New *preliminary* experimental results on Giant and Pygmy Dipole Resonances*

O. Wieland
for the AGATA, Prespec, HECTOR+ collaboration

*mainly AGATA and GSI related

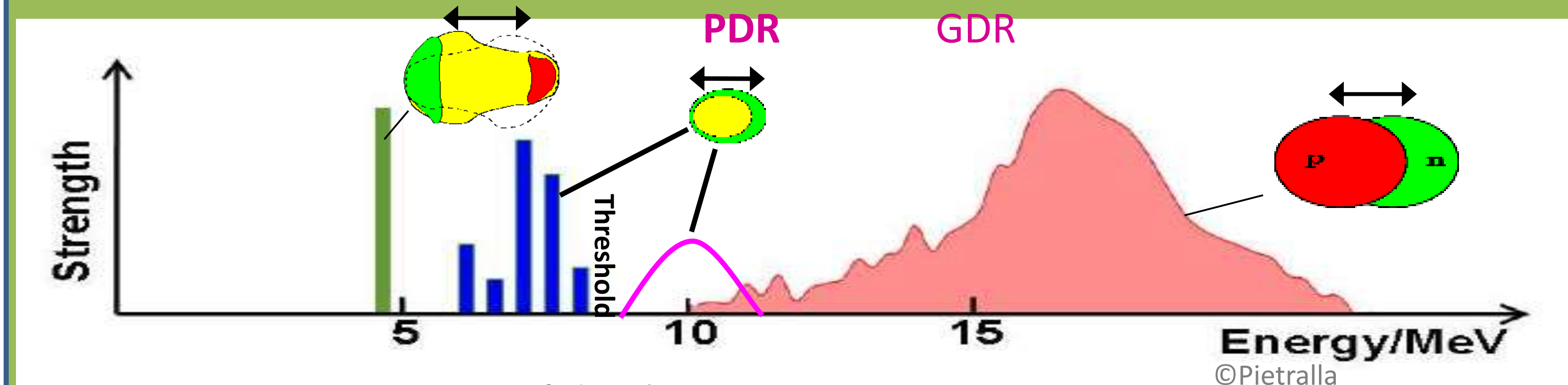
OUTLINE:

-Part one: Short notes on general features of GDR,… (pre-GSI-phase)

-Part two: Pygym Dipole Resonance
Experiments at GSI (AGATA,Prespec,…)

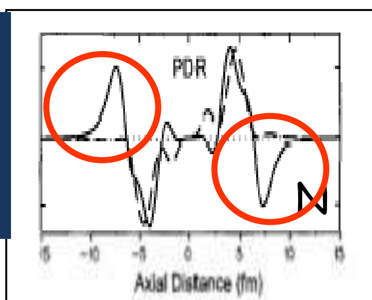
Electric Dipole <u>response</u> in Nuclei in measured gamma ray spectra

Dipole response

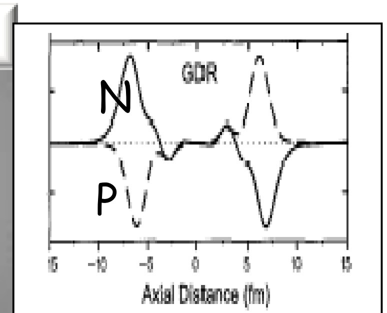


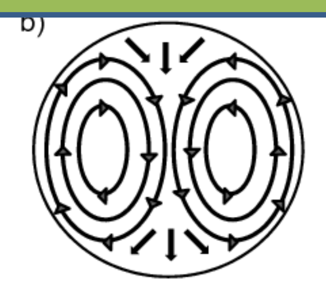
Gamma ray spectrum of dipole response

Average Transition charge densities



Pygmy Resonance





E1 toroidal

Repko A., et al
Phys.Rev. C87 (2013) 024305

Or Toroidal modes ?

GIANT RESONANCES IN NUCLEI

Observables

(E*, J, ... dependend):

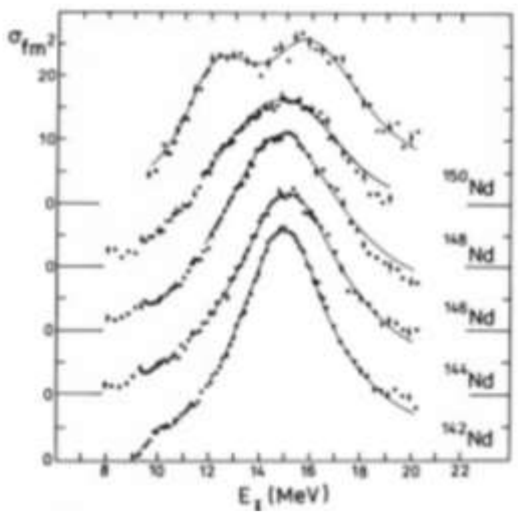
a) Centroid Energy
b) Width,
c) Strength,
d) Lineshape

→ **Information on nuclear structure**

a) Symmetry energy,
b) Damping
(T=0 Q-Fluctuations –coupling np-ph)
(T>0 Thermal Fluctuatioons, compound width,…),
c) Degree of collectivity,
d) deformation

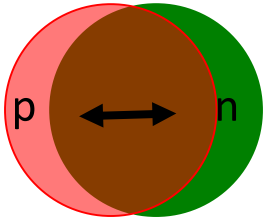
GDR et al,…How to measure ?

«*Traditionally*» with photoabsorption, NRF, nuclear reactions, p,p', alpha,alpha'-scattering experiments, DI, …
with stable nuclei or stable beam target combination *
but recently ALSO with fast exotic beams



Since long time we know:
GDR Lineshape **changes** with
Neutron number !

GDR Centroid:
Symmetry Energy –
length of
oscillation axis



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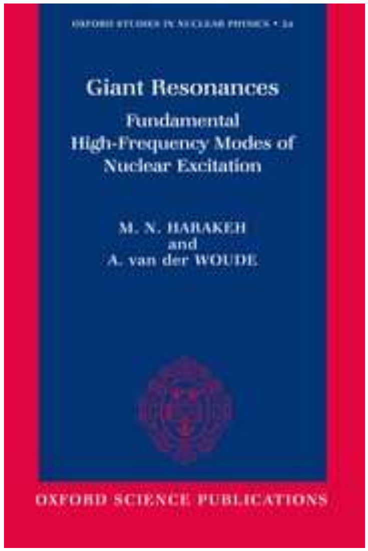
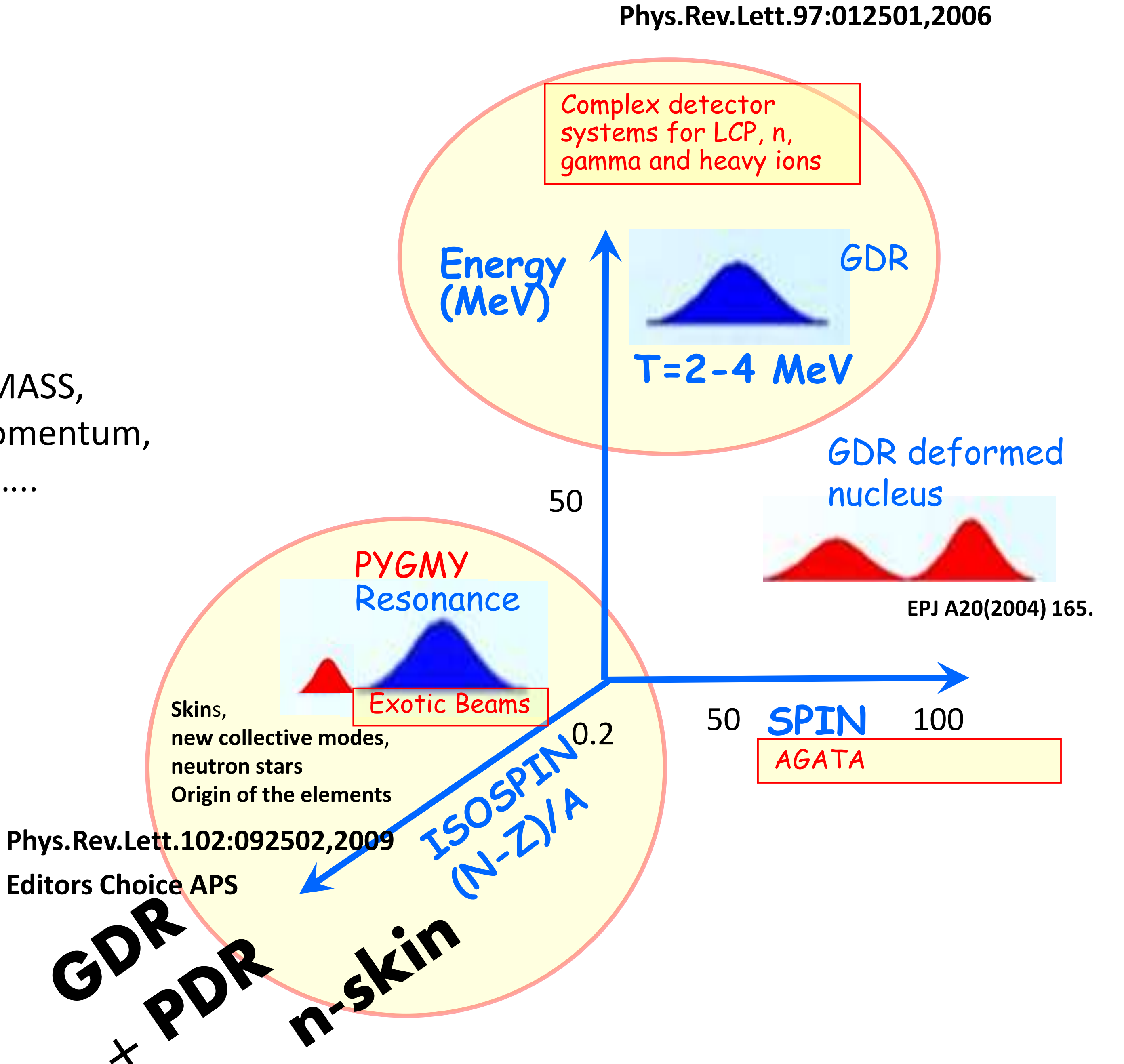


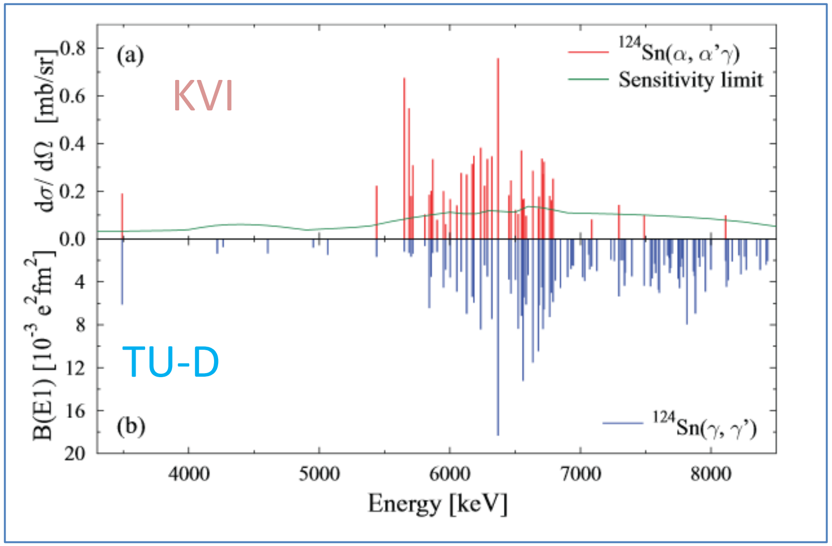
«GDR»

Dependance of GDR on MASS,
Temperature, angular momentum,
Isospin(mixing), lifetime…..



Splitting of E1 strength in the response in Nuclei to different probes

The splitting in the population of the states reveals a different underlying structure



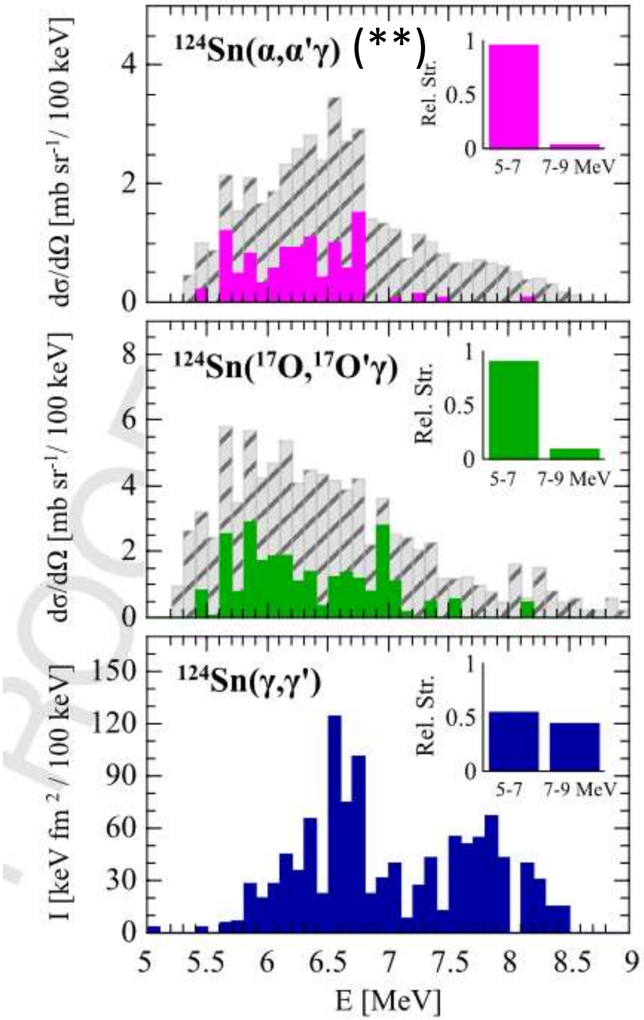
- ❑ low energy part → isoscalar character (*neutron-skin oscillations*)
- ❑ high-energy states → isovector nature (*transition towards the GDR*)

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

One important open problem for pygmy states is the <u>cross section sensitivity to transition densities</u> containing the nuclear structure information…

Results with **AGATA** on Pygmy states in ^{124}Sn (*) with ^{17}O probe

Phys. Rev. Lett. 113, 012501, 2014



- One of the crucial points of this work is the comparison of the presently measured cross sections with (γ,γ′) and (α,α′γ) results.
  - *discrete peaks*
  - *total measured counts* (unresolved strength dashed grey bars)

- **Splitting of the PDR states in two regions also in** (17O,17O′ γ)
  - isoscalar transition densities (*peaked on the surface, enhanced in the isoscalar E1 response*)
  - higher-lying states (*GDR type, suppressed in the isoscalar channel*)

