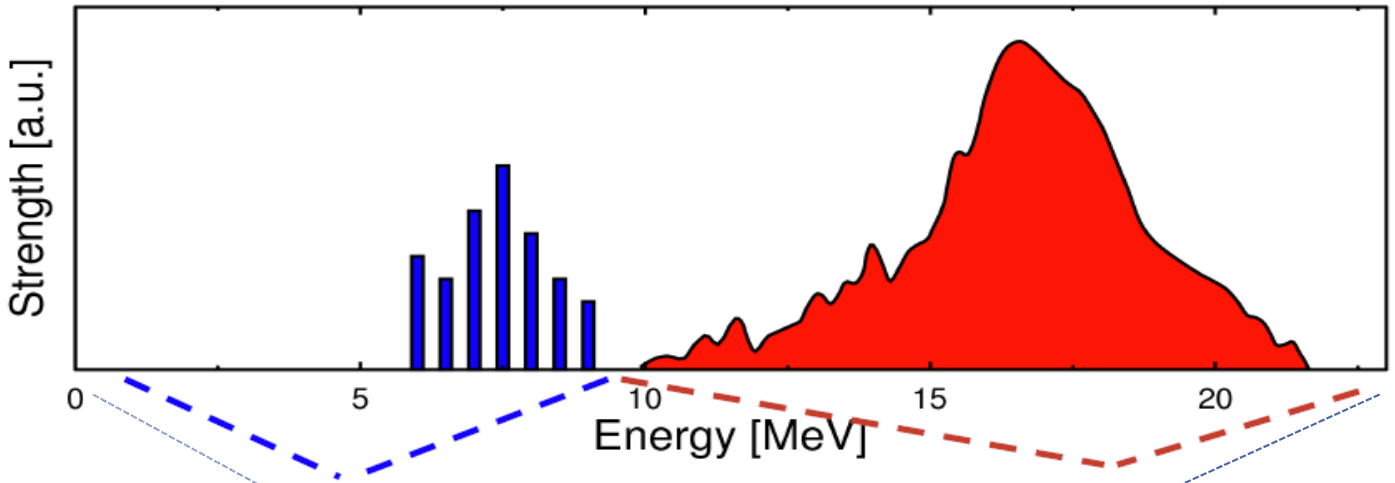
# PDR is measured in stable nuclei

# With different probes (in different Labs):

## -real photons

## -p,α,$^{17}$O,…

- High selectivity to dipole excitations
- Well-known excitation mechanism




LNL, OSAKA, …

ISOSCALAR part of Pygmy
(n & p behave similar)

**(p,p'); (α, α'); ($^{17}$O, $^{17}$O') …**

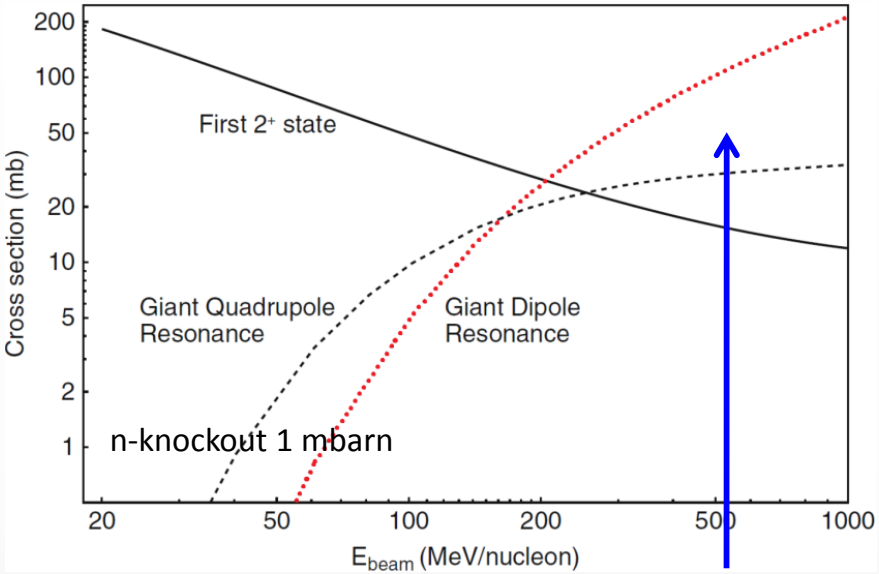
**(p,p',γ); (α, α',γ); ($^{17}$O, $^{17}$O',γ) …**

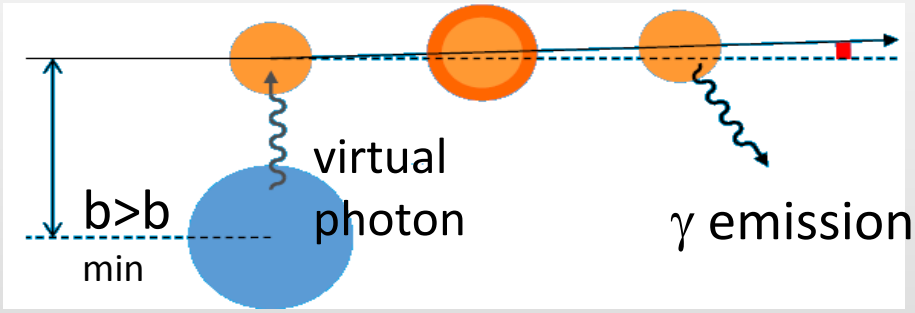
But in unstable nuclei of the r-process ?

# **Virtual photon scattering** for PDR search in n-rich nuclei

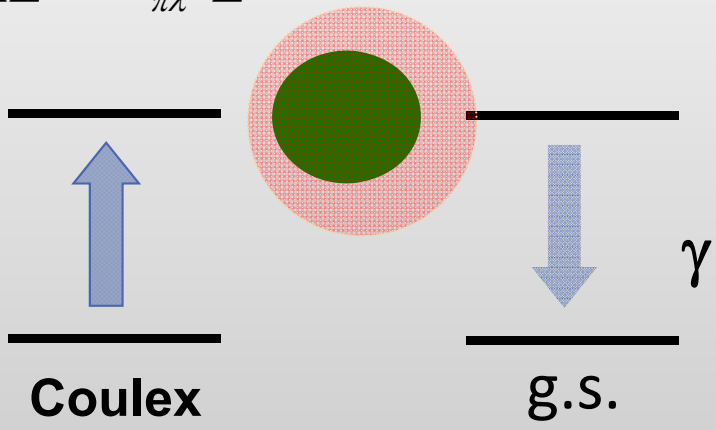
## high selectivity for dipole E1 excitation

**Technique used with high energy**
**40-80 GeV stable primary Beams.**
**After Fragmentation and selection**
**Impinging on thick targets (g/cm²)**




$$\frac{d\sigma_C}{dE^*} = \sum_{\pi\lambda} \frac{1}{E^*} N_\gamma^{\pi\lambda}(E^*) \cdot \sigma_\gamma^{\pi\lambda}(E^*)$$



# Milano's pioneering PDR Experiment

PRL **102,** 092502 (2009) PHYSICAL REVIEW LETTERS week ending 6 MARCH 2009

## Search for the Pygmy Dipole Resonance in $^{68}$Ni at 600 MeV/nucleon

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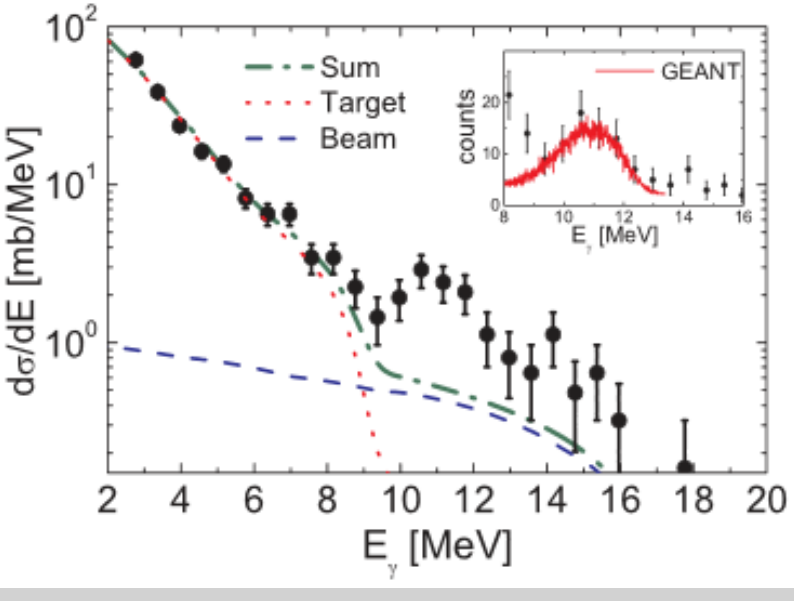
PRL **102,** 092502 (2009) PHYSICAL




GSI
- 400 MeV/u $^{68}$Ni + $^{197}$Au (May 2004)
- 600 MeV/u $^{68}$Ni + $^{197}$Au (April 2005)

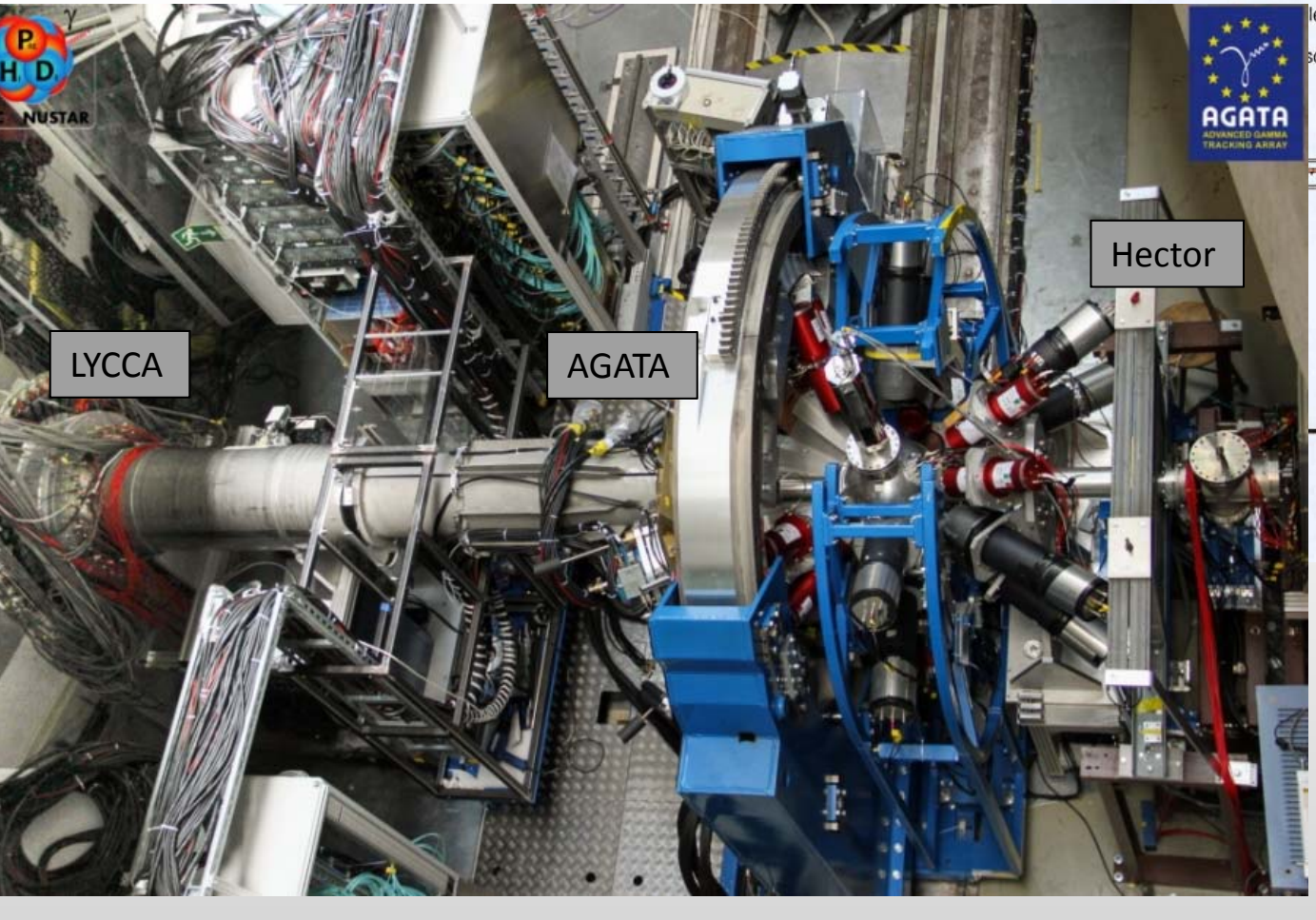
GSI
- 400 MeV/u $^{64}$Fe + $^{208}$Pb (October 2012)
- 430 MeV/u $^{62,64}$Fe + $^{197}$Au (April 2014)

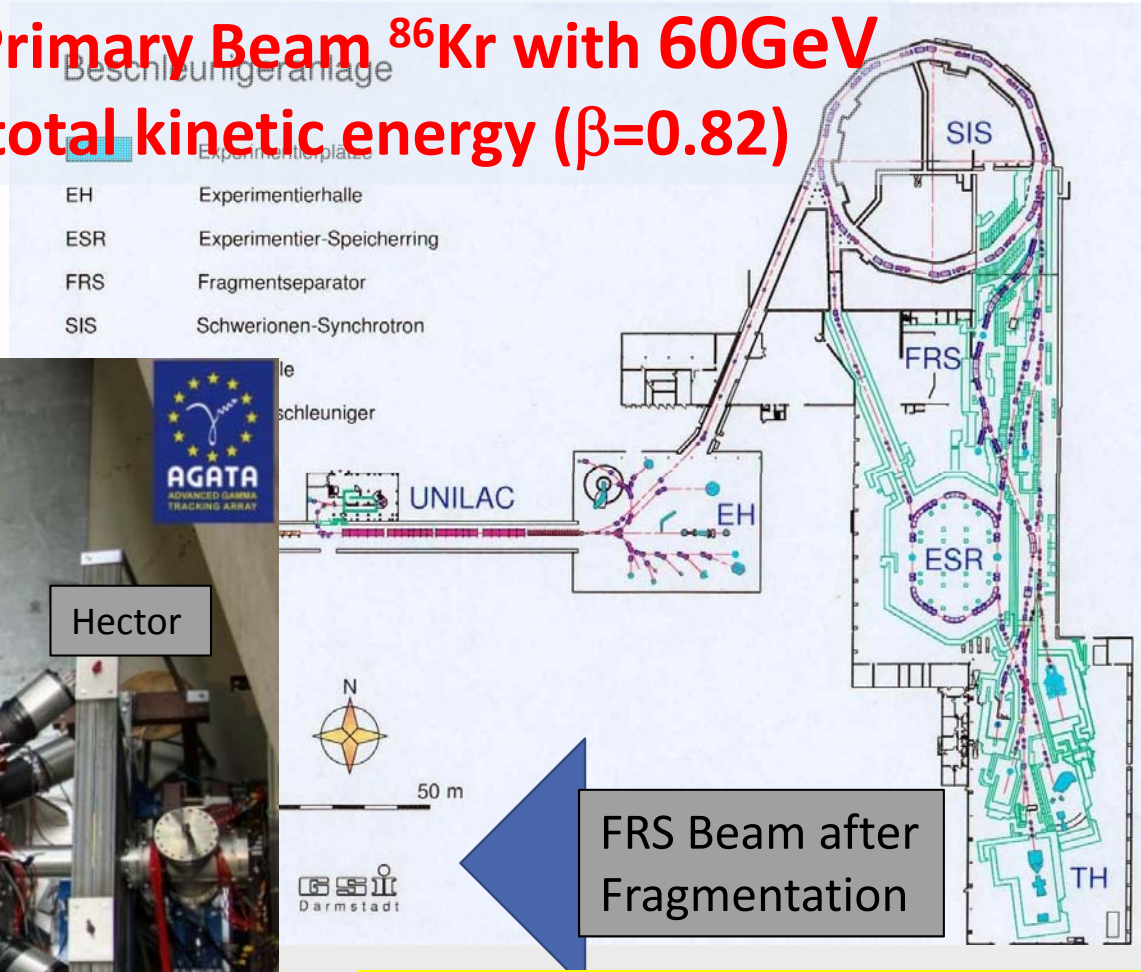
RIKEN
- 280 MeV/u $^{70}$Ni + $^{197}$Au (October 2014)
- 280 MeV/u $^{72}$Ni + $^{197}$Au (→PAC 2015)
- 200 MeV/u $^{5x}$Ca + $^{197}$Au ( 2016)

RCNP
- 80 MeV/u (p,p') + Stable Target (2016)
- ...

# PreSPEC-AGATA 2012 and 2014

**Primary Beam $^{86}$Kr with 60GeV total kinetic energy (β=0.82)**



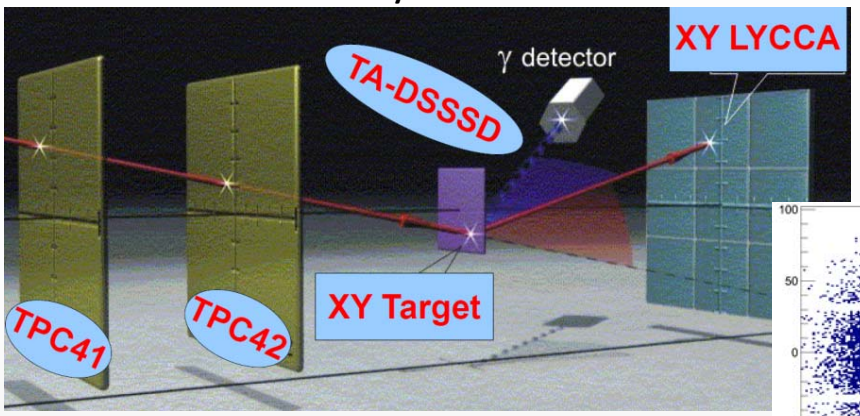




$^{62,64}$Fe 400-440 MeV/u ~$10^3$ pps

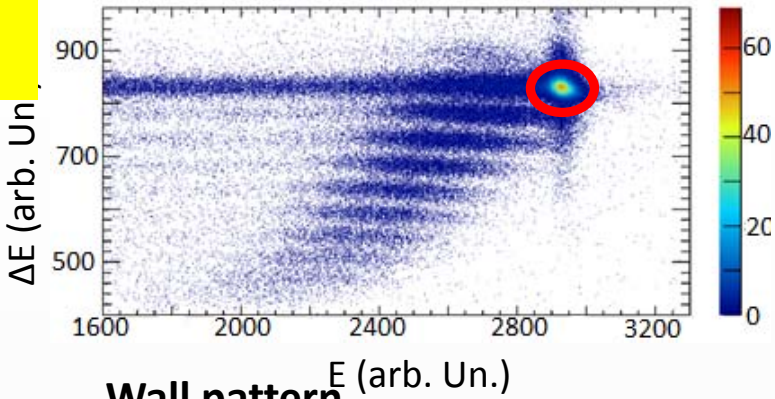
# Relativistic coulomb excitation selection

**EVENT by EVENT**
**Tracking of the heavy ions and identification of reaction products**

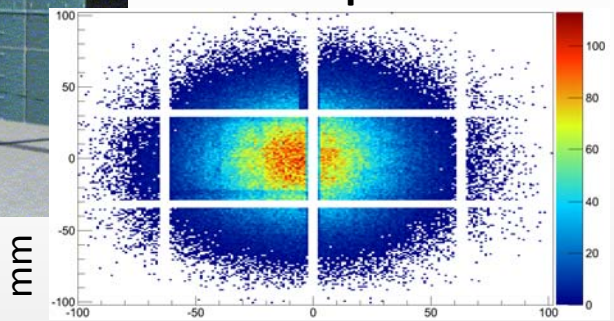
E-ΔE identification with Lycca Wall
Tracking of ions with TPCs in S4 and Lycca DSSSD