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

(*) L.Pellegri et al. Accepted for publication in PLB

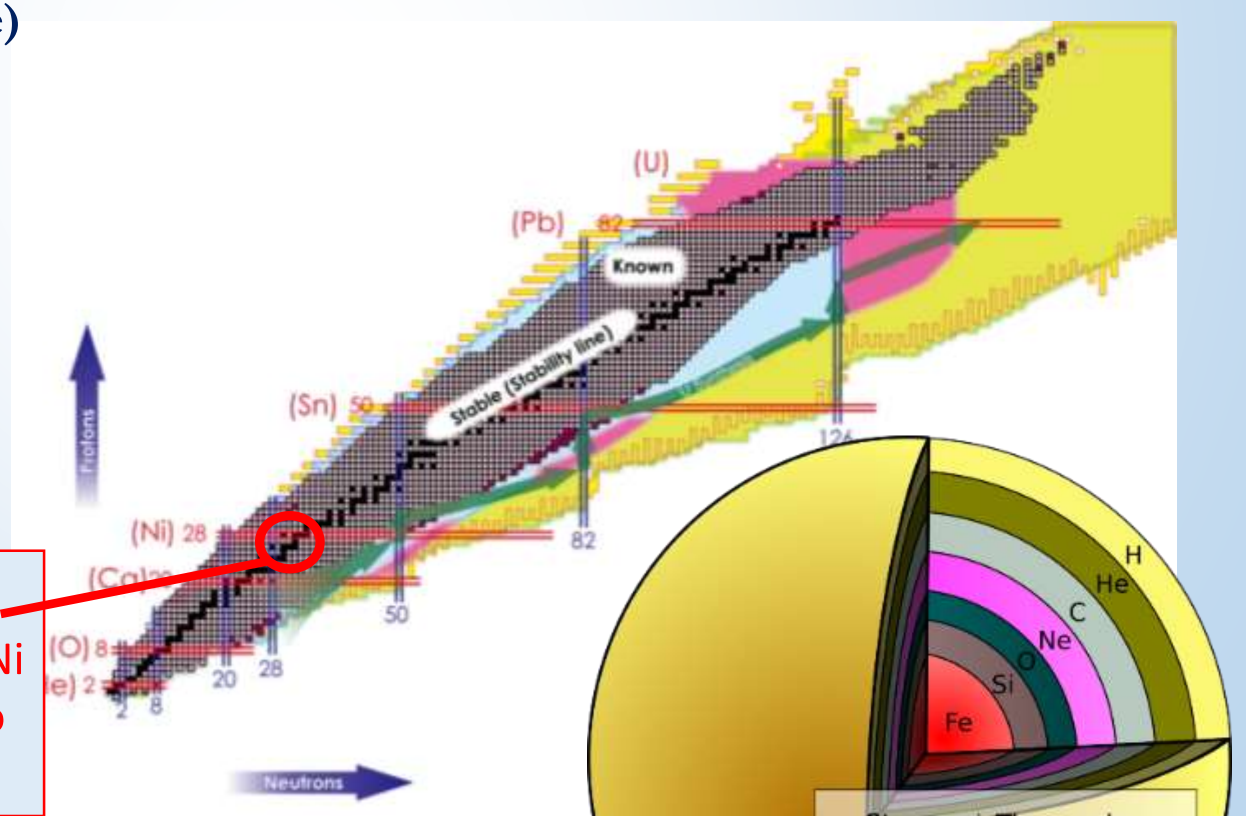
(**) J. Endres et al., Phys. Rev. Lett. 105, 212503 (2010)

OUTLINE Part 2

- Introduction and «replay» of past data of **PDR (pygmy dipole resonance)** search in in^{68}**Ni** and Results with **RISING (=Euroball+CATE+BaF$_2$)**
- The very recent experiments with ^{62}**Fe** and ^{64}**Fe**

and «near-line-results»

WITH PRESPEC (=AGATA+LYCCA+LaBr$_3$:Ce)



Supernova-Explosion

Starting points of r-process near Ni and Fe region going towards also more exotic nuclei

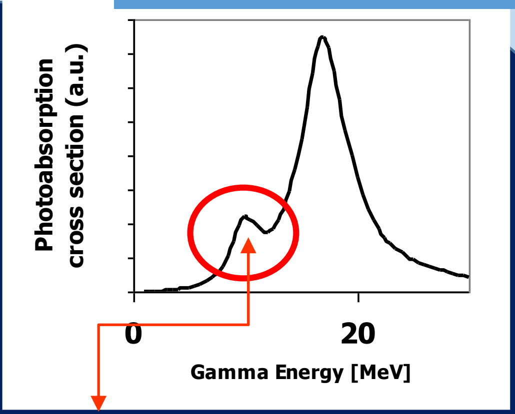
Pygmy Dipole Resonance

"Collective oscillation of
neutron skin against the core"

Open Questions,

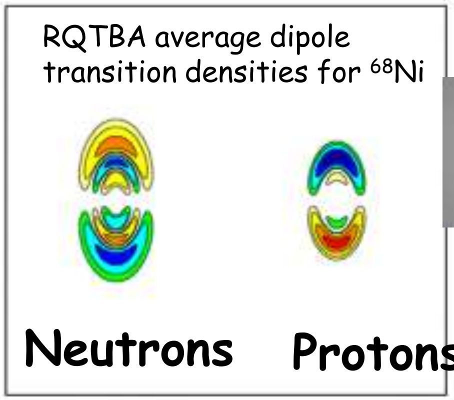
-Level of collectivity ?
-How (collective) properties change with n ?
-How isospin changes mean field ?
-In exotic nuclei: does PDR strength exist also below neutron threshold ?
-No High resolution/statistics measurements available
-Various nuclei and mass regions
-Effect of deformation ?
-Proton Pygmy, still to proof (2008Land?)
-"Picture " of PDR, toroidal mode ?
- from pygmy strength deduce dipole polarizability

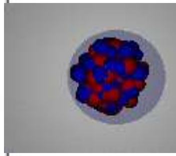
From Experiment



E1 strength shifted
Towards lower energy

From Theory



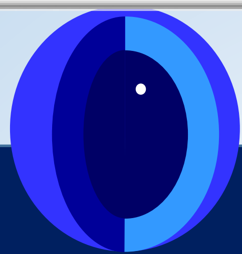


Litvinova 2012

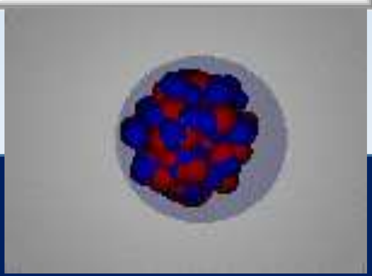
In exotic Nuclei: extremely few experimental Data available

P. Adrich et al., Phys. Rev. Lett. 95, 132501 (2005)
J. Gibelin et al., Phys. Rev. Lett. 101, 212503 (2008)
O.Wieland et al. PRL 102, 092502 (2009)
D.Rossi et al. PRL 111, 242503 (2013)
refernces therein and cited by

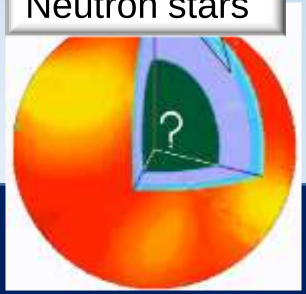
Neutron Skins



Pygmy Resonance



Neutron stars



Why ?

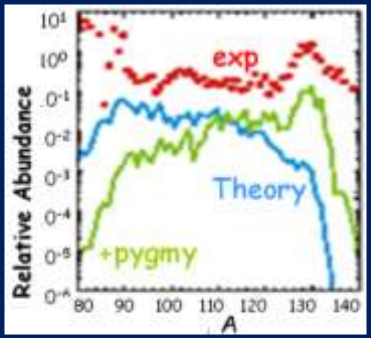
? EOS

The **PDR strenght** gives **measure of neutron skin** radius.
Carbone et al. Phys. Rev. C 81, 041301(R) (2010)

→Determine nuclear polarizebility.
Relation between **neutron skin** and neutron stars :
both are built on neutron rich nuclear matter
so that one-to-one correlations can be drawn.
Yet both radii depend on the knowledge of **equation of state** of neutron rich matter.

+

Pygmy Resonance in exotic nuclei and especially low E1 strength
may have an very important
impact on the r-process Nucleosynthesis
and on nuclear phenomenology



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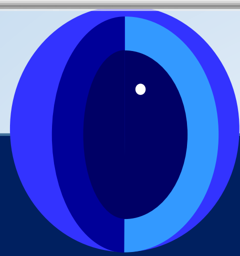


?

EOS

Nupecc long range plan 2004-2010

"Giant resonances are of paramount importantce for nuclear astrophysics"

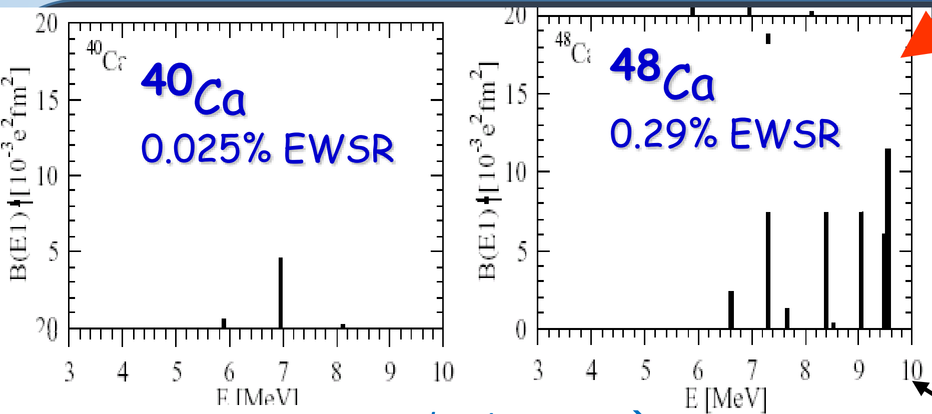
…"It is of particular interest to study the collective strength in short-lived nuclei…"

INPC 2013 – Nucl. Astrophysics session:

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

Features of this mode

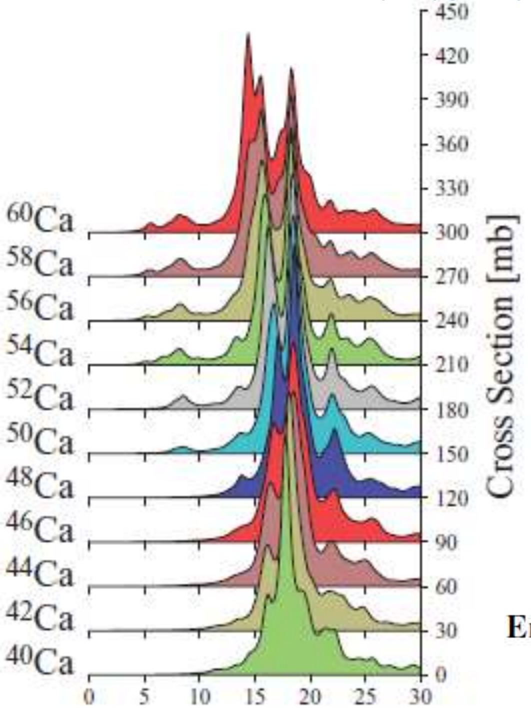
There is a **trend** of the strength to **increase** with the **proton-to-neutron asymmetry**



n-number increase →

T. Hartmann PRL85(2000)274

Stable nuclei ⇒
photon scattering,Photoabsorption
(γ,γ '),(γ,n)...



Exotic nuclei

?

Features ... How to measure in exotic nuclei?

VERY VERY DIFFICULT !
NOT possible
@
TU-Darmstadt
HIγS, ELBE
ELI-NP,...

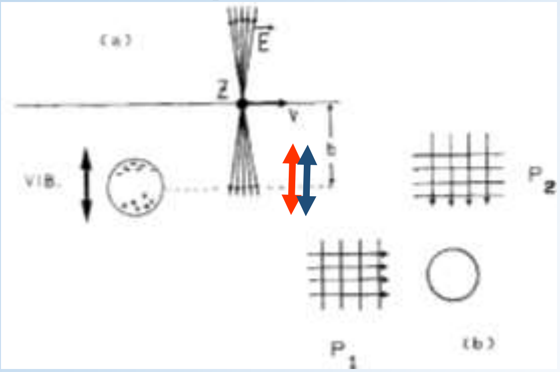
PHYSICAL REVIEW C **84**, 021302(R) (2011)

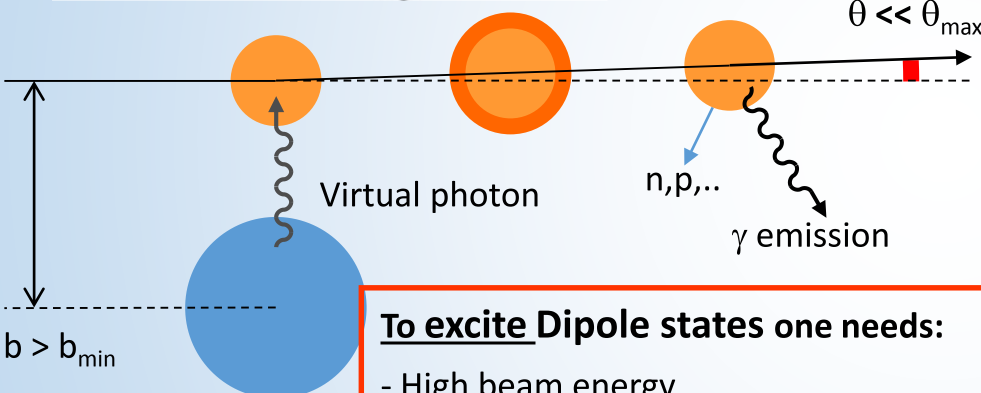
Emergence of pygmy dipole resonances: Magic numbers and neutron skins

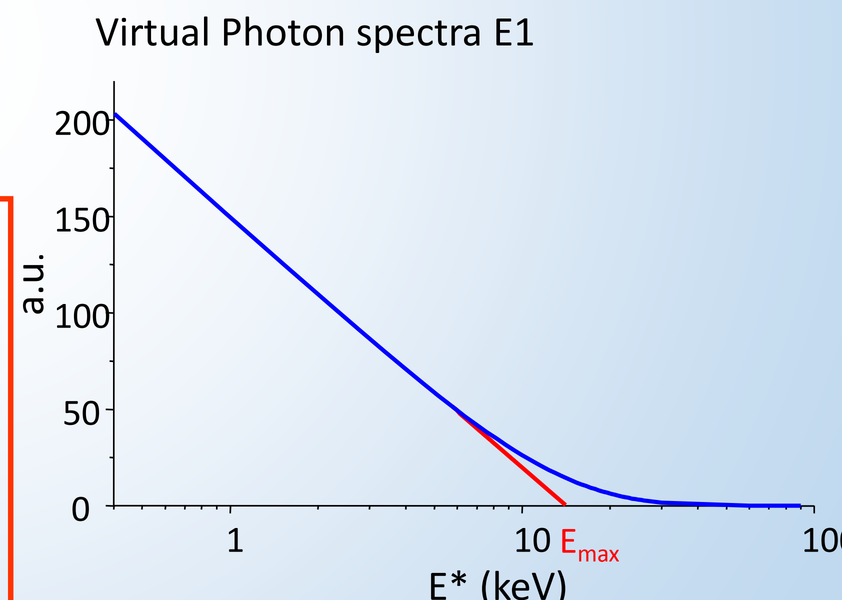
Tsunenori Inakura,[1] Takashi Nakatsukasa,[1,2] and Kazuhiro Yabana[2,1]

Relativistic Coulomb excitation after fragmentation

- **Peripheral heavy-ion collision on a high Z target at relativistic energies**
- **Virtual photon excitation and decay**







<u>To excite</u> Dipole states one needs:

- High beam energy
  - Large cross sections
  - Large $\sigma_{GDR}/\sigma_{GQR}$ ratio

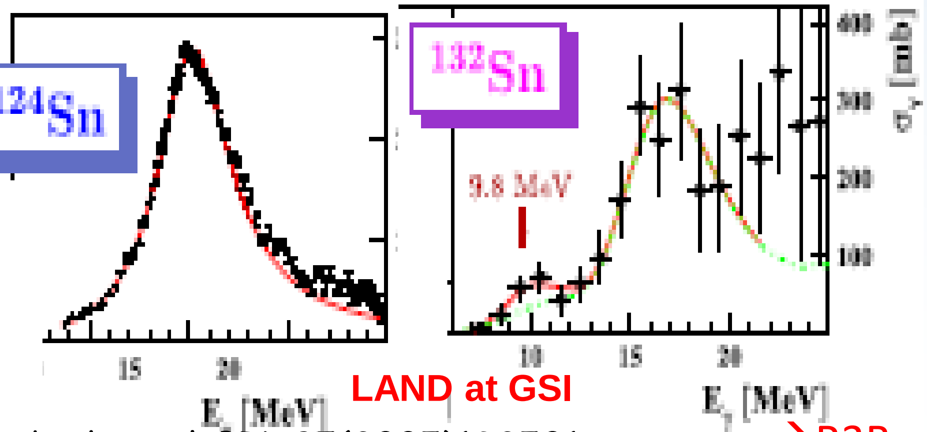
<u>To Select</u> projectile PDR one needs:

- High beam energy
  - Large Doppler effects
    → <u>Background REDUCTION</u>
  - Good Z_{proj}/Z_{target} ratio

$$E_{\max} = \frac{\beta\gamma}{b_{\min}} \hbar c$$

maximum excitation energy (adiabatic cut off)
ca. E*max=18.5 MeV

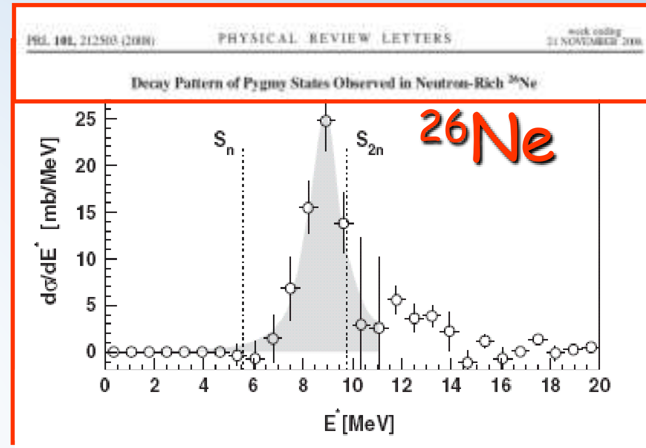
Coulomb break-up (above S_n)



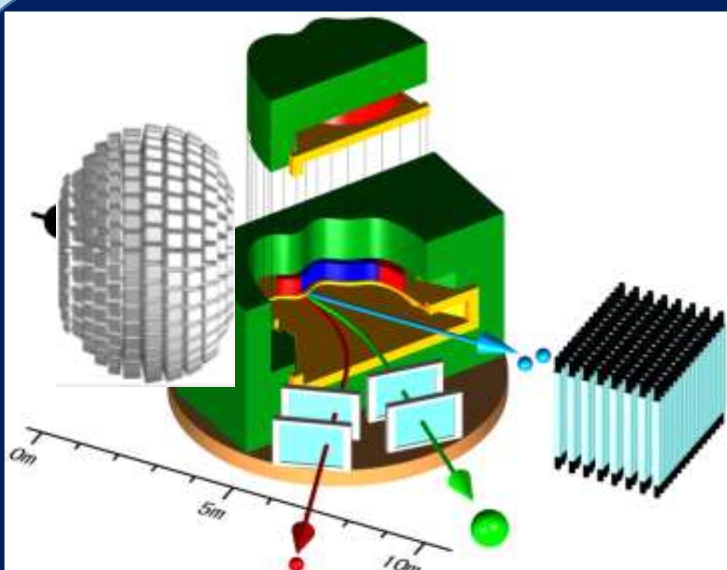
LAND at GSI

Adrich et al. PRL 95(2005)132501

→R3B



RIKEN experiment at 58 MeV/u
Measured and extracted
pygmy with 4.9 (+/- 1.6) % EWSR
(45mbarn)



Future of BU:

SAMURAI, Shogun@RIKEN

..R3B-GSI/Fair

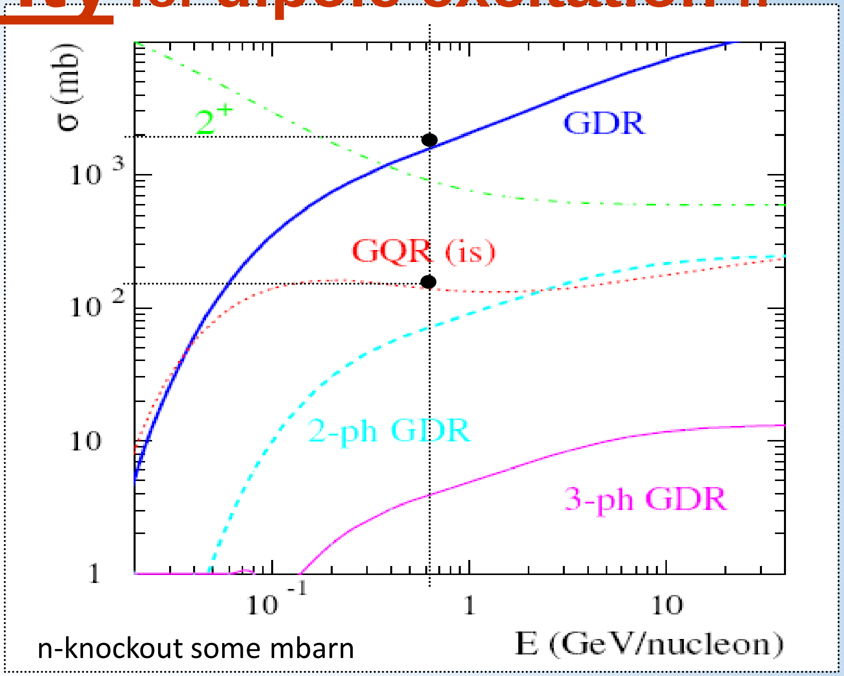
→ (But for astrophysical $(\gamma,n)(n,\gamma)$ not so important above threshold as below and around, also only gamma decay branch is important)

Virtual photon scattering technique

• **ADVANTAGE: High selectivity for dipole excitation !!**

GDR + PYGMY Excitation

400 MeV/u ^{68}Ni + ^{197}Au (May 2004)
600 MeV/u ^{68}Ni + ^{197}Au (April 2005)
400 MeV/u ^{64}Fe + ^{208}Pb (October 2012)
430 MeV/u ^{62,64}Fe + ^{197}Au (April 2014)



T.Aumann et al EPJ 26(2005)441

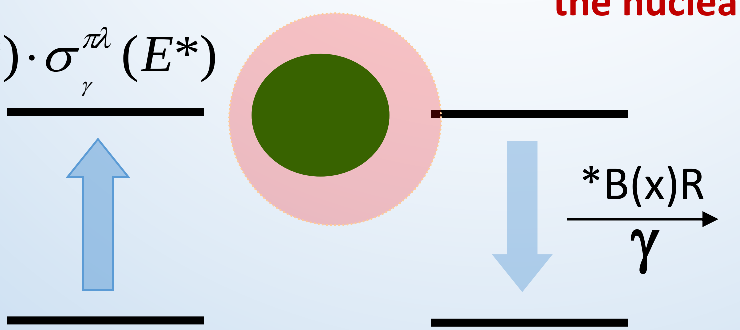
$$\frac{\sigma(GDR)}{\sigma(GQR)} \approx 20$$

→At large energies the cross section for the Coulomb excitation of the GR overcomes the nuclear geometrical cross section!

Virtual photon excitation

and decay of **GDR + PYGMY**

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



Coulex g.s.

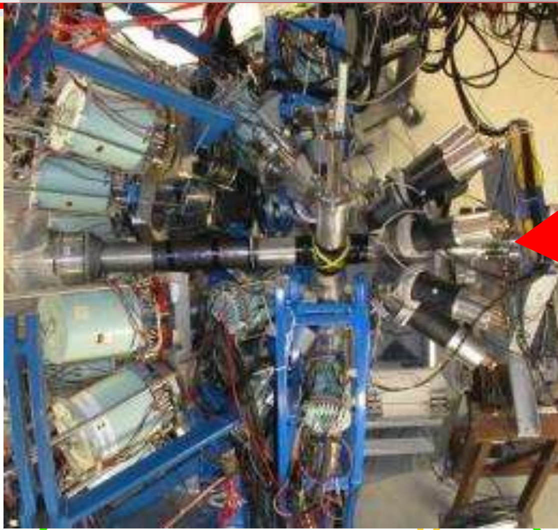
GDR Ground state decay branching ratio ~ 2% measured on ^{208}Pb

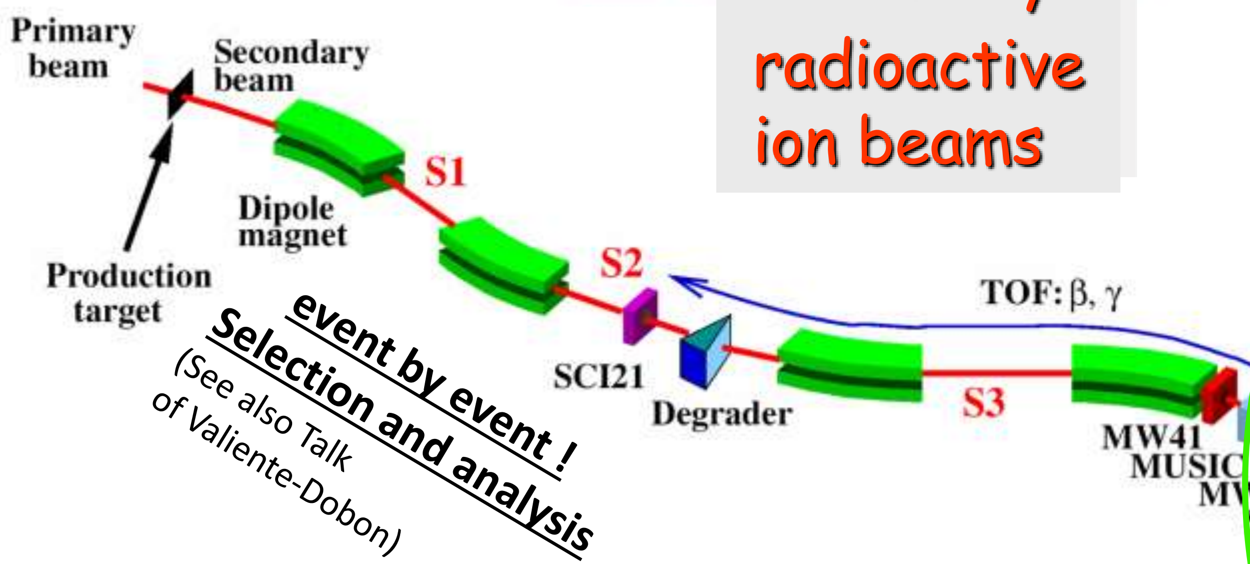
[Beene et al PRC 41(1990)920]

High resolution γ-spectroscopy at the FRS of GSI

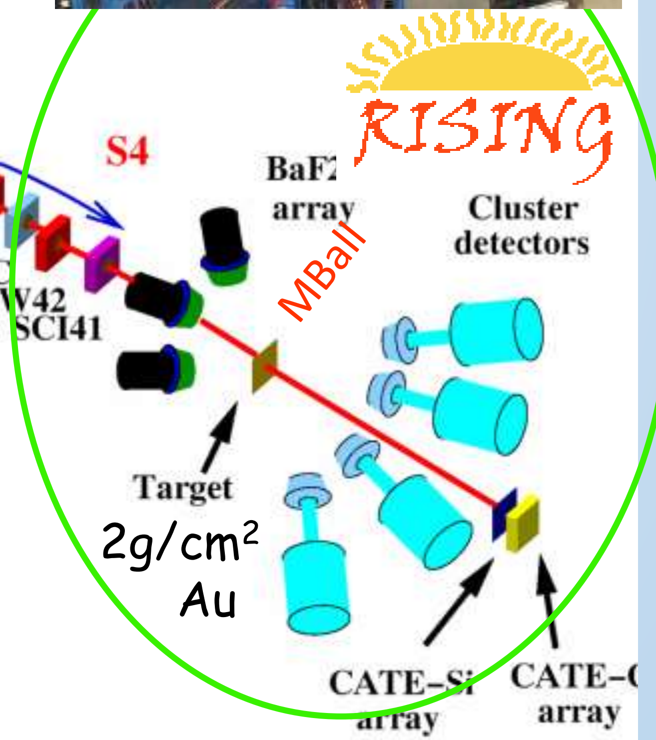
- ^{68}Ni beam by fragmentation of ^{86}Kr @ 900 MeV/u on Be target (4g/cm^2):
- 10^{10} ppspill ^{86}Kr, Spill length 6s,period 10 s

FRS provides secondary radioactive ion beams

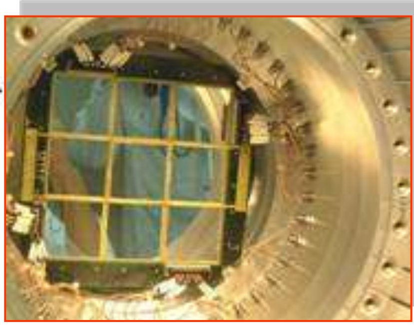




event by event !
Selection and analysis
(See also Talk of Valiente-Dobon)



Calorimeter Telescope for beam identification
CATE
Position sensitive



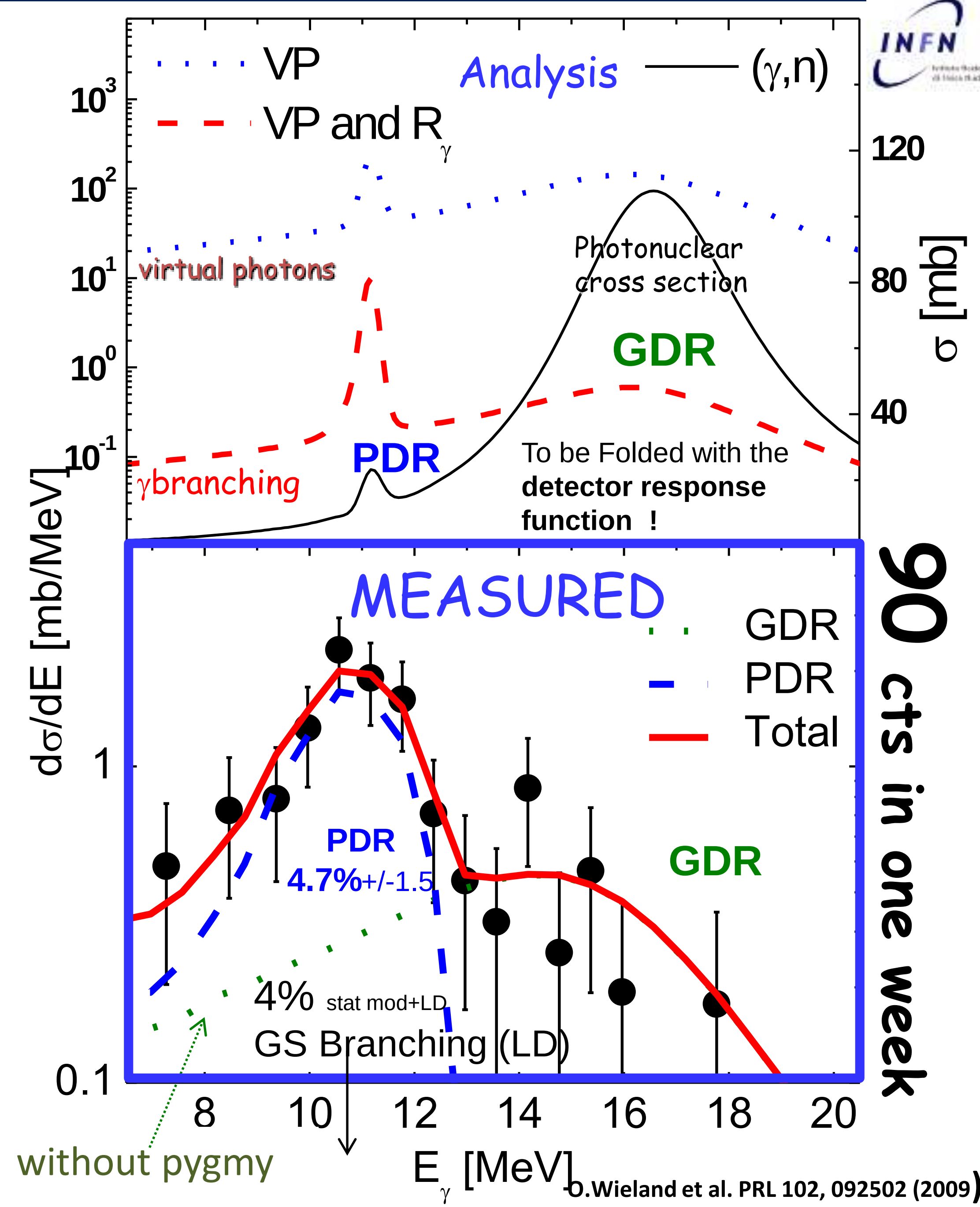
^{68}Ni ANALYSIS of Experiment at GSI (RISING-Setup) (+LAND/R3B)

Relativistic Coulomb excitation is directly proportional to the Photonuclear cross section.