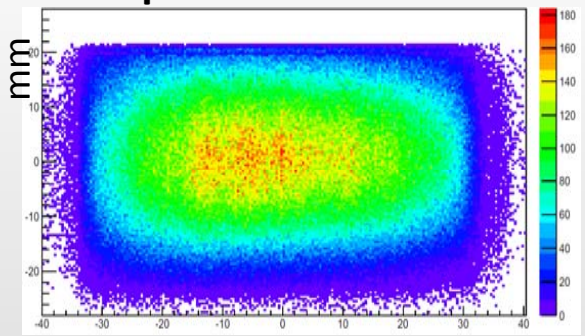

**E- ΔE identification**




**Wall pattern**

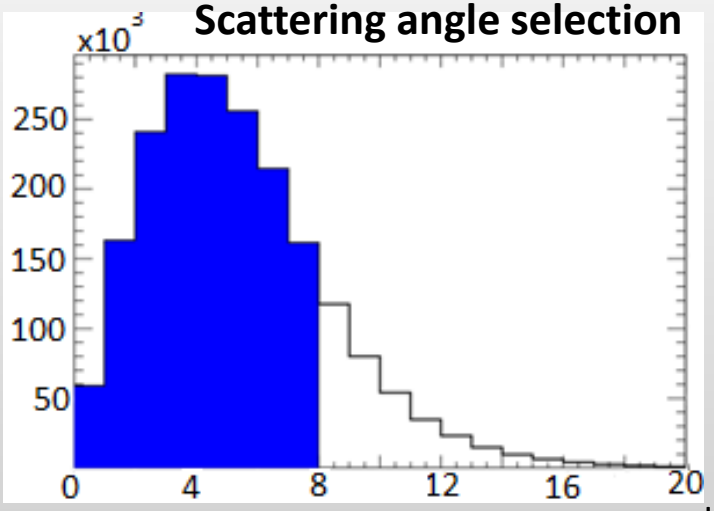



**TPC pattern**

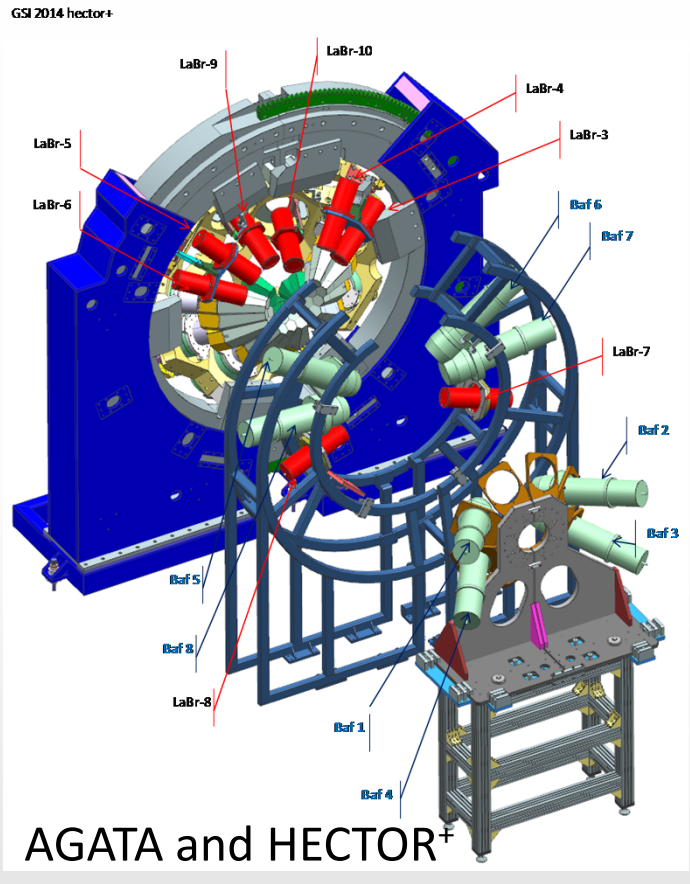



This complex ion tracking system coupled with E- ΔE identification allowed the selection of coulomb excitation (17 fm of impact parameter >> 15 fm usually considered)

**Scattering angle selection**

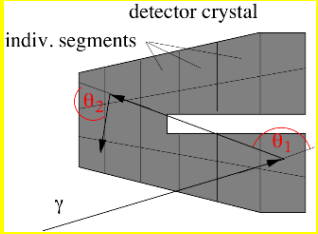


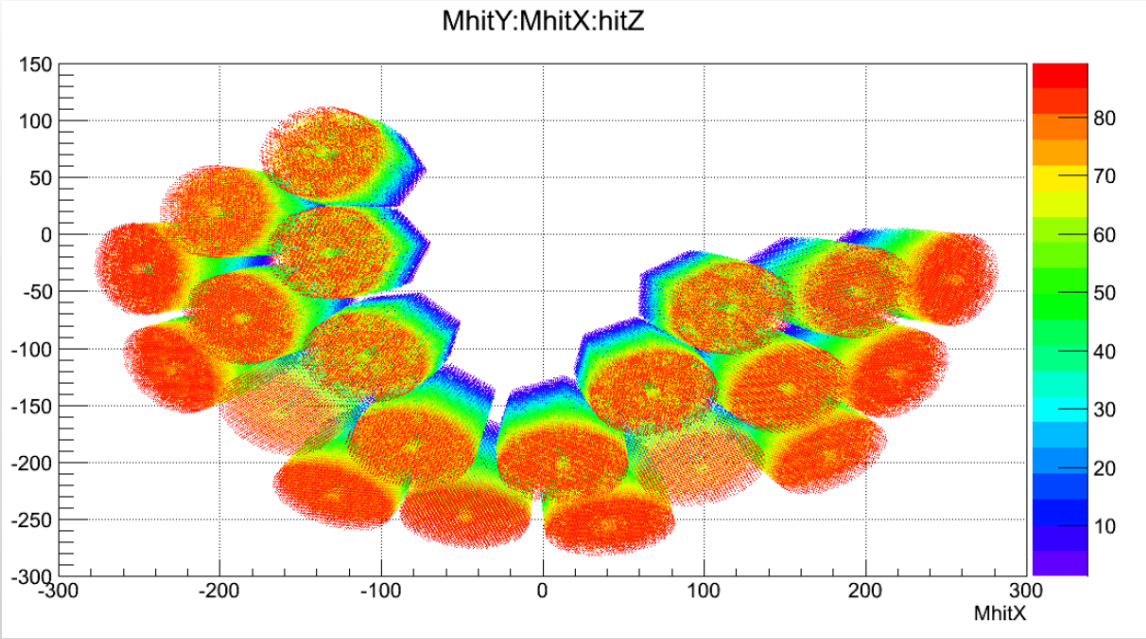
# Nuclear Spectroscopy with relativistic coulomb excitation of $^{64}$Fe up to 430 AMeV v/c=0.73 and AGATA



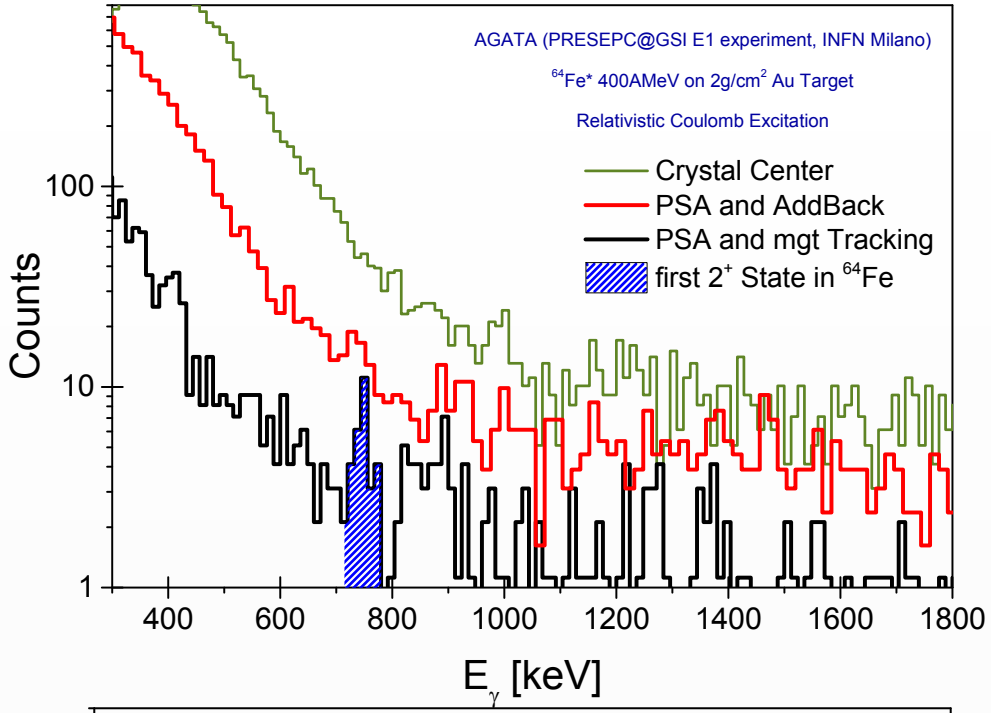

AGATA and HECTOR$^{+}$

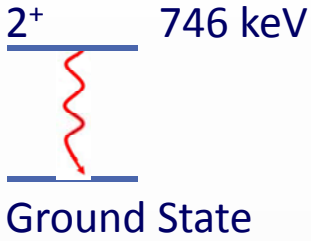
AGATA = Gamma Ray Tracking array

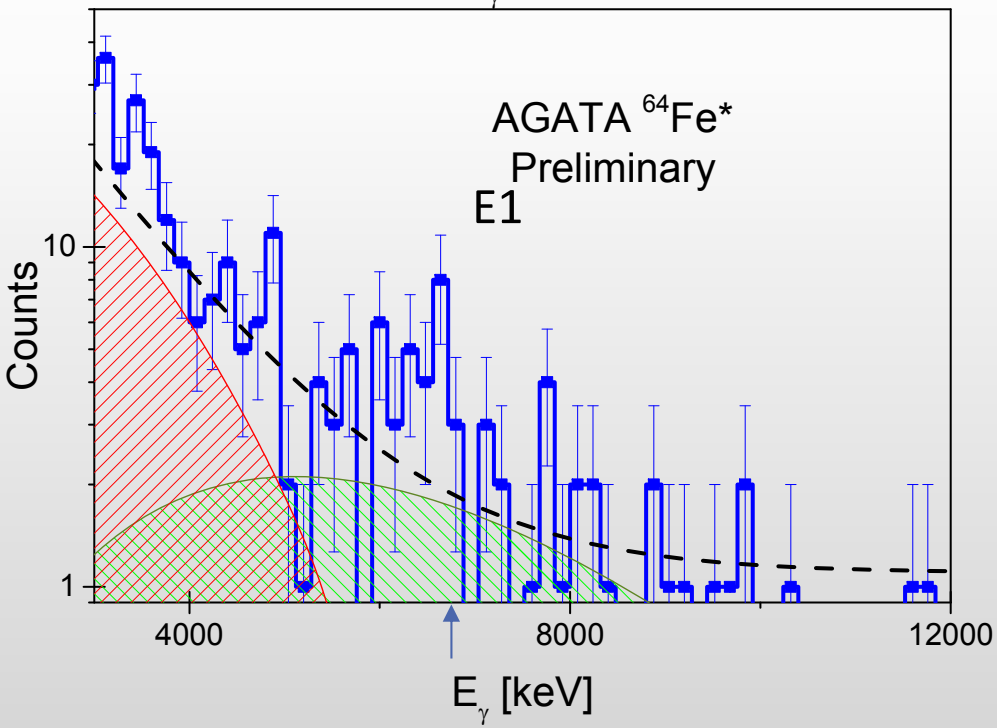


# AGATA
# Gamma ray spectra



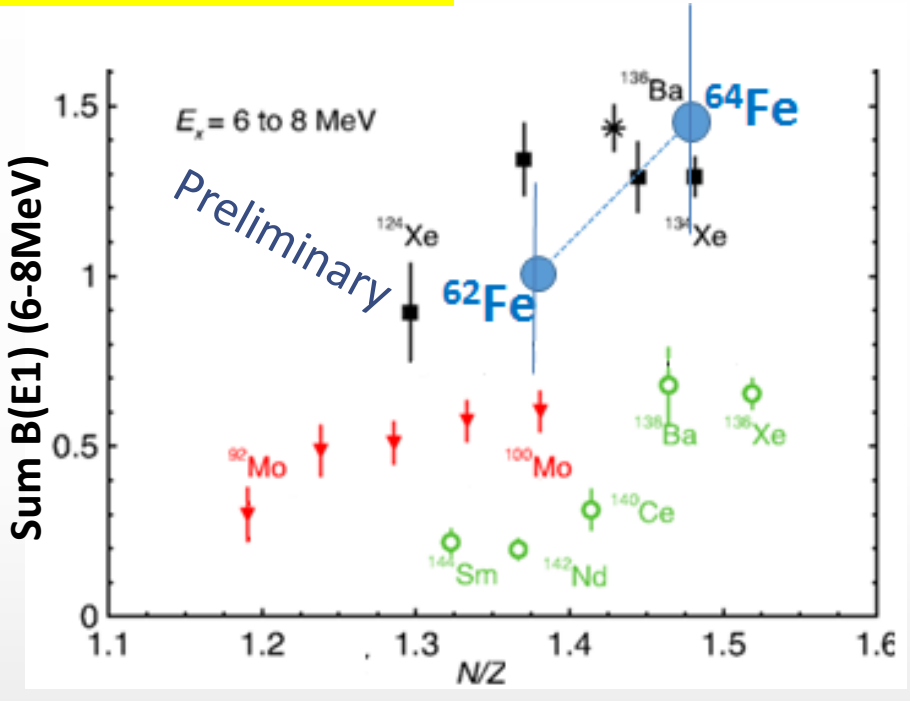

Angular
Distribution
Confirms E1 character

AGATA High energy spectra obtained with Add-Back ad Pulse shape analysis procedure
Structures at 6-7 MeV above the background

R. Avigo 2015

# Results about E1 strength

## Pygmy strength Integral




Phys. Rev. Lett. 112, 072501

Preliminary B(E1) estimation shows similar trend with summed B(E1) obtained in other papers on stable nuclei.
The well known challenge of understanding the r-process abundances requires measurements of the E1-strength function especially towards the neutron-drip line.
Paramount importance for nuclear astrophysical scenarios.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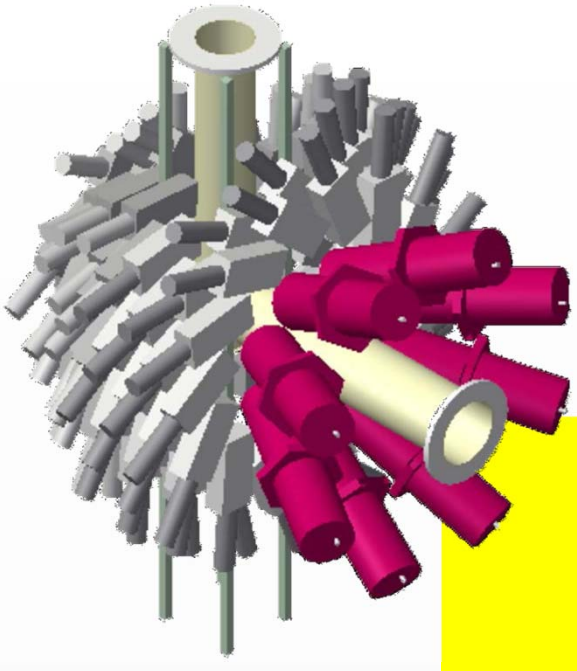
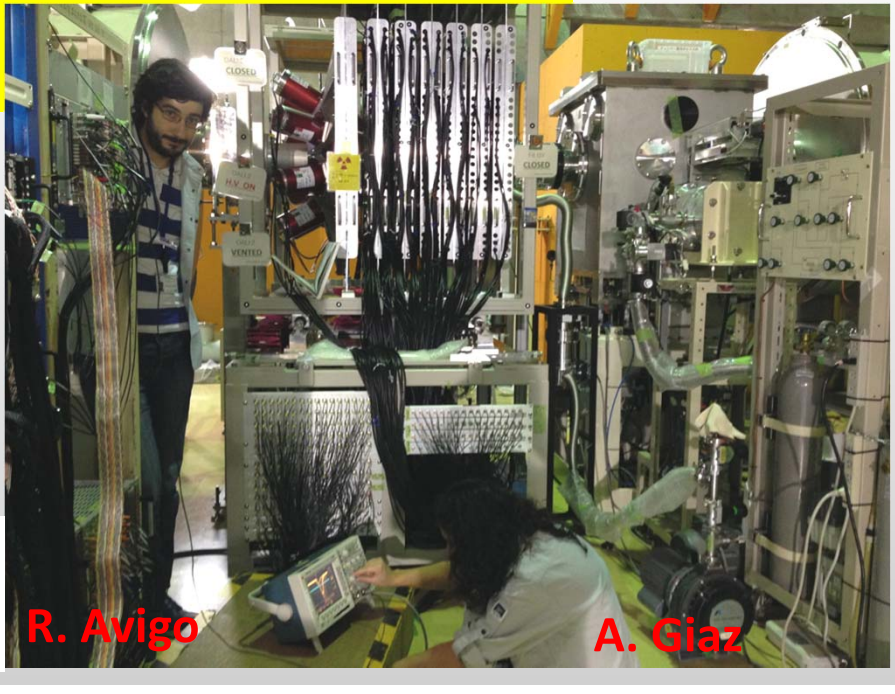
<u>Go further and beyond:</u>
Milano group was invited to go to more exotic nuclei
far away in Japan: RIKEN Tokyo



Worldwide largest

# HECTOR+ & DALI2 @ RIKEN (Tokyo)

## CAMPAIN of 3 experiments in 2014

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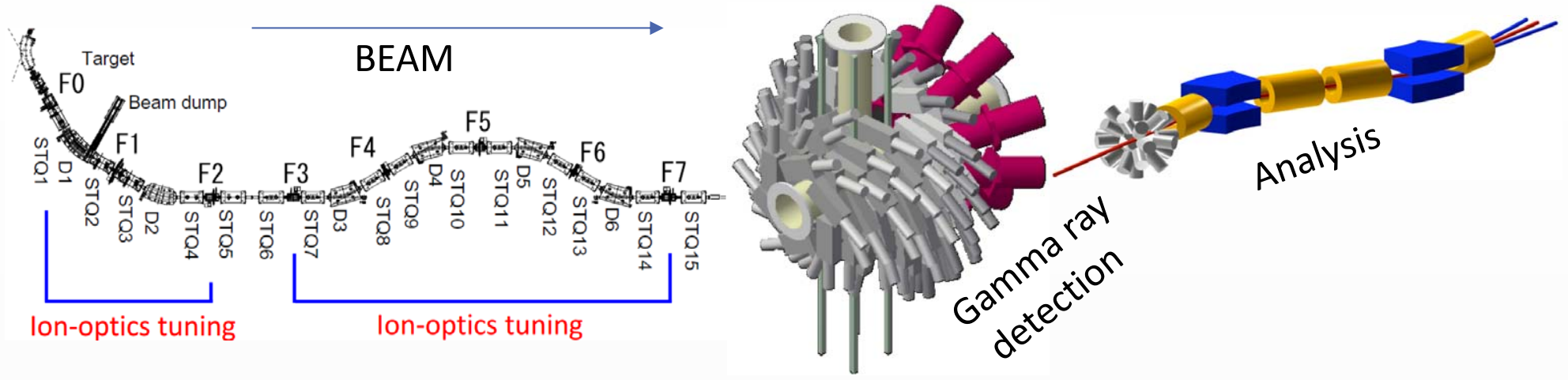
R. Avigo

A. Giaz

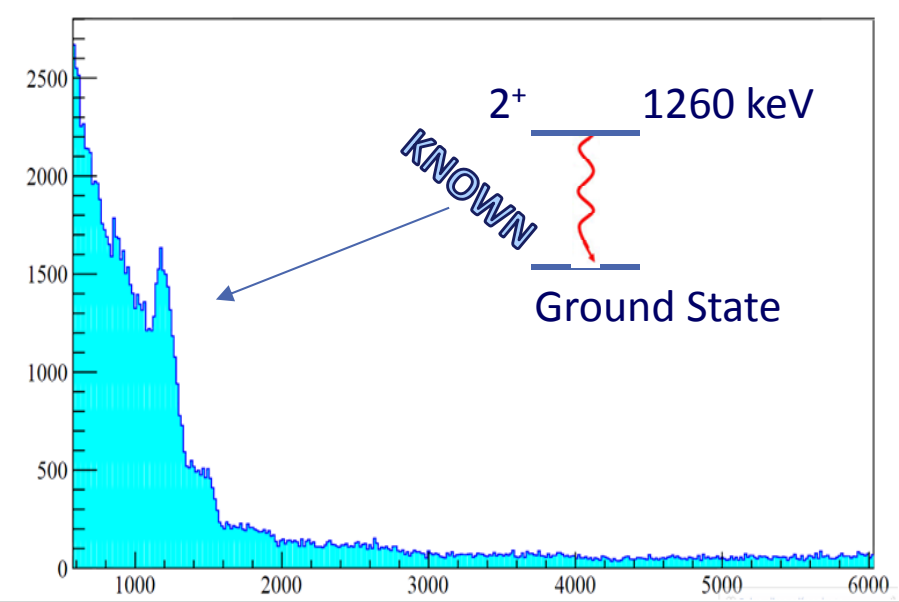
# $^{70}$Ni measurement @ Riken

## Primary Beam $^{238}$U with 82GeV total kinetic energy

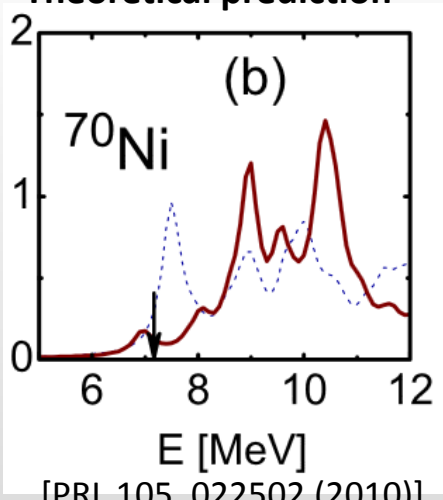



Experiment at Riken laboratory to measure PDR in **$^{70}$Ni** with NaI (DALI) and $LaBr_3$:Ce detectors

$2^+$ state decay already identified




**Theoretical prediction**




[PRL 105, 022502 (2010)]