[Eisenberg,Greiner, Bertulani, Baur, Alder,Winther, Weizsaecker, Williams…]

$$\frac{d\sigma_{C\gamma}}{dE_\gamma} = RF\left\{\frac{1}{E_\gamma} N_\gamma(E_\gamma)\cdot\sigma_\gamma(E_\gamma)\cdot R_\gamma(E_\gamma)\right\}$$

ResponseFunction



O.Wieland et al. PRL 102, 092502 (2009)

AFTER RISING-GSI MEASURE-

(The two main papers of this experiment were cited >250 times)

Recent theoretical calculations

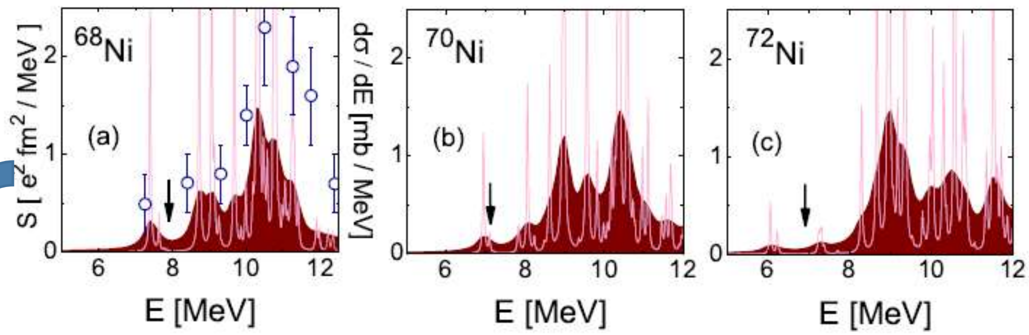
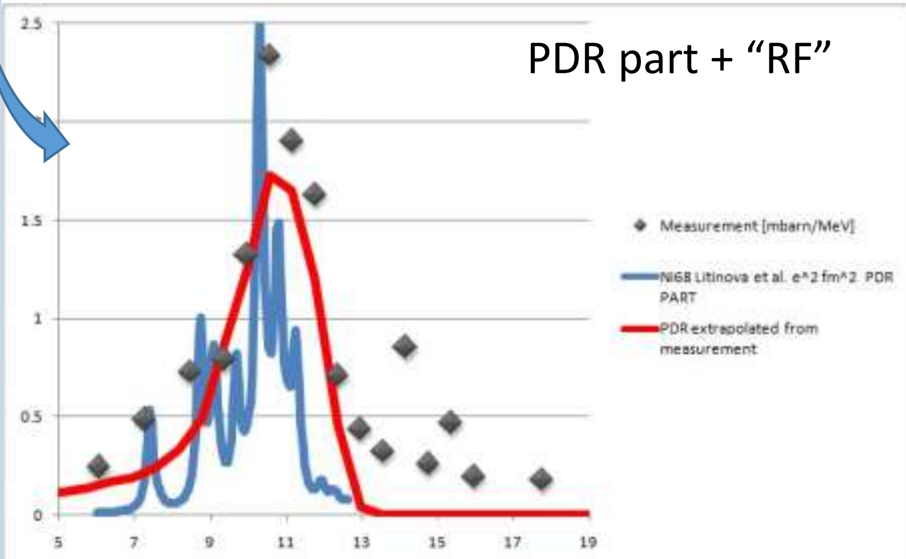
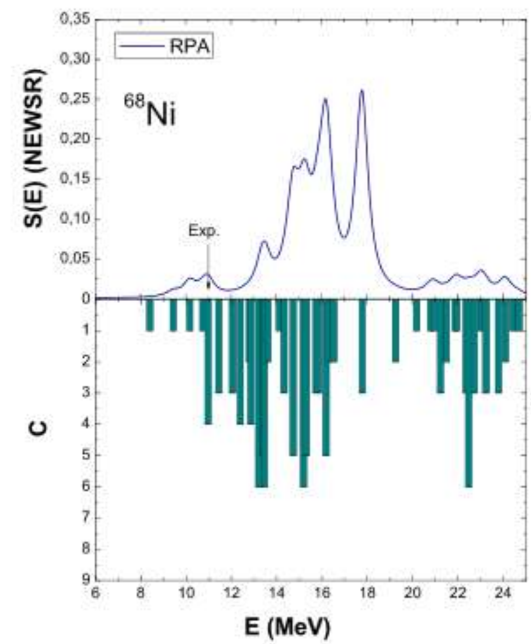


FIG. 3: Low-lying dipole spectrum of ^{68,70,72}Ni calculated within the RQTBA-2 with a smearing ... ains also the data from ... hresholds.



Elena Litvinova, Peter Ring and Victor Tselyaev 2009

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



E. Yüksel et al. / Nuclear Physics A 877 (2012) 35–50

PHYSICAL REVIEW C 87, 014621 (2013)

Pygmy and giant dipole resonances by Coulomb excitation using a quantum molecular dynamics model

C. Tao (陶城),[1,2] Y. G. Ma (马余刚),[1,*] G. Q. Zhang (张国强),[1] X. G. Cao (曹喜光),[1] D. Q. Fang (方德清),[1] and H. W. Wang (王宏伟)[1]

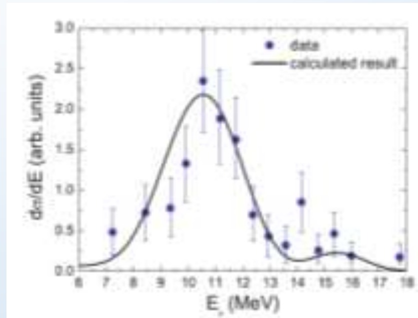
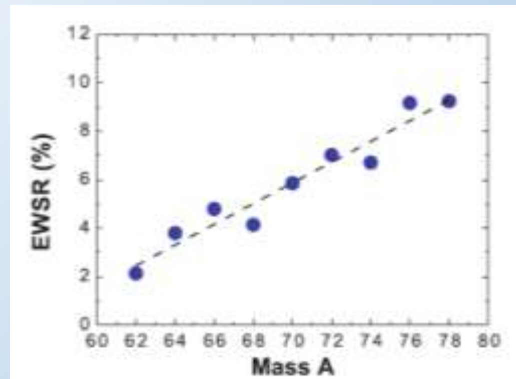
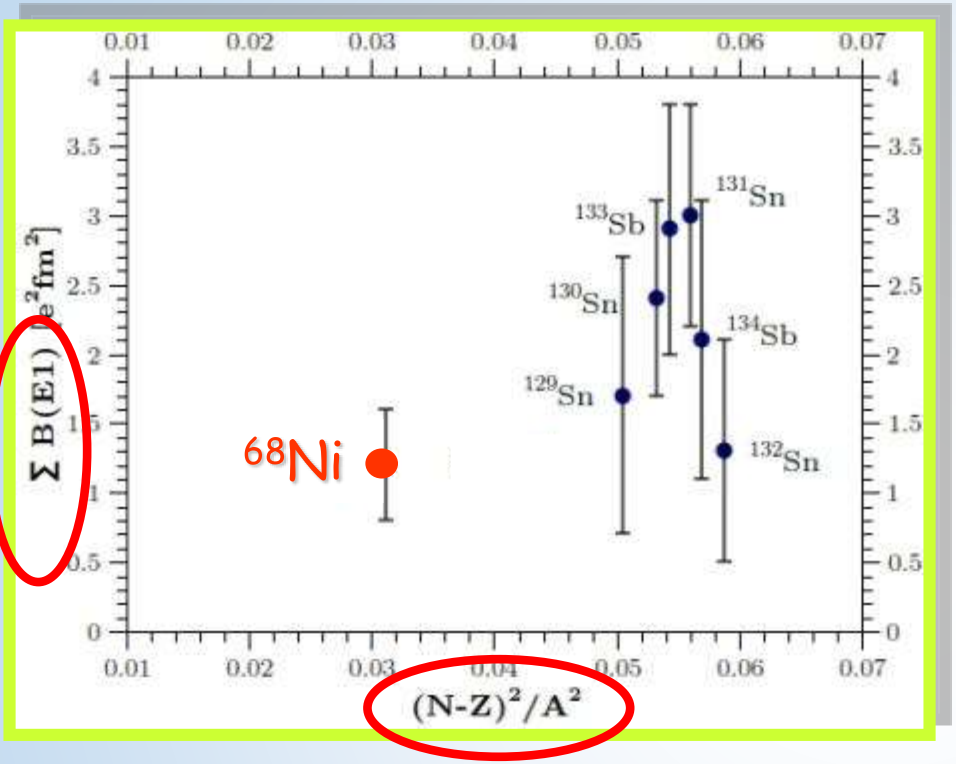


FIG. 2. (Color online) The calculated PDR result of ⁶⁸Ni compared with the experimental data. The blue circle with error bar is the experimental data in Ref. [11], the black line is the calculated result.



Compare the strength in ^{68}Ni with Sn data

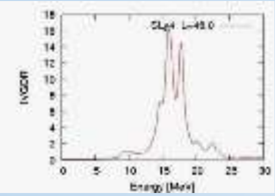


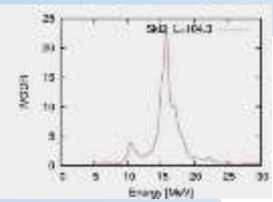
- Lower value of the B(E1) in ^{68}Ni as compare to the Sn region
- This is consistent with the fact that $(N-Z)^2/A^2$ is smaller
- $(N-Z)^2/A^2$ governs the symmetry energy in finite nuclei

This is the first hint that from the strength of the pygmy one could get information on the **symmetry energy**

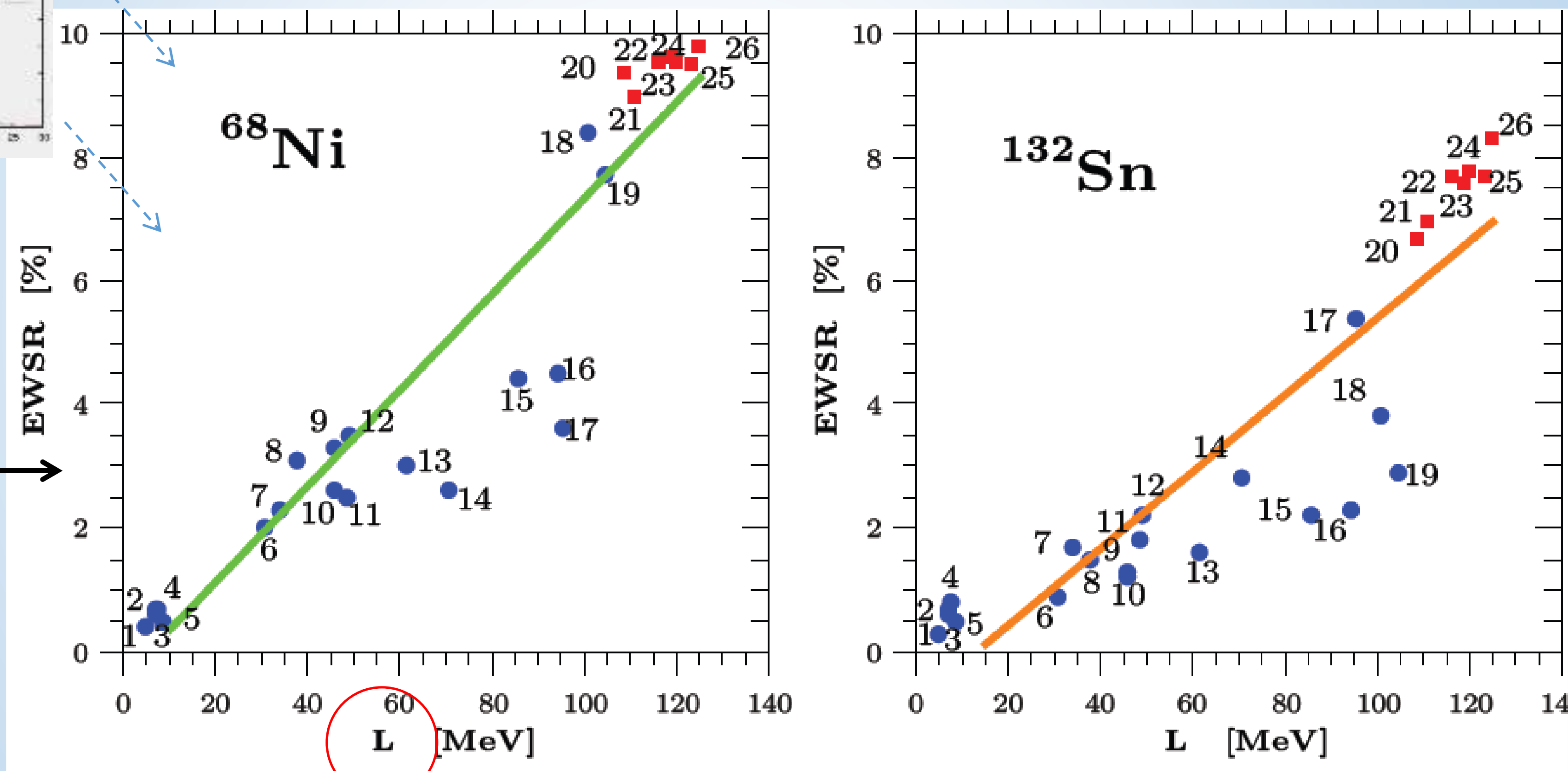
Possible Correlation that connects L and the PDR strenght

Carbone et al. Phys. Rev. C 81, 041301(R) (2010)





Predicted Strength Of PDR For different Forces (L)



L slope parameter at saturation density of the EOS

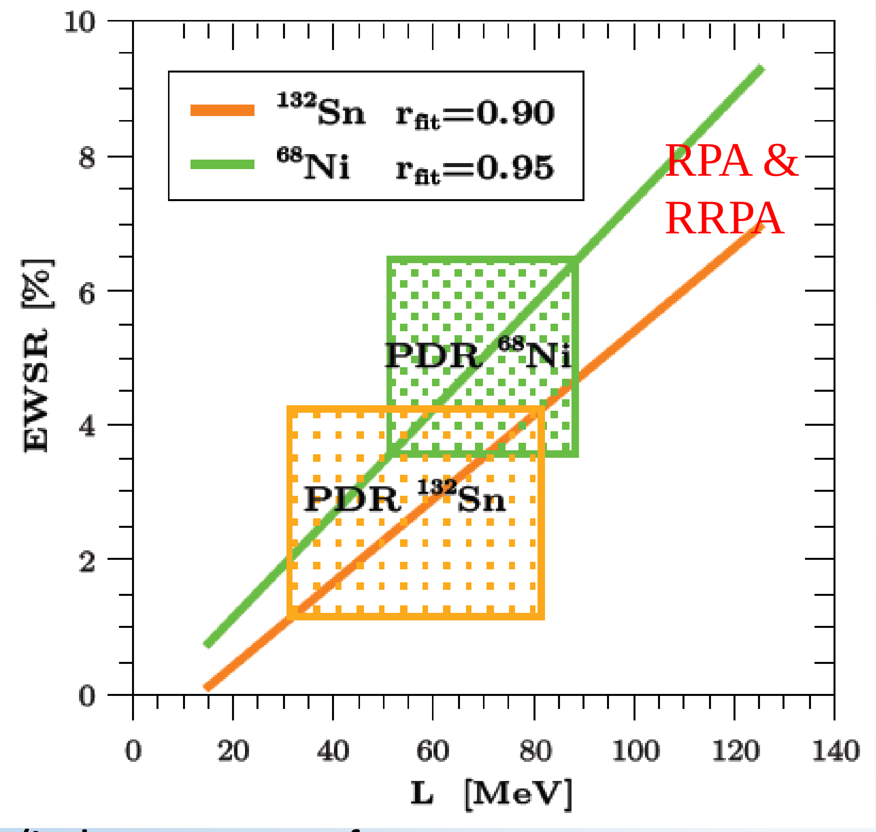
1,2,3,…..19 Skyrme forces 20,…26 RMF (meson exchange) Lagrangians