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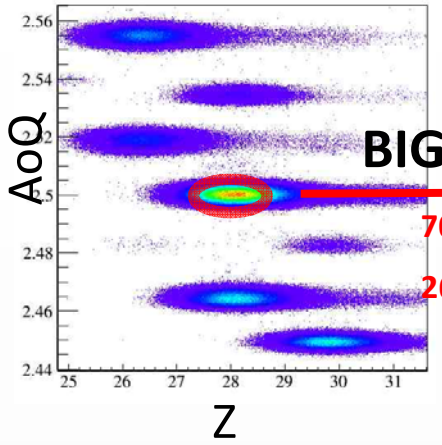
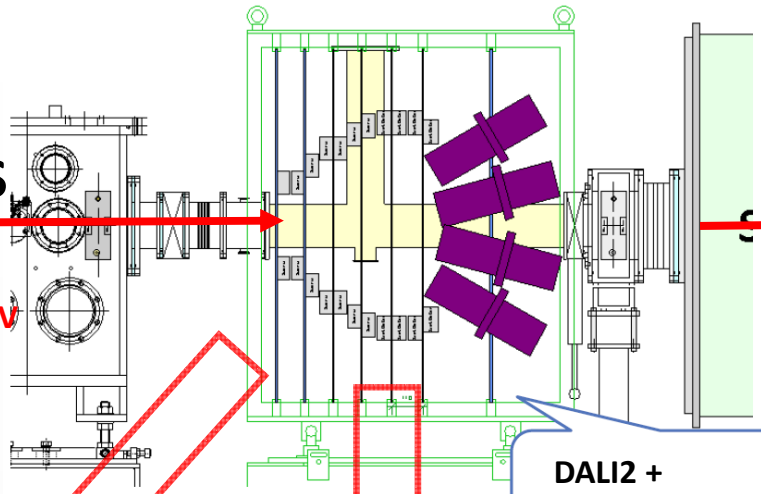
# Setup/Experiment

**November 2014**



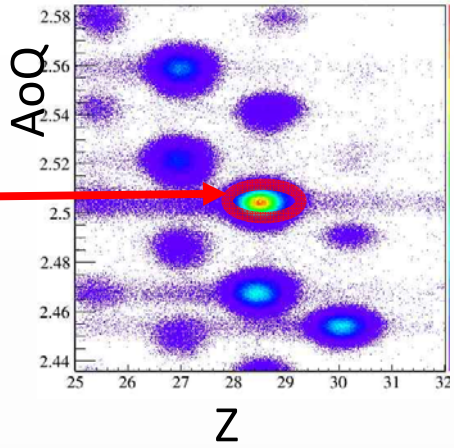

**BIGRIPS**

$^{70}$Ni
260AMeV

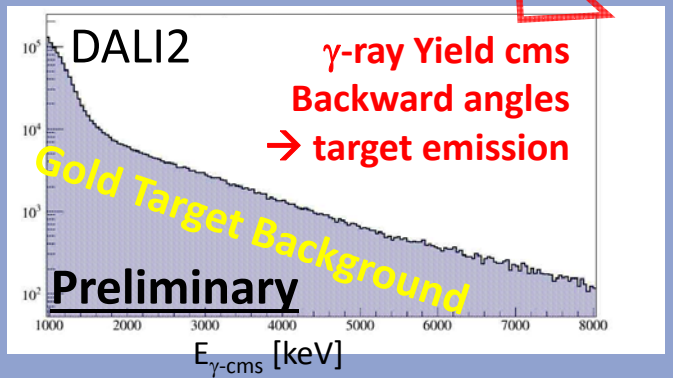


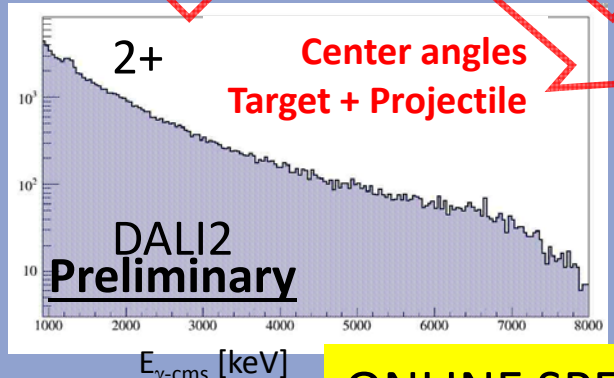
**ZDS**

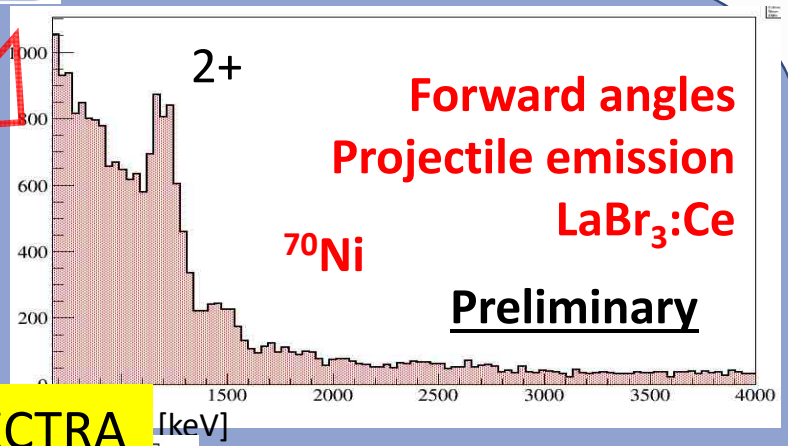
$^{70}$Ni*



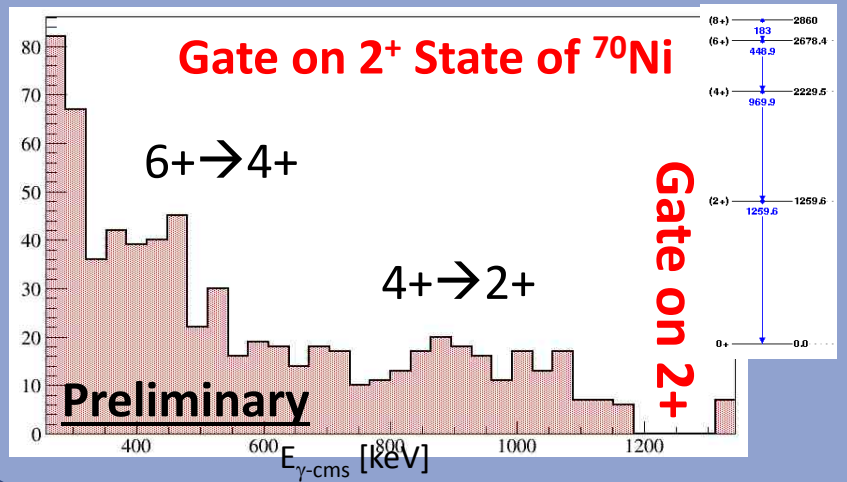

DALI2 +
8 LaBr:Ce (3.5''x 8'')

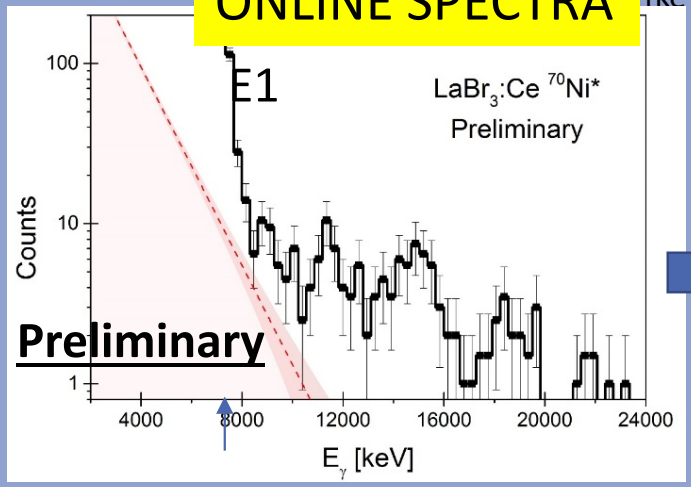



ONLINE SPECTRA




Successfull 2014/2015
Measures **gives rise to**
**Next**
**Propsal 2016 for $^{72}$Ni**
**→2017**

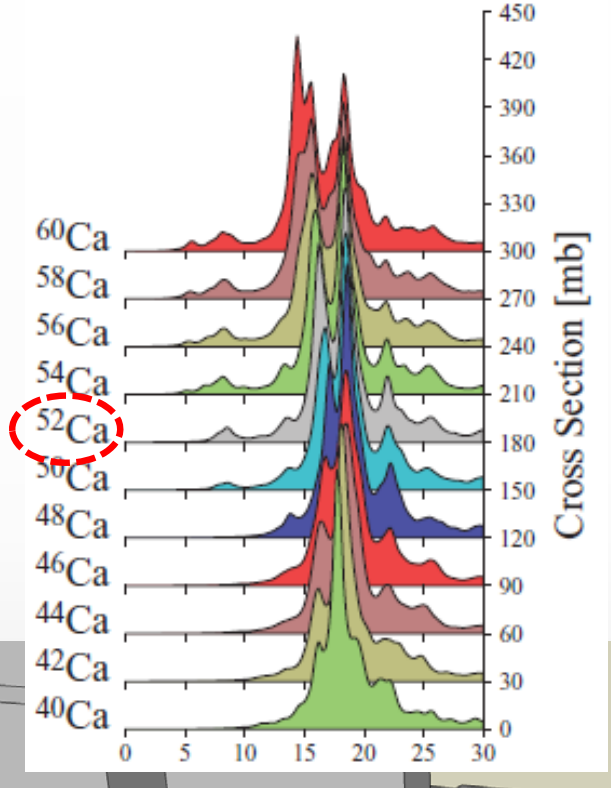
**R. Avigo**

PHYSICAL REVIEW C 84, 021302(R) (2011)

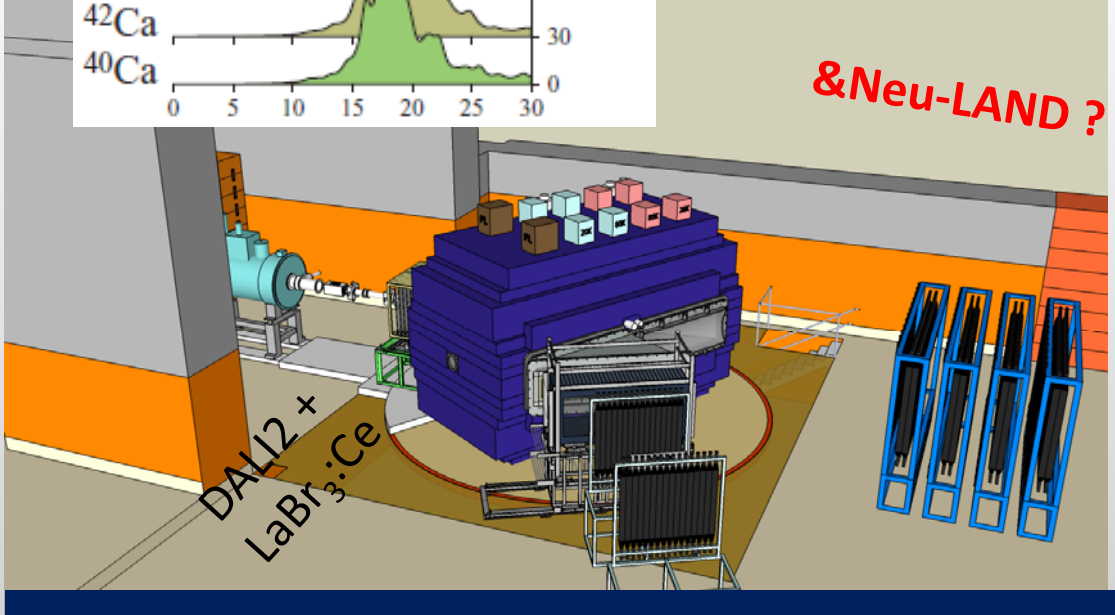
## Emergence of pygmy dipole resonances: Magic numbers and neutron skins

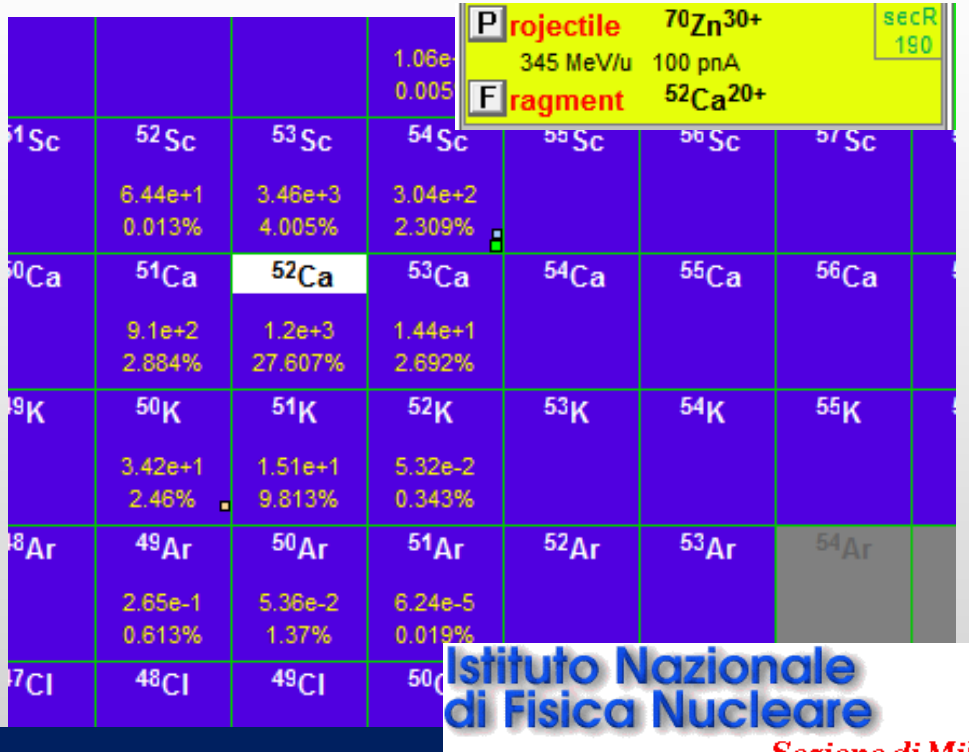
Tsunenori Inakura,[1] Takashi Nakatsukasa,[1,2] and Kazuhiro Yabana[2,1]

**Approved by RIKEN PAC**
**For 2016**




With Zn Beam and SAMURAI
and Dali2+8$LaBr_3$:Ce
To arrive at $^{52,54}$Ca
and beyond

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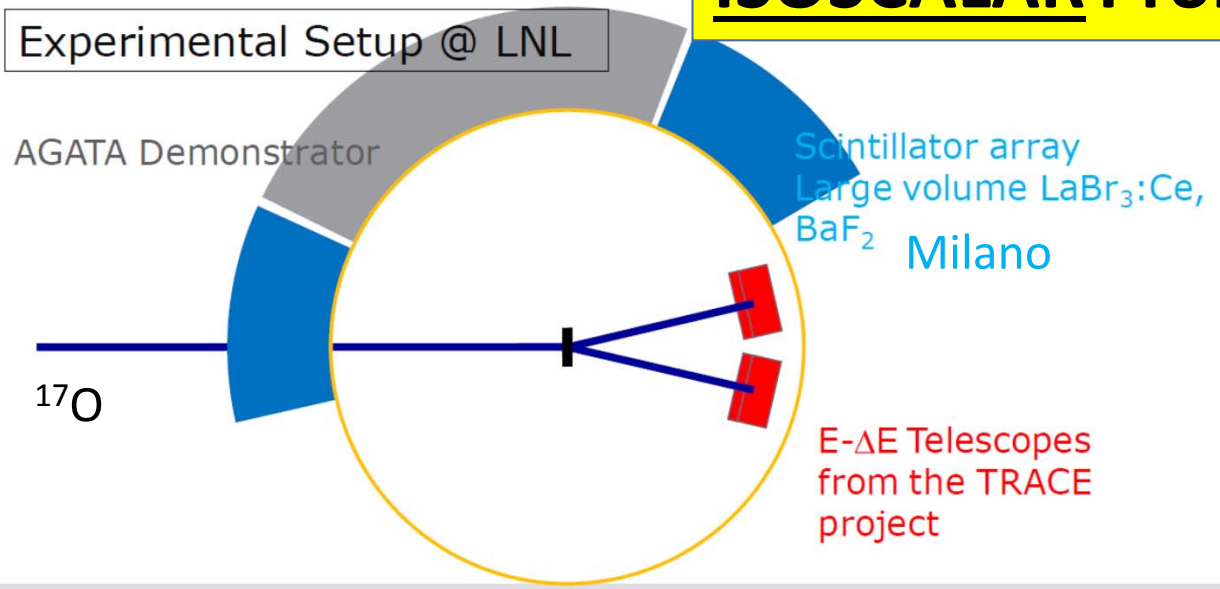
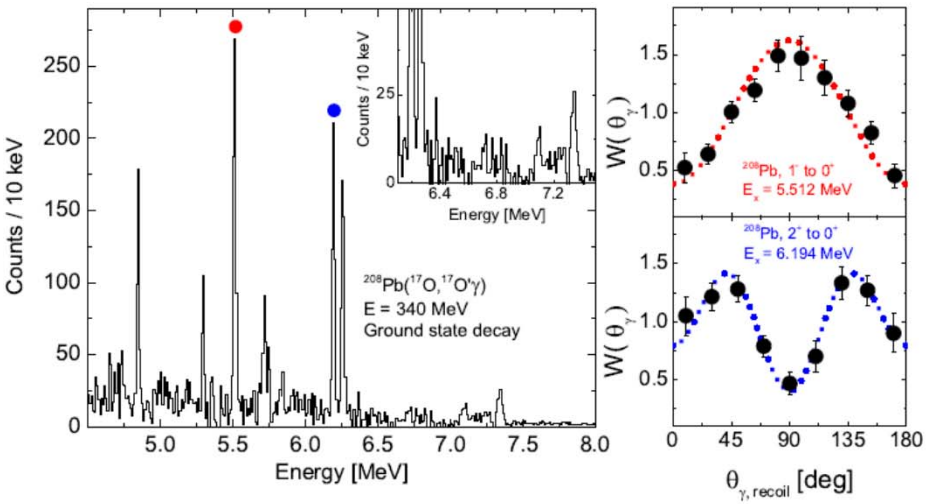
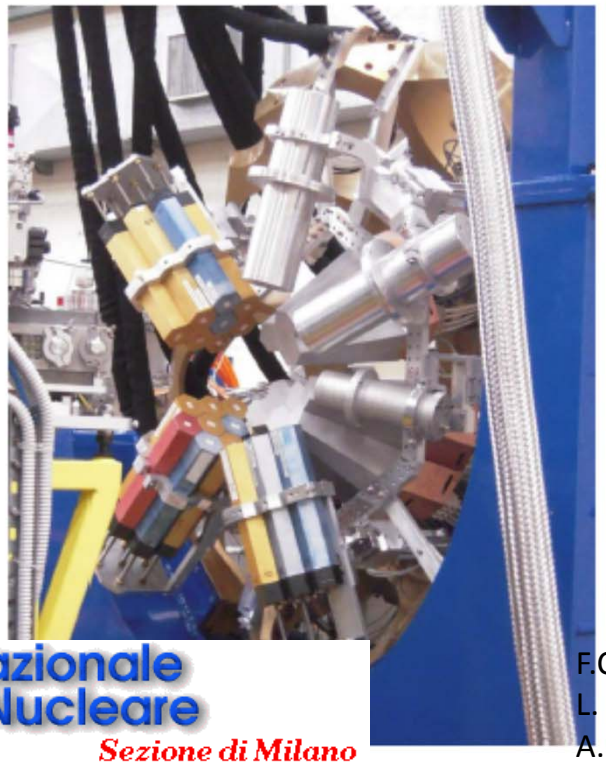
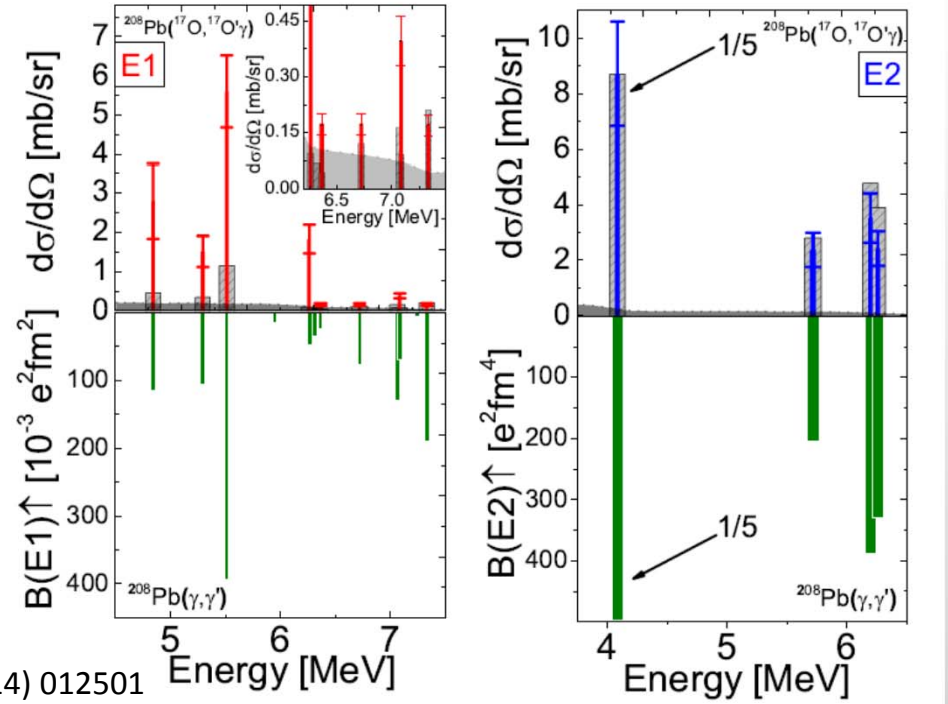
# ISOSCALAR Probe for Pygmy Dipole Strength (LNL)