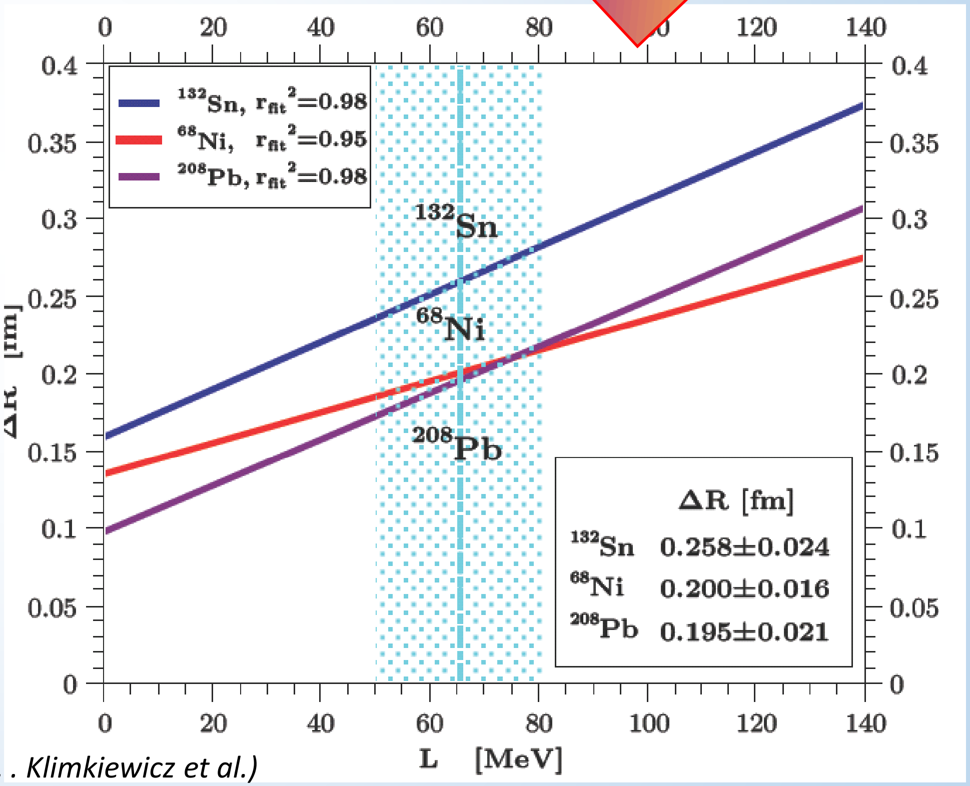
B.A. Brown, PRL 85, 5296 (2000);
S. Typel and B.A. Brown, PRC 64, 027302(R) (2001).
R.J. Furnstahl, NPA 706, 85 (2002);
S. Yoshida and H. Sagawa, PRC 69, 024318 (2004).

Exp. values from O. Wieland *et al.*, PRL 102, 092502 (2009);

A. Klimkiewicz *et al.*, PRC 76, 051603(R) (2007).

Correlations between L and ΔR (the neutron skin thickness) **have been noticed previously**.





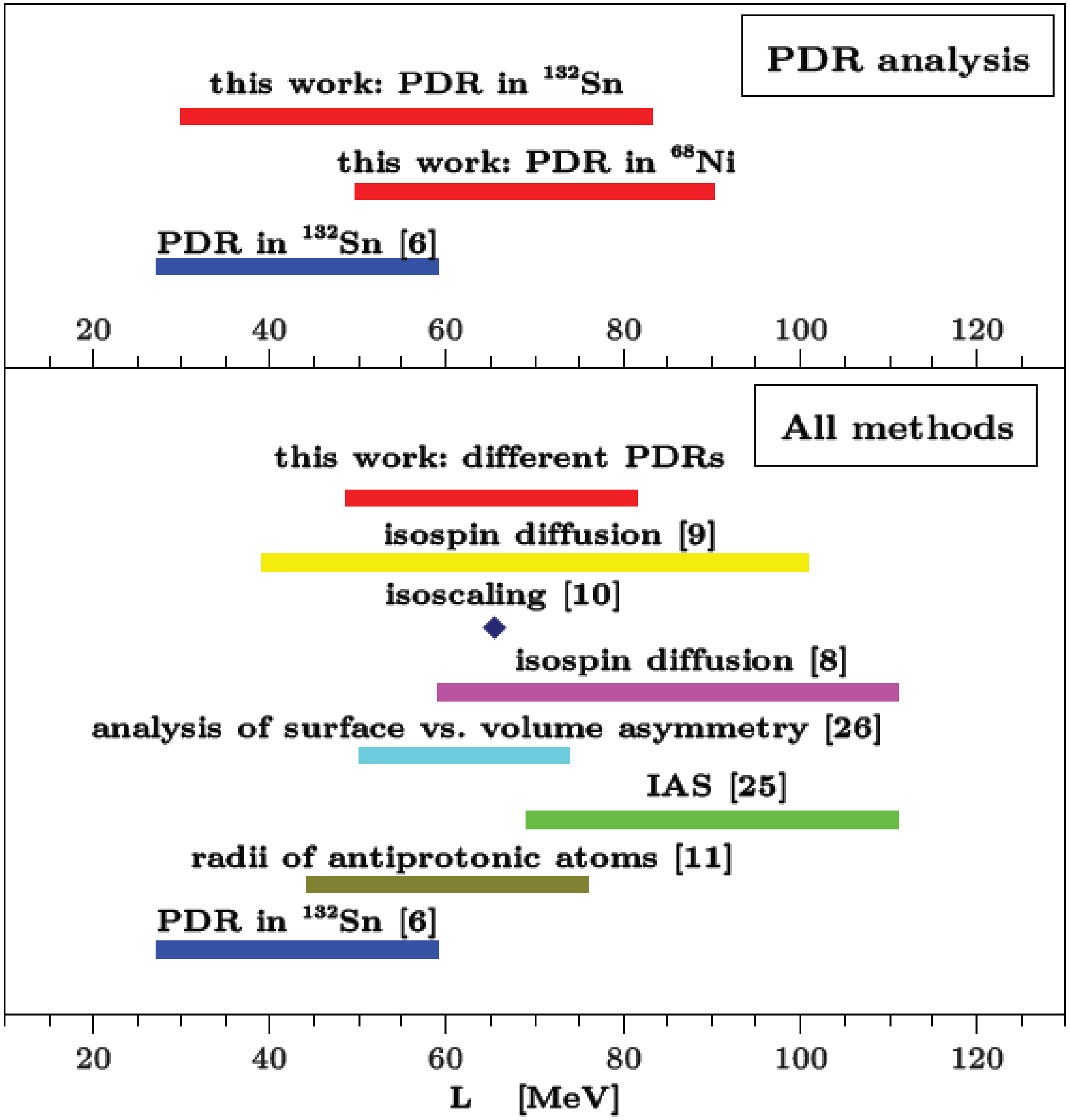
(L=slope parameter of symmetry energy at saturation)

The idea has been previously presented, and exploited in part (Furnstahl, . Klimkiewicz et al.)

However, here <u>for the first time the approach has been pursued with different nuclei</u> **<u>and many different classes of EDFs</u>**.

Carbone et al. Phys. Rev. C 81, 041301(R) (2010)

Comparison with other ways of constraining L



Possible approach of **extracting L** (derivative of symmetry energie) **from the PDR strenght**

→ Contraints on the symmetry energy in agreement with heavy ion fragmentation and with Anti-proton

BUT:

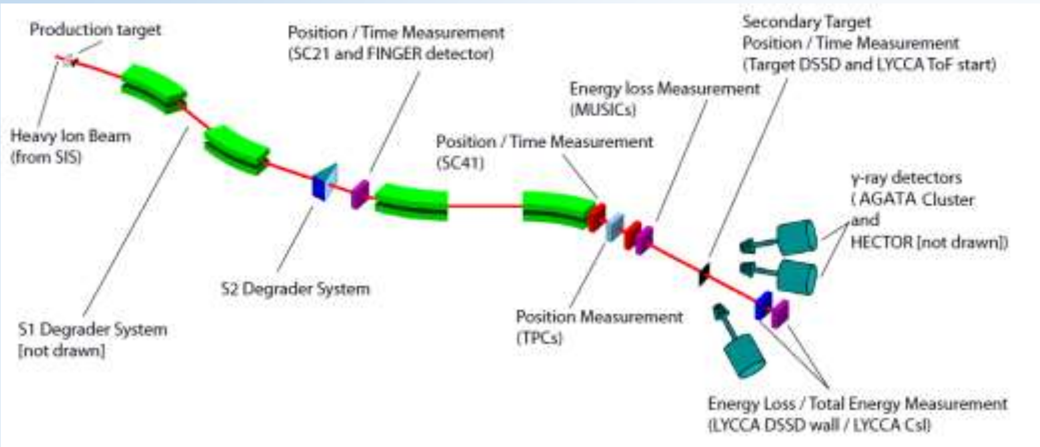
MUCH MORE DATA ARE NEEDED

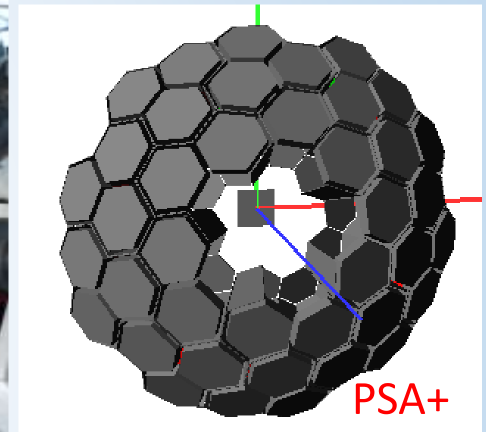
[THIS WORK] A. Carbone et al., Phys. Rev. C 81, 041301(R) (2010)
[9] M. B. Tsang et al., Phys. Rev. Lett. 102, 122701 (2009).
[10] D. V. Shetty et al., Phys. Rev. C76, 024606 (2007).
[8] L. W. Chen et al., Phys. Rev. Lett. 94, 032701 (2005).
[26] P. Danielewicz, Nucl. Phys. A727, 233 (2003).
[25] P. Danielewicz and J. Lee, Nucl. Phys. A818, 36 (2009).
[11] M. Centelles et al., Phys. Rev. Lett. 102, 122502 (2009);M. Warda et al., Phys. Rev. C80, 024316 (2009).
[6] A. Klimkiewicz et al., Phys. Rev. C76, 051603(R) (2007).

PDR in (64 and 62) Fe – Experiment at GSI

primary beam : ^{86}Kr @ 730 MeV/nucleon

Relativistic coulomb excitation: ^{64}Fe @ 400-440 MeV/u on ^{208}Pb and ^{197}Au target

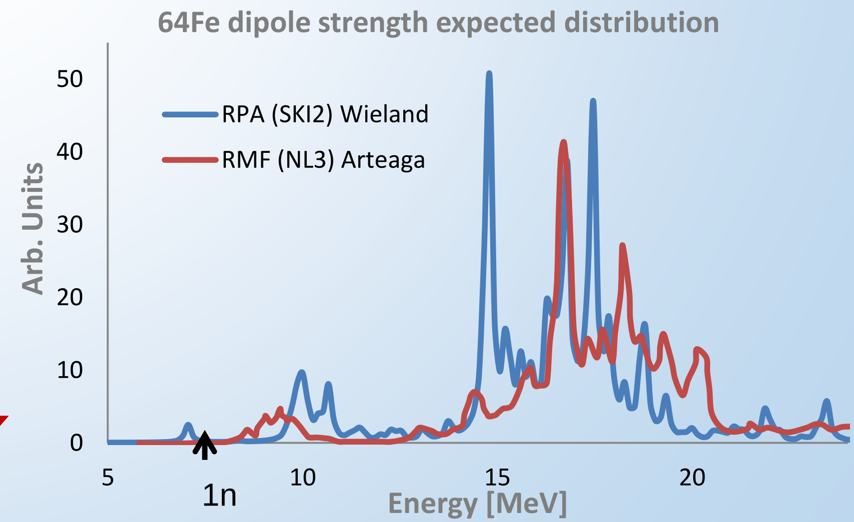




PDR gamma decay : expected gammas at ~10 MeV in CM frame (low multiplicity)

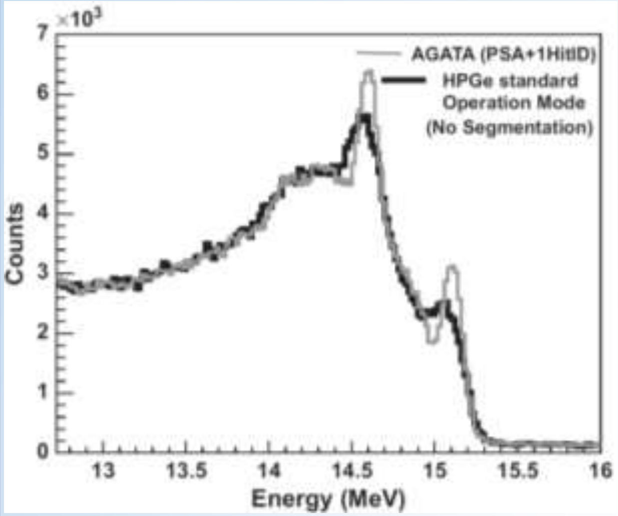
Expected Energies in Lab frame of PDR
~ 20 MeV

Gamma detector arrays:
AGATA [forward angles]
HECTOR+ [10$LaBr_3$:Ce + 8BaF_2 at different angles]



Experiments suffered from severe CUT in beam Time assignement, low primary beam intensity and difficult settings in SIS FRS

AGATA PreSPEC setup – gamma detection <u>TESTs prior to measurement</u>



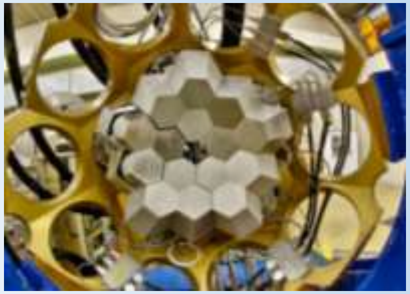
F.C.L. Crespi et al. NIMA 705(2013)47-54

AGATA

→Rivelatori HPGe di grandi dimensioni segmentati elettronicamente

→Algoritmi di Pulse Shape per ricostruire la posizione dell'interazione

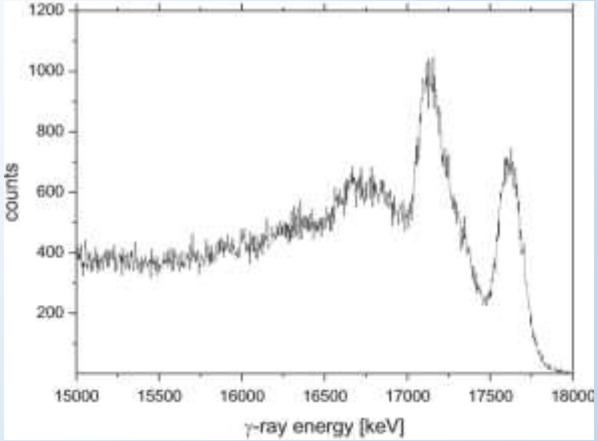
→Algoritmi di tracciamento dei raggi gamma per sopprimere il background