F.C.L. Crespi, et al., PRL113 (2014) 012501
L. Pellegri, et al., PLB738 (2014)519
A. Bracco F.C.L. Crespi and E.G. Lanza, EPJA(2015)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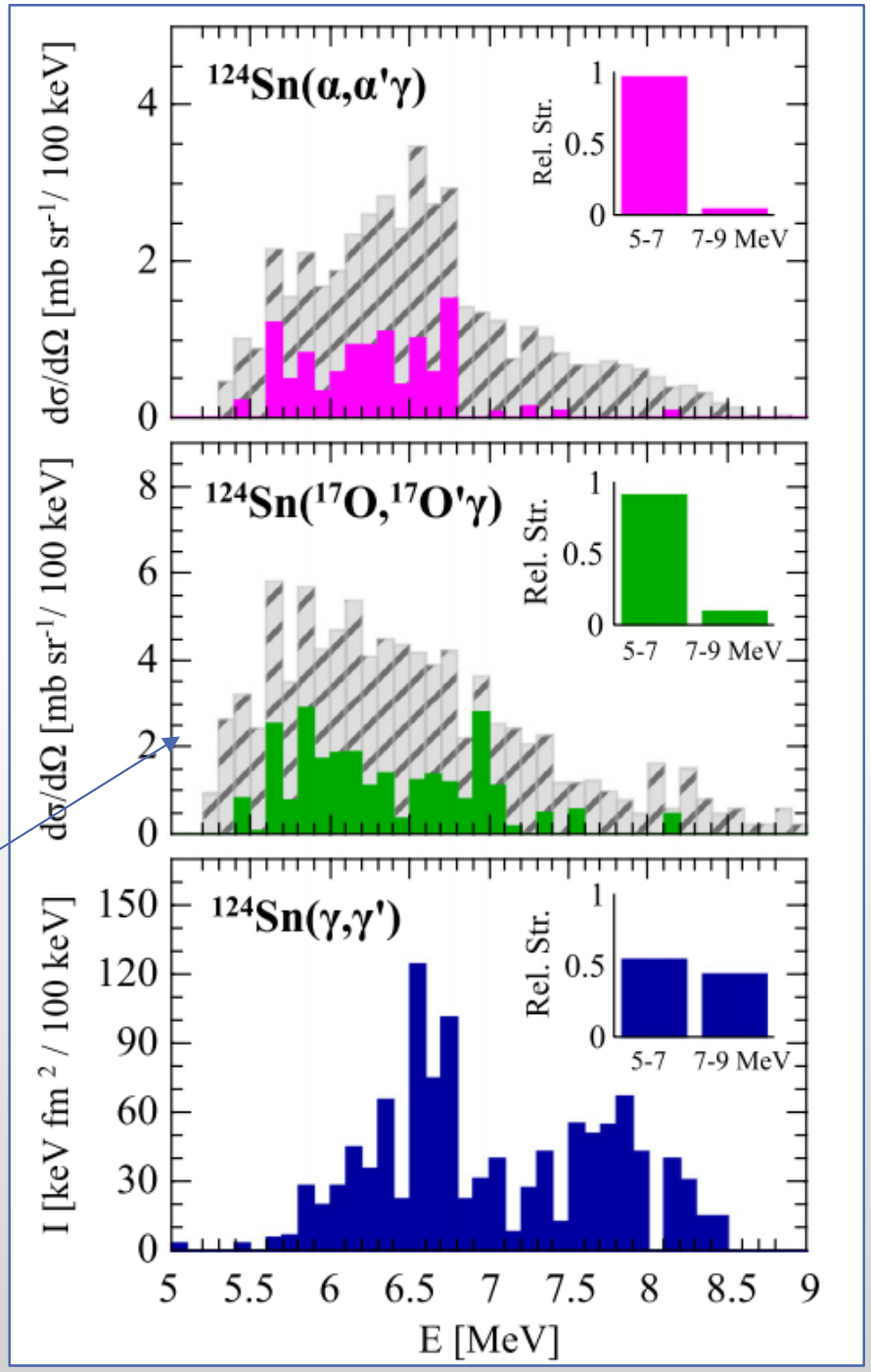
## Results on the Low-Lying E1 Strength → *splitting of PDR into IV and IS part*

**$1^-$ excitation with $^{17}O$ at 20 MeV/u Measured at LNL with AGATA**

**Results for $^{124}Sn$**

Comparison with alpha and γ scattering

The **splitting of the PDR** region becomes even more evident if we integrate the strength in the discrete peaks measured in each experiment into two regions, 5–7 and 7–9 MeV




(**) J. Endres et al., Phys. Rev. Lett. 105, 212503 (2010)

L. Pellegri, et al., PLB738 (2014)519

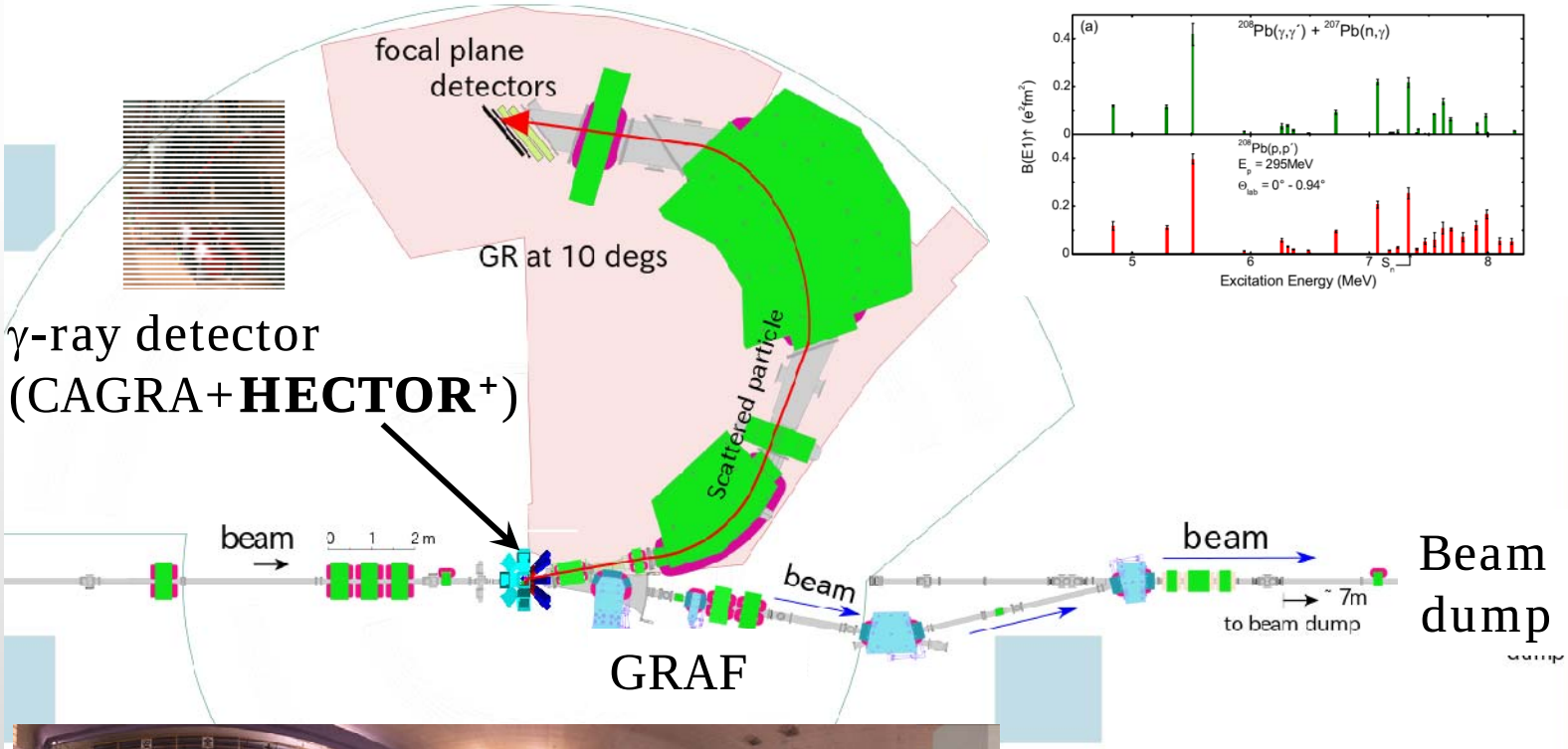
New Proposals in preparation

# OSAKA: GRAF (Grand RAiden Forward beam line)

To measure γ-ray at around the target position of GR,
low background condition is necessary.

➡ Primary beam particles are led to wall beam dump!

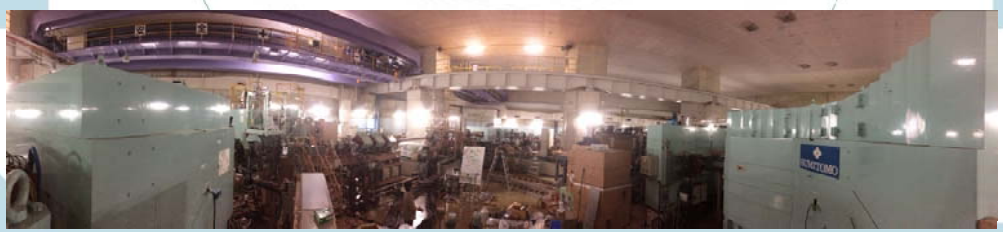
ISGDR $(\alpha,\alpha',\gamma)$







**Study the ISOSCALAR part Of the PDR**



Misura 2015, 2016,..
F. Crespi

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# Pubblicazioni recenti (PDR/GDR)

- "Study of the soft dipole modes in 140Ce via inelastic scattering of 17O" M. Krzysiek et al. Phys. Scr. 89 (2014) 054016.
- "On the Road to FAIR: 1st Operation of AGATA in PreSPEC at GSI" Pietralla,et al EPJ 66 (2014)02083
- "Isospin character of low-lying pygmy dipole states in 208Pb via inelastic scattering of 17O ion" F.Crespi et al Phys. Rev. Lett. 113, 012501 – Published 2 July 2014
- "Pygmy dipole resonance in 124Sn populated by inelastic scattering of 17O", L.Pellegri, et al. PhysicsLettersB738(2014)519–523
- "Measurement of dynamical dipole gamma-ray emission in the N/Z-asymmetric fusion reaction 16O+116Sn at 12 MeV/nucleon", A. Giaz, et al. PHYSICAL REVIEW C90, 014609 (2014)
- "Onset of quenching of the giant dipole resonance at high excitation energies" D. Santonocito, et al. PHYSICAL REVIEW C90, 054603 (2014)
- "Search for E1 strength in 62,64Fe around the threshold" O. Wieland, et al. J. Phys.: Conf. Ser. 580 012058 (2015)
- "Giant dipole resonance built on hot rotating nuclei produced during evaporation of light particles from the 88Mo compound nucleus", M. Ciemala et al. 10.1103/PhysRevC.91.054313 (2015)

# Grazie

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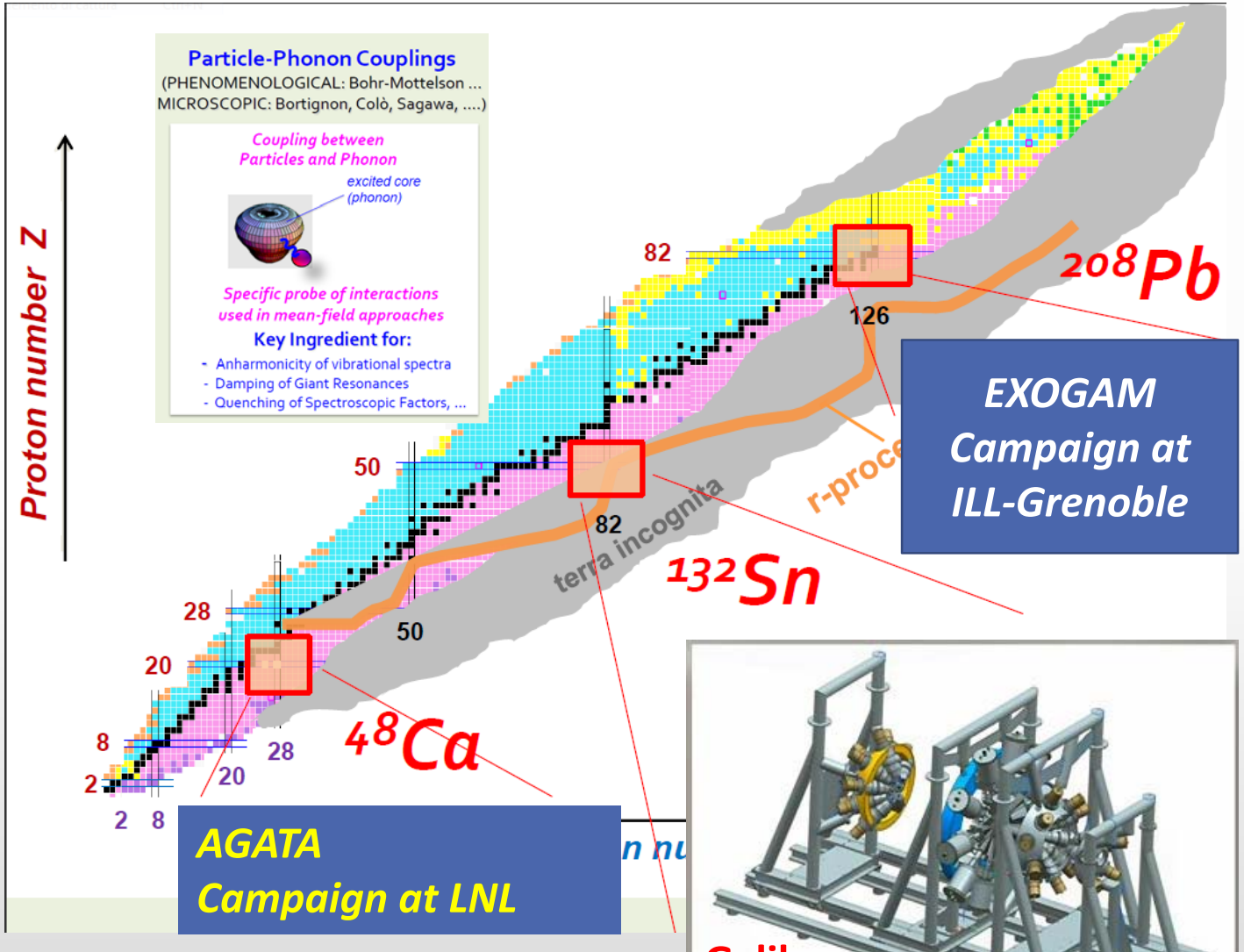
*A. Bracco, A. Giaz, A. Mentana, B. Million, F. Camera, F.C.L. Crespi, G. Benzoni, N. Blasi, O. Wieland, R. Avigo, S. Brambilla, S. Riboldi, A.I. Morales, G. Bocchi, S. Leoni, S. Ceruti, …*

**Per**

- **Esperimenti a Legnaro LNL (Italia)**
- **Esperimenti a Darmstadt GSI (Germania)**
- **Esperimenti a Tokyo RIKEN (Giappone)**
- **Esperimenti a Osaka RCNP (Giappone)**

# Particle Phonon Coupling




Proposals ongoing for 2016

## GDR at finite temperature and determination of ISOSPIN MIXING measurment in $^{80}$Zr at T=1-3MeV

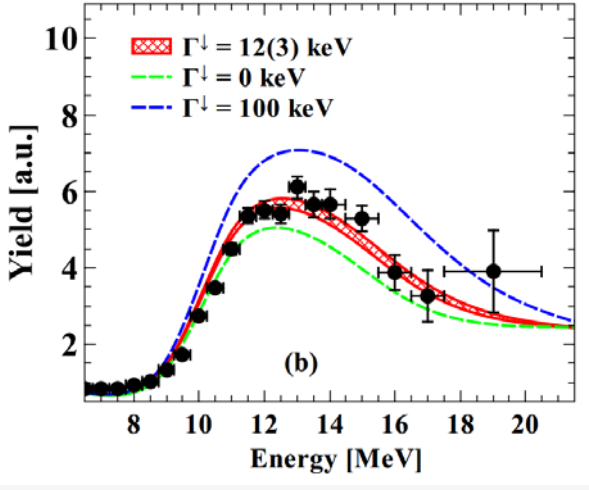
- In the nuclear matter the **isospin symmetry** is broken by the presence of the coulomb interaction (***isospin mixing***).
- **GDR γ decay** is a tool to test the isospin symmetry in N=Z nuclei.
- From the **GDR γ decay** data we extract the degree of ISOSPIN mixing $\alpha^2$ and coulomb spreading width Γ.

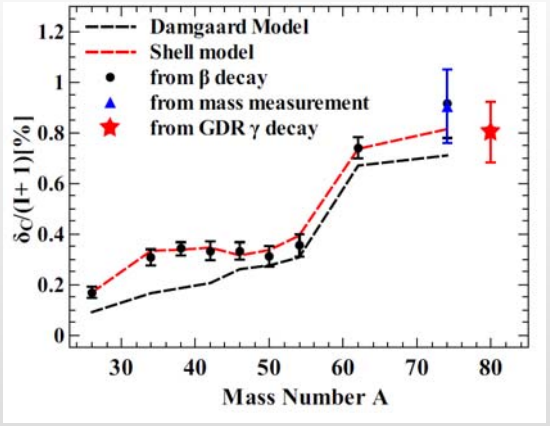
Isospin Mixing contributes as fundamental quantity to extract the **Vud** (matrix transition element) term of the **CKM** matrix

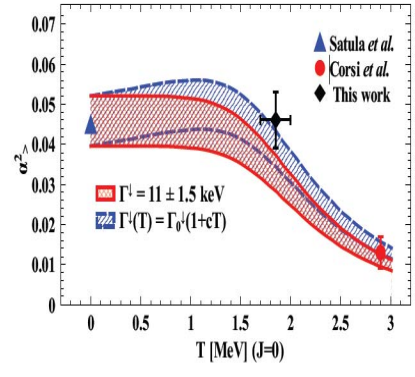
**Vud** ⟵ $Ft \equiv ft(1+\delta_R)(1-\delta_C)$

Isospin mixing correction term ~ $\alpha^2$

GDR γ decay spectrum of $^{80}$Zr




**Restoration of Symmetry between n and p at high temperature**

S. Ceruti et al.
APP B46 (2015)
PhysRevC.84.041304,
PRL submitted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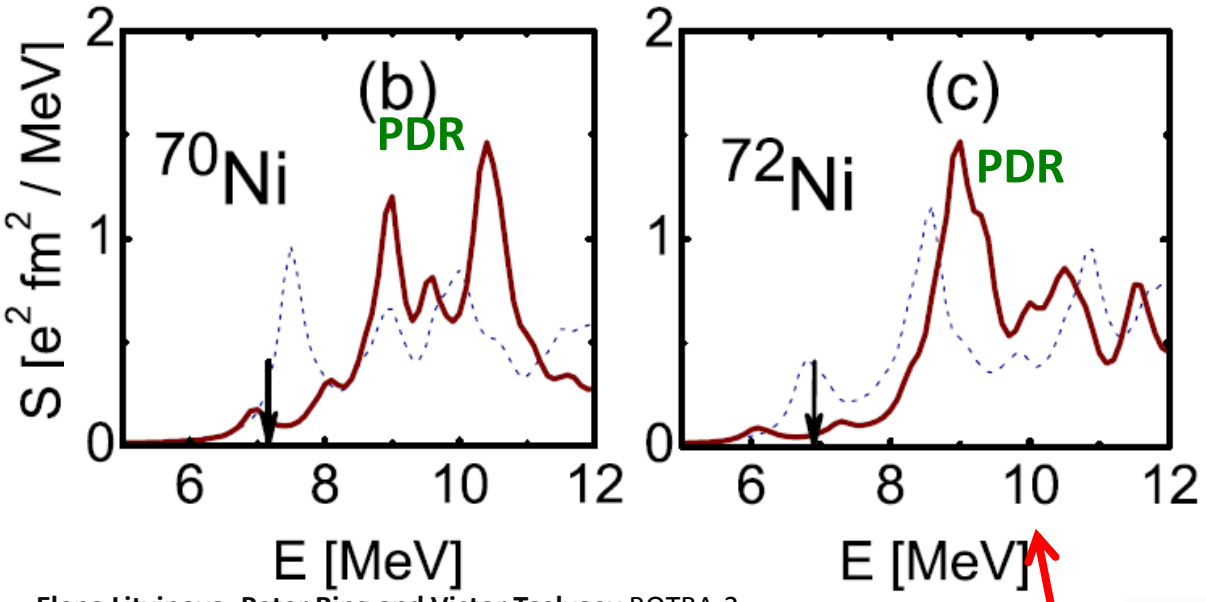
**New Proposal 2016 with Galileo@LNL**

# Propsal 2014/2015 $^{70}$Ni and 2016 for $^{72}$Ni →2017




**Elena Litvinova, Peter Ring and Victor Tselyaev** RQTBA-2

**Phys. Rev. Lett. 105, 022502 (2010)**

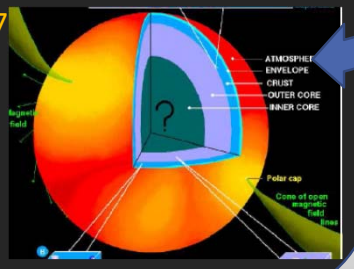
"the $^{70;72}$Ni isotopes can be suggested for future measurements."

**PHOTON SCATTERNING**
POSSIBLE NOW only AT RIKEN

| | B.E.(MeV) | $r_c$ (fm) | $r_n$-$r_p$(fm) |
|---|---|---|---|
| $^{16}$O | -128.112( -127.619) | 2.735(2.730) | -0.15 |
| $^{40}$Ca | -341.578( -342.052) | 3.470(3.485) | -0.14 |
| $^{48}$Ca | -413.615( -415.990) | 3.470(3.484) | 0.14 |
| $^{72}$Ni | -612.168( -613.152) | 3.892 | 0.26 |

G. A. Lalazissis, et al. Phys.Lett. B 647,111(2007

Neutron SKIN




1 to 1
Relation between
PDR
neutron skin
and EOS → n-Star