HECTOR+

Rivelatori BaF_2 e $LaBr_3$:Ce di grandi dimensioni di alta efficienza

Buona risoluzione energetica e ottima risoluzione temporale



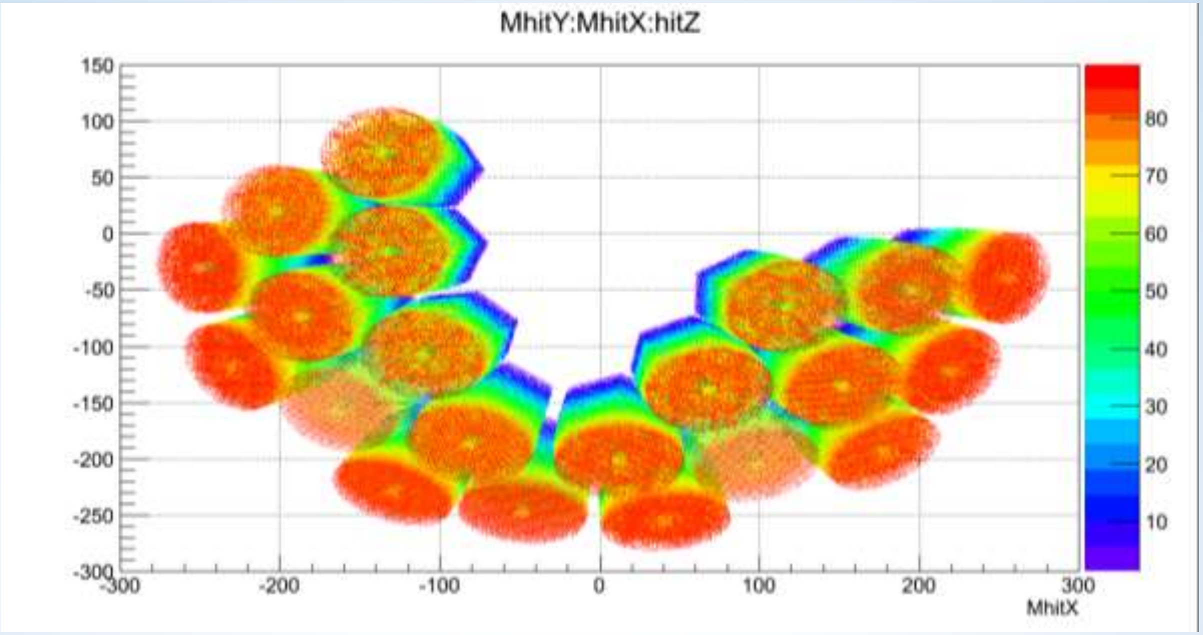
A.Giaz et al. NIMA 729(2013)910-921

Nuclear Spectroscopy with **AGATA**

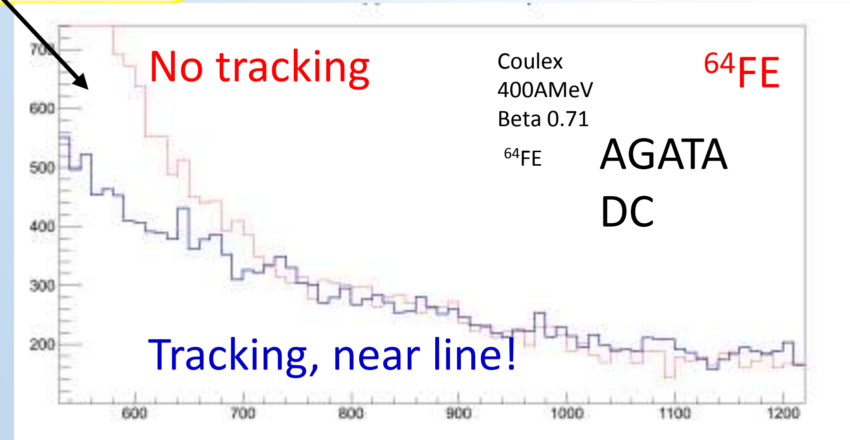
with relativistic coulomb excitation of ^{64}Fe up to 430 AMeV v/c=0.73 !

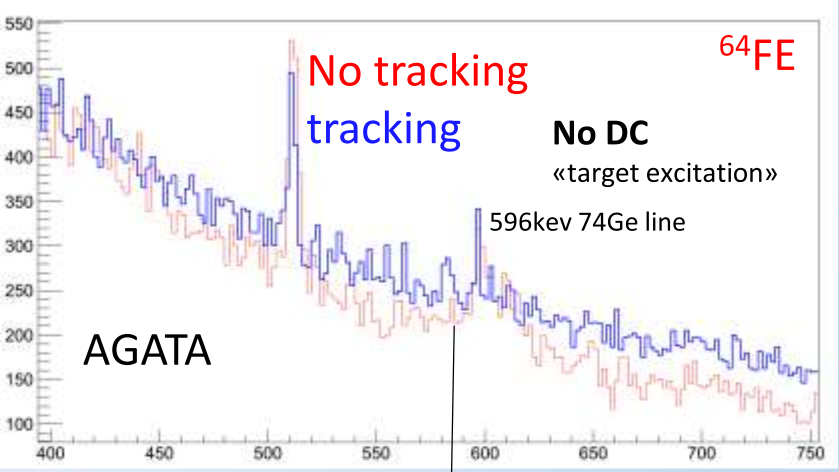
Messhütte

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



DC spectra: Tracking cleans background!

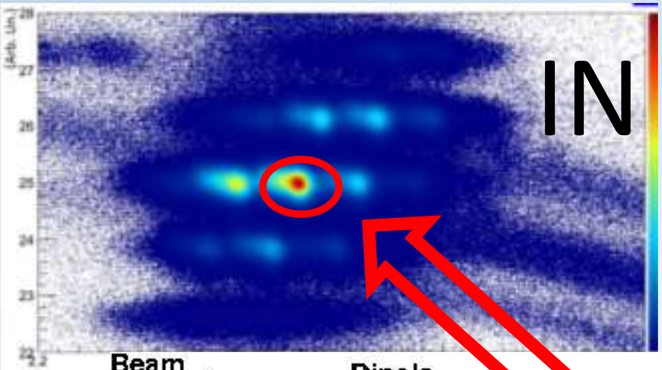


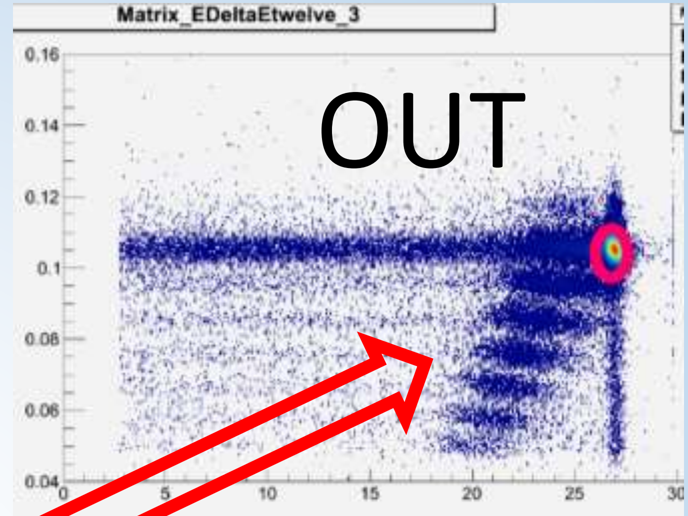


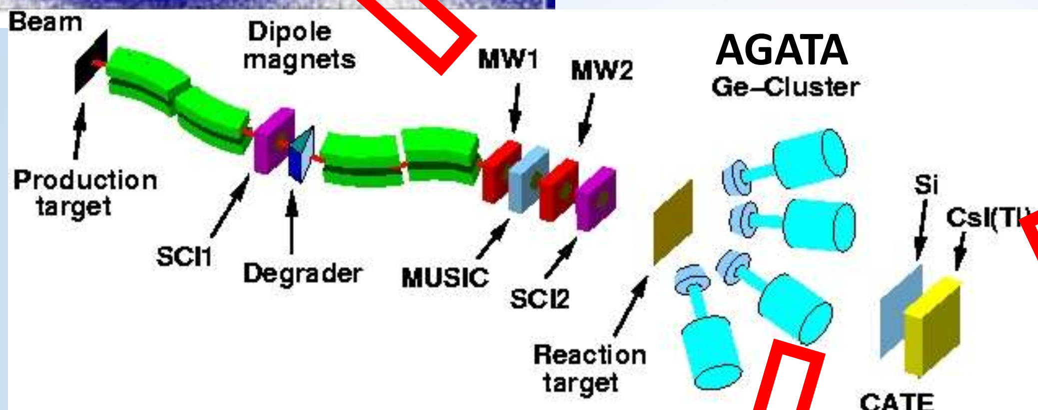
583KeV ^{208}Pb 5- → 3-

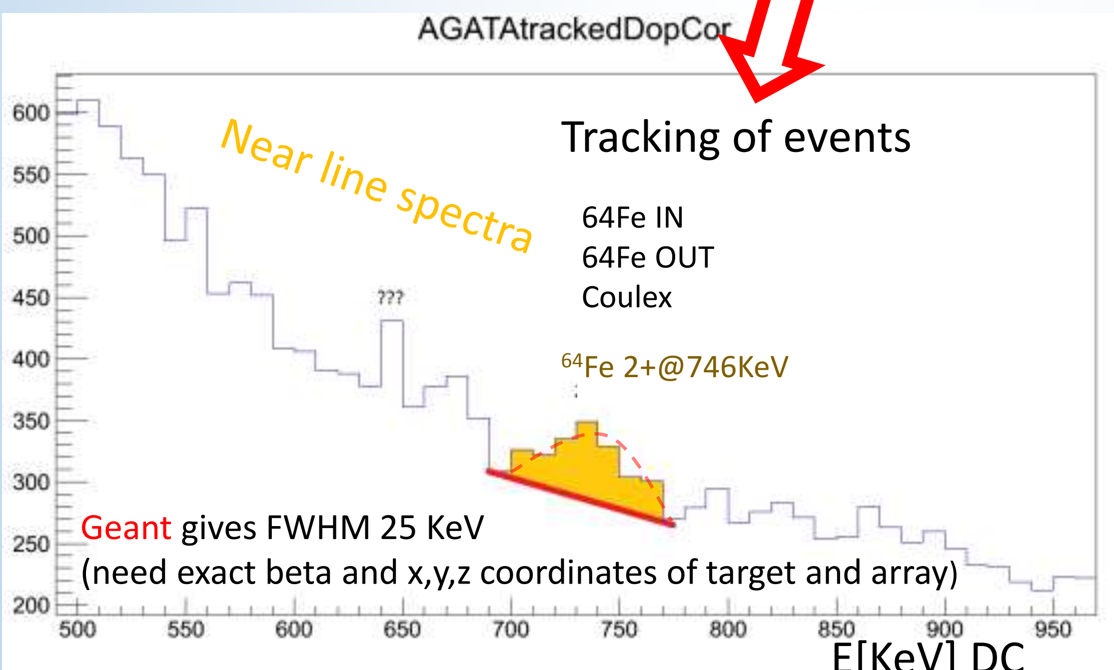
R. Avigo

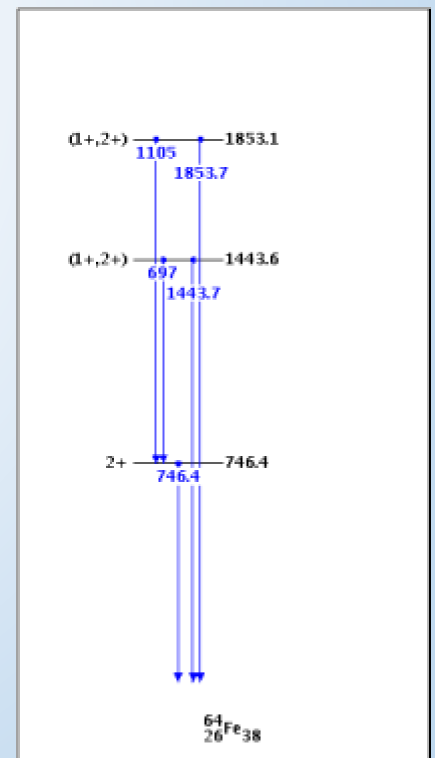
Coulex of ^{64}Fe @400AMeV





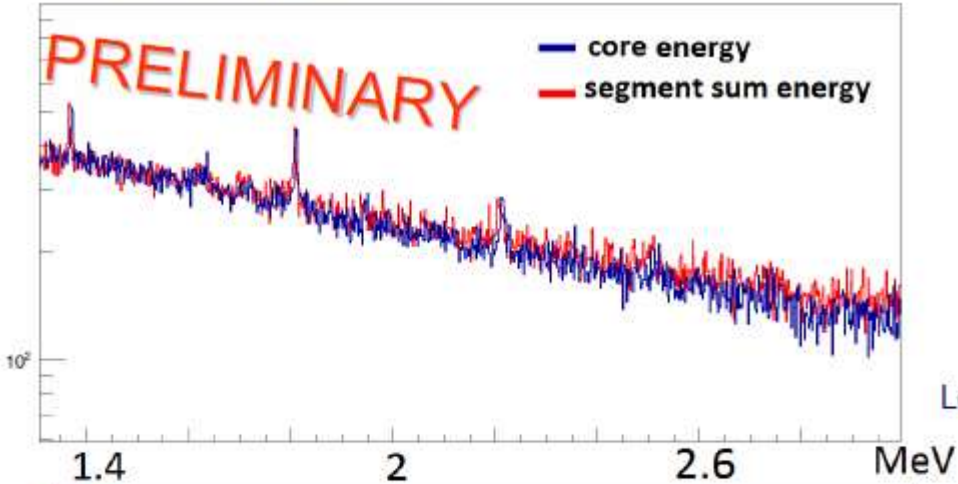




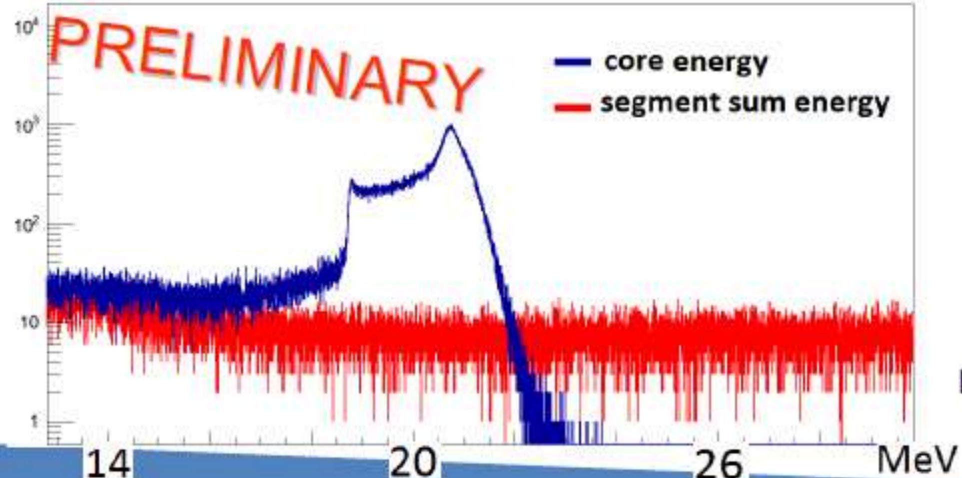


2012 High Energy AGATA data (replay)

2012 runs with long range segments (16 MeV) show that summing energy segments allows to overcome the core saturation energy. Events at so high energies are a good test for MGT libraries and for other possible algorithm used for tracking gammas



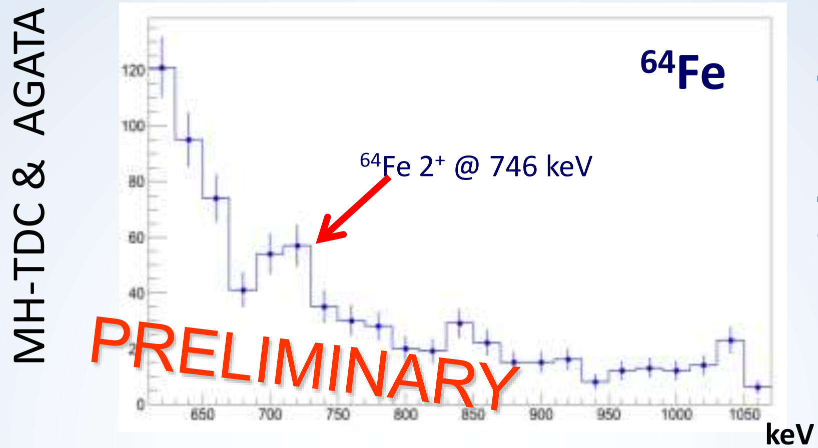
Low Energy spectrum comparison



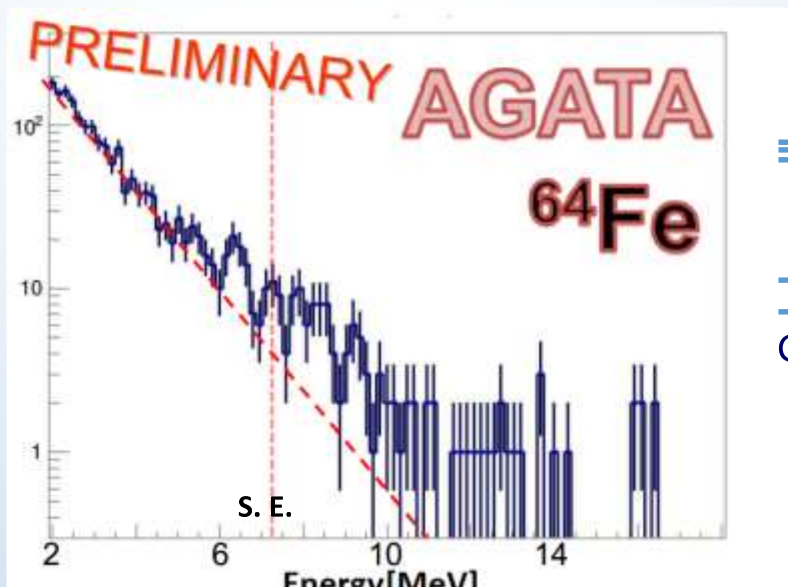
High Energy spectrum comparison

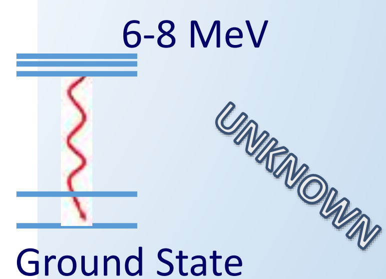
Spettri preliminari ^{64}Fe

Lo spettro gamma a bassa energia ottenuto con AGATA mostra un accumulo in corrispondenza dell'energia del livello 2^+ che conferma che si stanno osservando le reazioni sul nucleo di interesse



R. Avigo

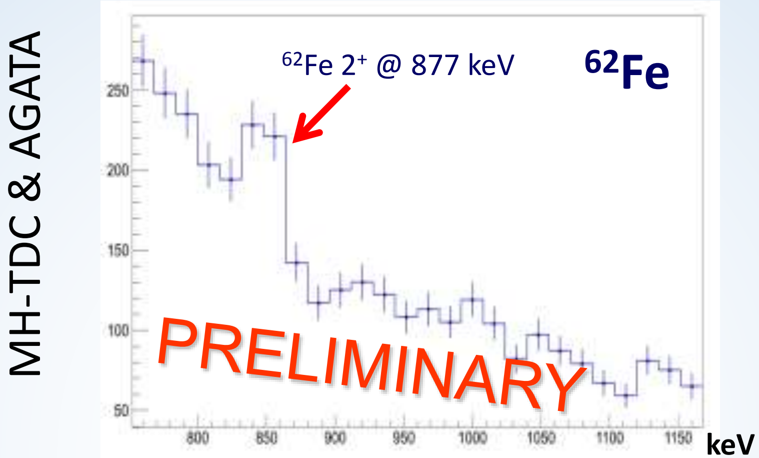




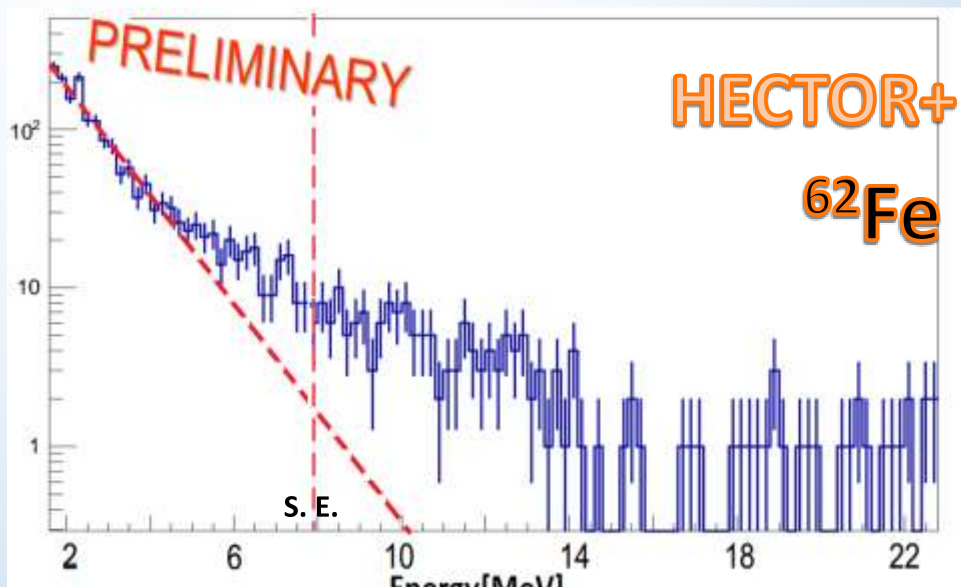
R. Avigo

Spettri preliminari ^{62}Fe

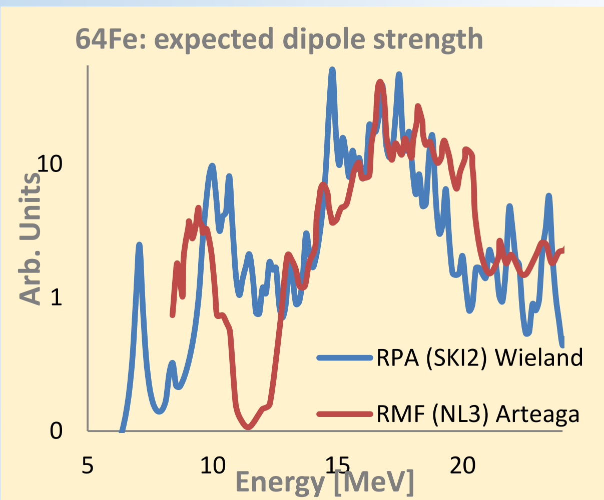
Lo spettro gamma a bassa energia ottenuto con AGATA mostra un accumulo in corrispondenza dell'energia del livello 2⁺ che conferma che si stanno osservando le reazioni sul nucleo di interesse



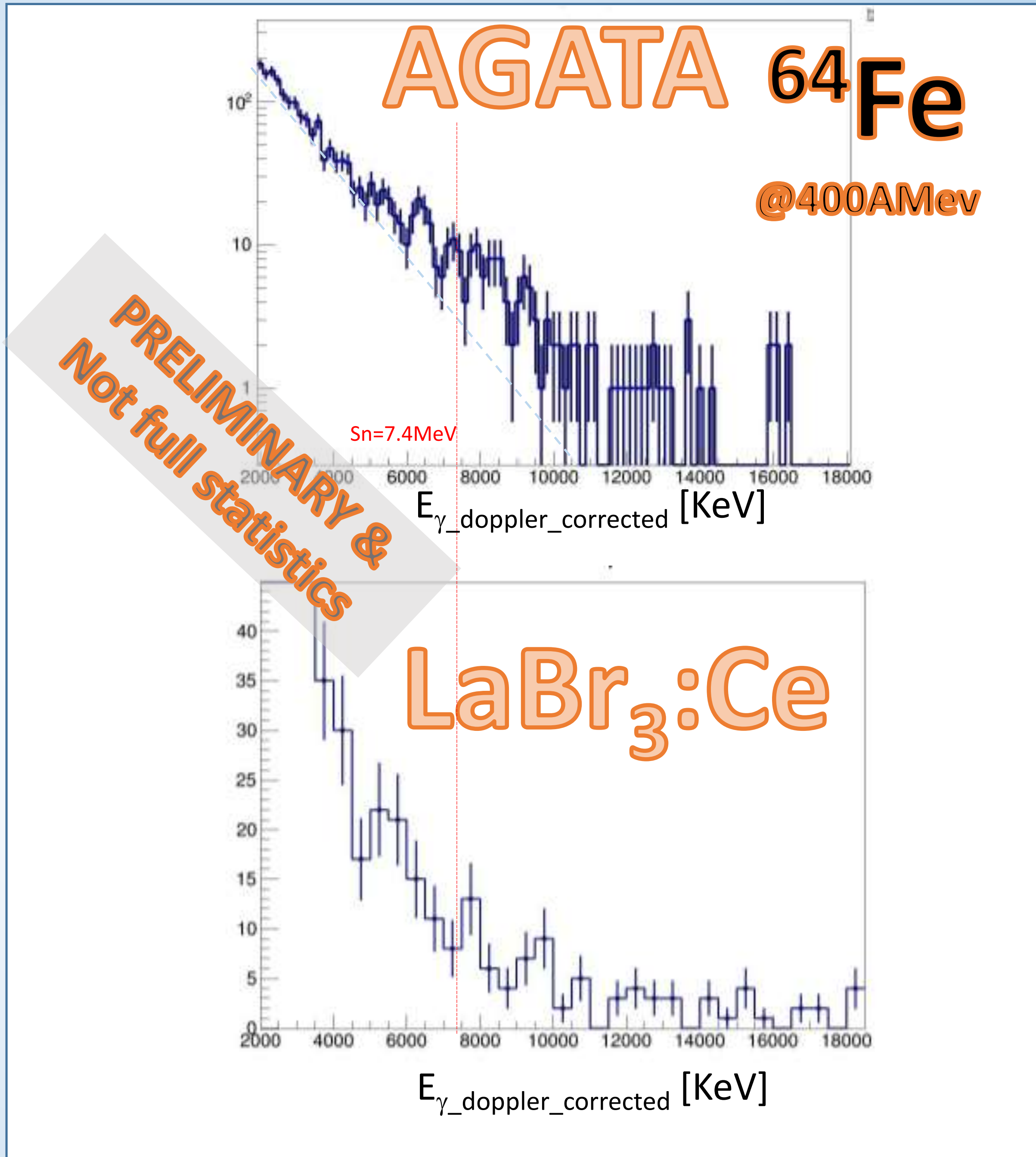
R. Avigo

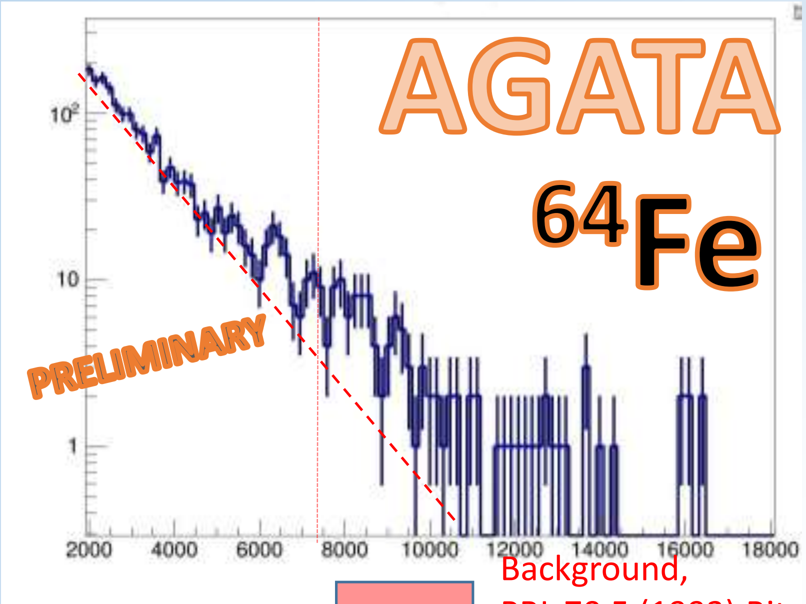


R. Avigo

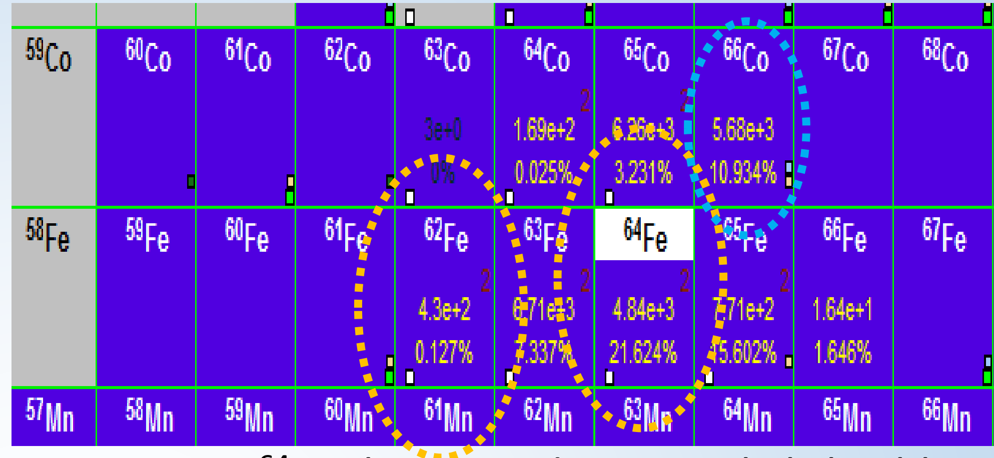

64Fe: expected dipole strength
Arb. Units
10
1
0
5
10
15
20
Energy [MeV]
RPA (SKI2) Wieland
RMF (NL3) Arteaga

LL-E1 PDR GDR

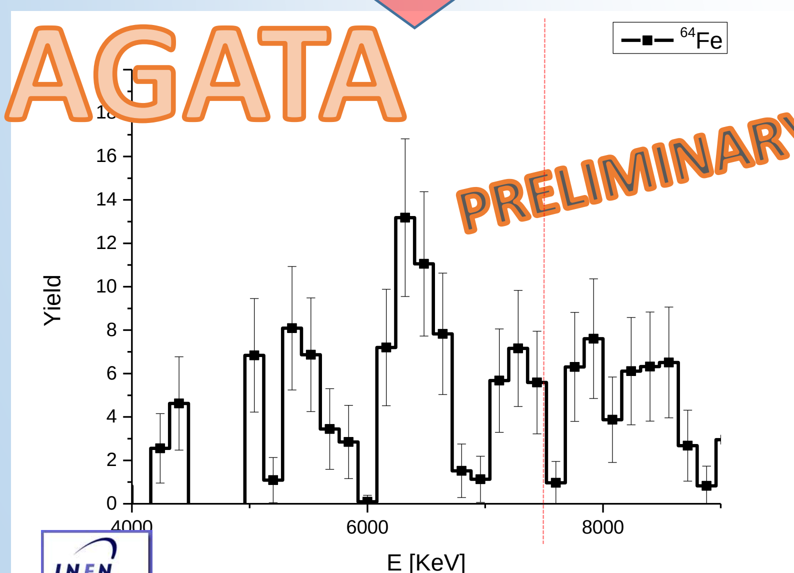

AGATA
^{64}Fe
@400AMev
PRELIMINARY &
Not full statistics
Sn=7.4MeV
10²
10
1
2000
4000
6000
8000
10000
12000
14000
16000
18000
$E_{\gamma\_doppler\_corrected}$ [KeV]
LaBr$_3$:Ce
40
35
30
25
20
15
10
5
0
$E_{\gamma\_doppler\_corrected}$ [KeV]



Background,
PRL 70,5 (1993) Ritman et al



In ^{64}Fe the ground state is slightly oblate,
With beta2=-0.05



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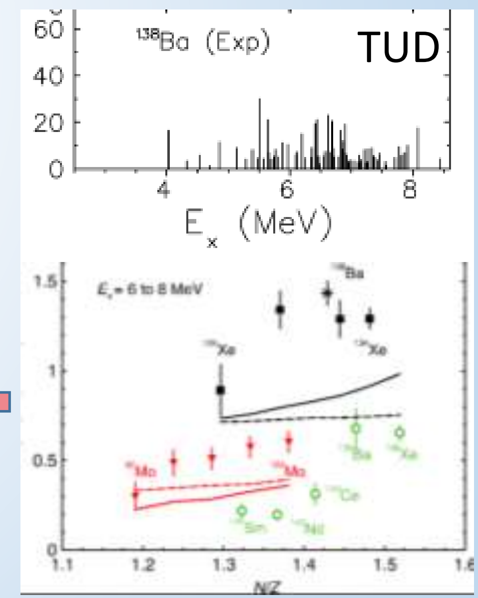
What is the nature of these Peaks ??

All E1 ?
B(E1) ok



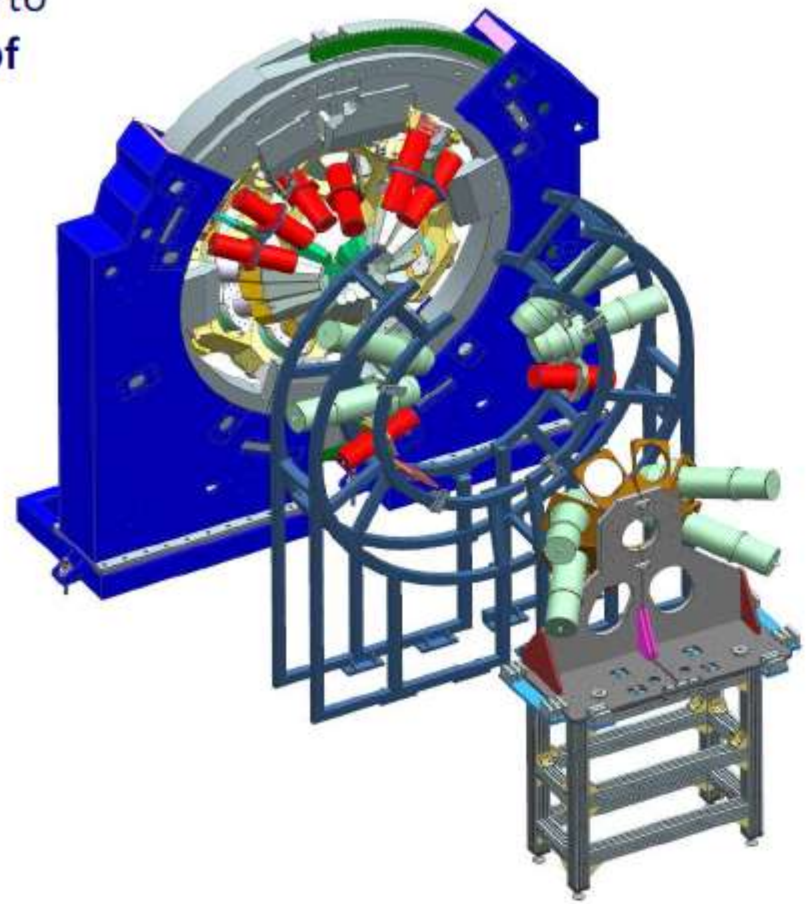
R. Massarczyk et al. PRL 112, 072501 (2014)

Multipolar character of strength

Dweiko calculations can be exploited to obtain E1 and E2 angular distribution

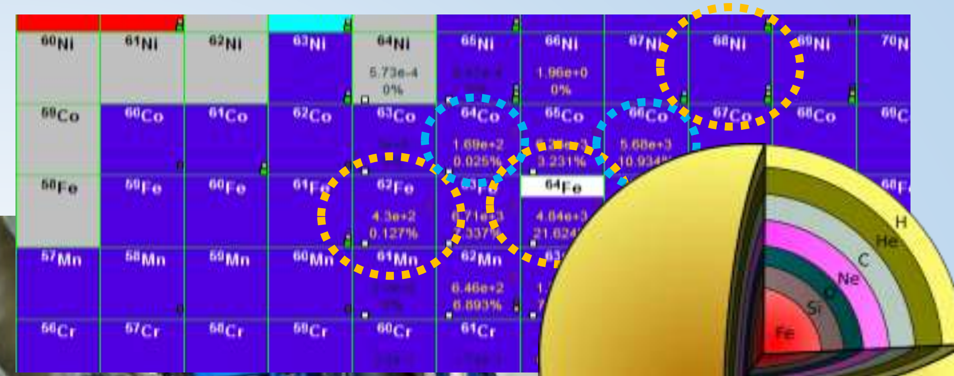
HECTOR+ array coupled with **AGATA** allow to have angular distribution in a **wide range of angles**

	2012 setup		2014 setup	
	$LaBr_3$	BaF	$LaBr_3$	BaF
22.5 °	--	--	2	--
68°	4	--	4	--
95°	4	4	2	4
142°	2	4	--	4



RESUME:

E1 Strength Distribution in n-rich ^{68}Ni and ^{62,64}Fe



VERY PRELIMINARY

Possible

E1 strength found around

Threshold in neutron rich

^{62}Fe and ^{64}Fe !

First time ever below

threshold for exotic

nucleus !

Analysis will go on to find

Pygmy and determine

n-skin also

and future measurements ? →→→→→→→→

Whats next ?

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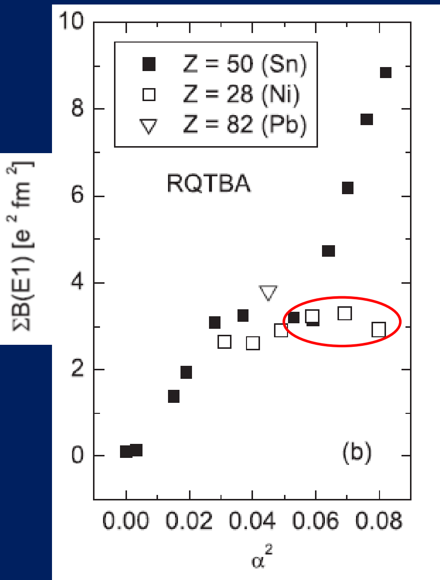
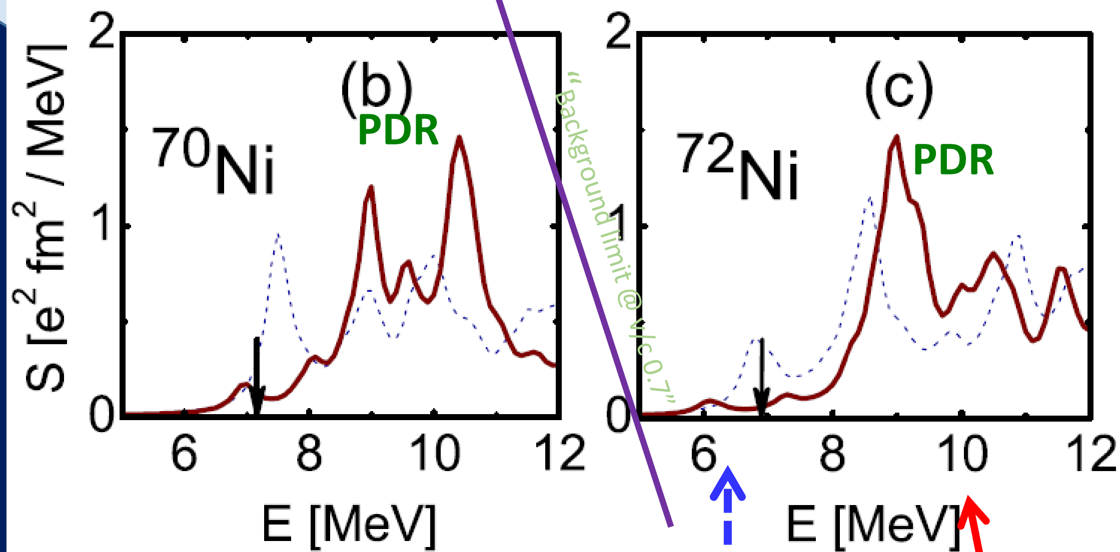
Theoretical Predictions



E.Litvinova et al, PRC **79, 054312 (2009)**



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."

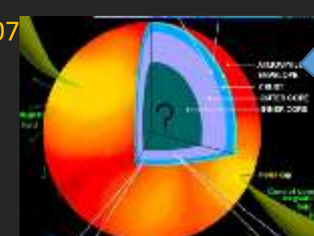
PHOTON SCATTERING

POSSIBLE NOW only AT RIKEN

+possibly (Lower states 1-,2+,.
(large scale) Shell model
Calculations to be done
(in ^{68}Ni K. Langanke,)

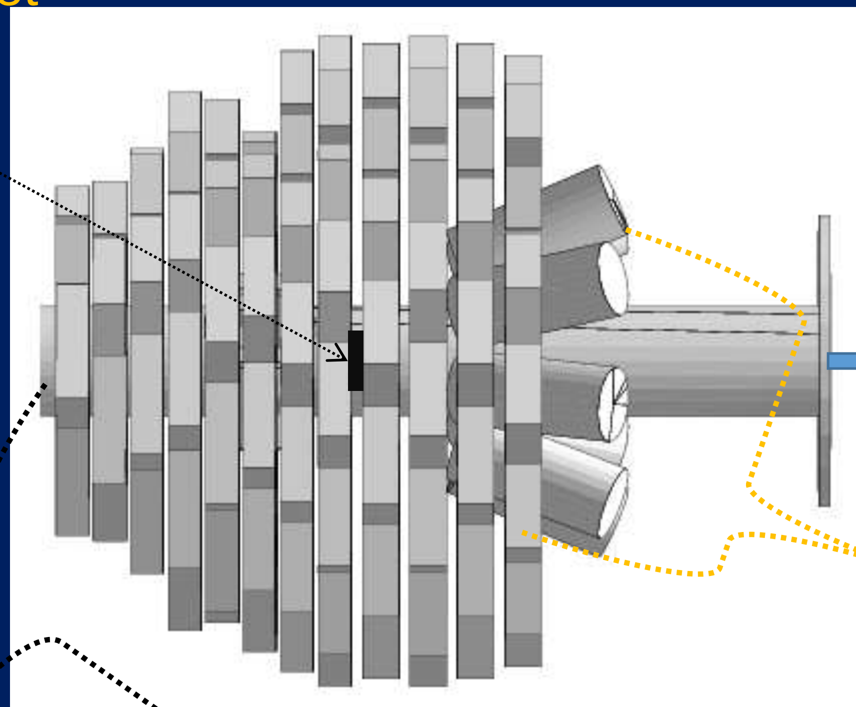
	B.E.(MeV)	r_c (fm)	r_n-r_p(fm)
^{16}O	-128.112(-127.619)	2.735(2.730)	-0.15
^{40}Ca	-341.578(-342.052)	3.470(3.485)	-0.14
^{48}Ca	-413.615(-415.990)	3.470(3.484)	0.14
^{72}Ni	-612.168(-613.152)	3.892	0.26

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



2014: RIKEN/RIBF → Approved Proposal with Experimental Setup for γ-ray detection with DALI2+

Liquid He, Au,.. Target



$^{70,72,7X}Ni$

$^{124,132}Sn$

$^{16,22,..}O$

ZDS,

***SAMURAI**

Hector$^+$

$LaBr_3:Ce$

(ε_{Fep}=2%)

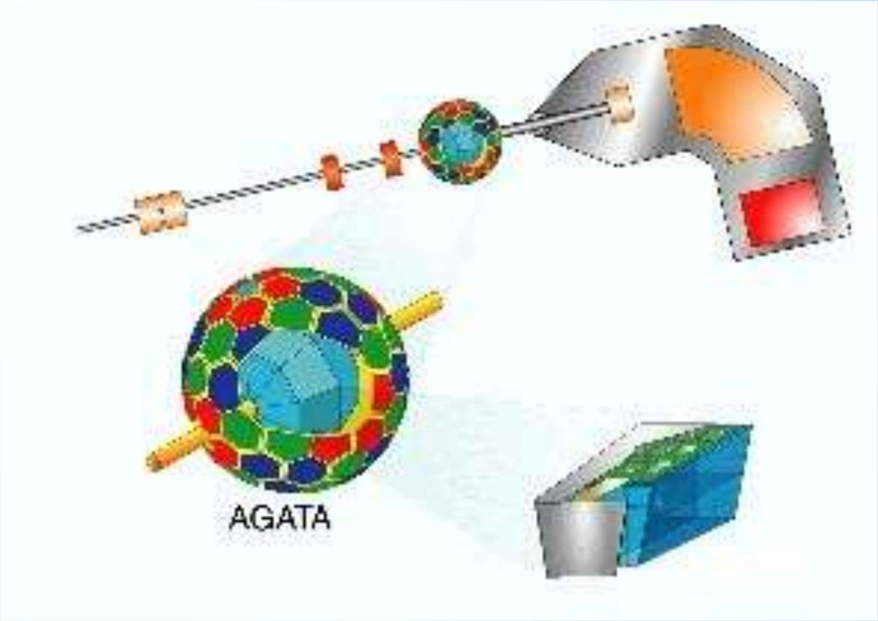
DALI 2

NaI (ε_{Fep}=4% @ E_γ=10MeV, m_γ=1)

To go further in the PDR, E1,GDR search:

(especially for r-process nuclei, which are of paramount interest for determining γ,n equilibrium in solar processes) **we need →**

AGATA / SPEC **@&** FAIR



+R3B ?

PRESPEC et al : Thanks to A Great Collaboration

PRESPEC et al : Thanks to A Great Collaboration

Thanks to:

Collaboration:

- *O. Wieland, R. Avigo, A. Bracco, F. Camera, S. Ceruti, G. Benzoni, N. Blasi, S. Brambilla, F.C.L. Crespi, S. Leoni, B. Million, A. Morales, L. Pellegri, A. Giaz et al., Dip. di Fisica and INFN, Sezione di Milano, Italy*
- *A. Maj, M. Kmiecik, P. Bednarczyk, et al., The Niewodniczanski Institute of Nuclear Physics, PAN, Krakow, Poland*
- *G. de Angelis, D.R. Napoli, et al., INFN, Laboratori Nazionali di Legnaro, Italy*
- *D. Bazzacco, E. Farnea, S.M. Lenzi, S. Lunardi, et al., Dip. di Fisica and INFN, Sezione di Padova, Italy*
- *J. Gerl, M. Gorska, H.J. Wollersheim, T. Aumann, P. Boutachkov, M. Reese, D. Ralet et al., GSI, Darmstadt, Germany*

- ***et al. …***

HECTOR^{+}

- *and the AGATA-PRESPEC and FRS collaboration.*

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