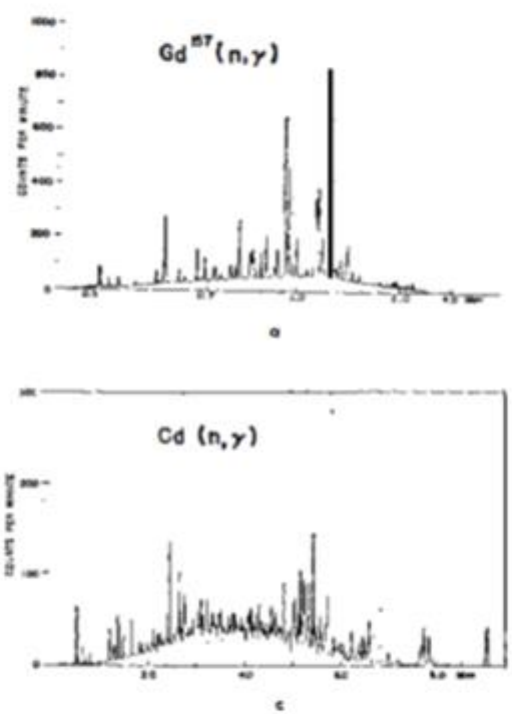
Dipole excitations in open shell nuclides near the neutron threshold from (γ, γ’) experiments : The case of Ge isotopes

Nadia Benouaret
University of Sciences and Technology (USTHB), Algiers (ALGERIA)

Plan

- Introduction: what is known?
- ^{70}Ge dipole response measurements by photon scattering experiments
- Analysis
- Results

Introduction: Pygmy Dipole Resonance Strength



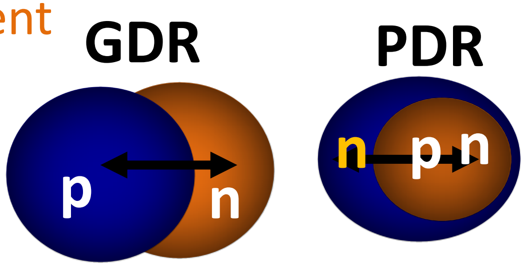
Neutron capture gamma rays

G. A, Bartholomew, Ann. Rev. Nucl. Sci. ***11*** *(1961) 259*

Three-fluid hydrodynamical model :
(*R. Mohan et al, Phys. Rev. C* ***3*** *(1971) 1740)*

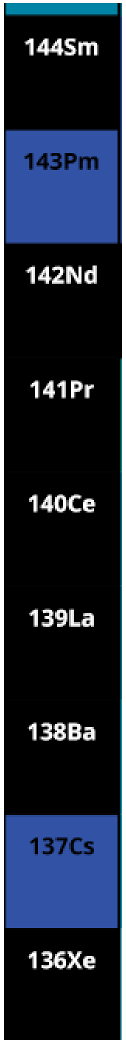
protons, neutrons of the same orbitals
and the loosely bound **neutron excess (N - Z)**

Two independent Electric Dipole modes

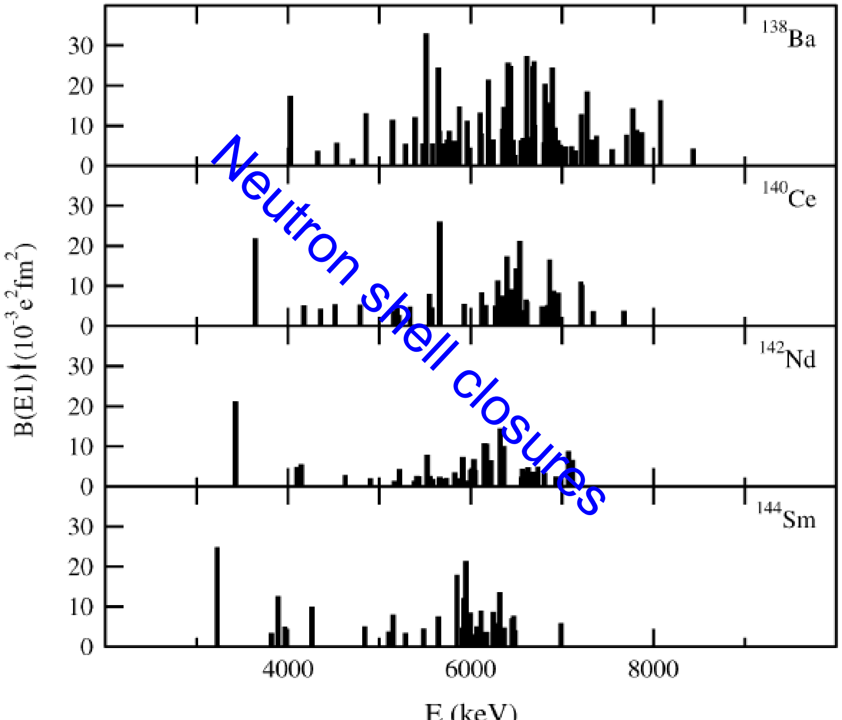


Pygmy Dipole Resonance Strength

Photon scattering experiments **(γ, γ') :** **Nuclear Resonance fluoresence (NRF)**
(DHIPS-Darmstadt, γELBE-Dresden) + HIGγ (Duke Univ,)

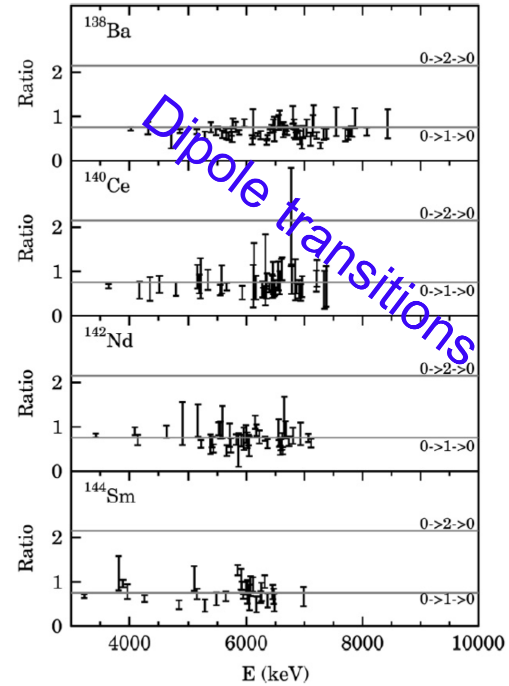


N=82

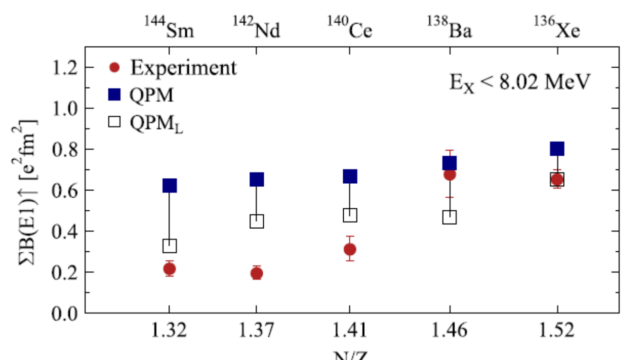


Concentration of dipole strengths below the neutron threshold energy

S. Volz et al. Nucl. Phys. A 779 (2006) 1



Parity measurements:
predominantly E1 transitions
A.P. Tonchev *et al*.,
Phys. Rev. Lett. **104**, 072501 (2010).

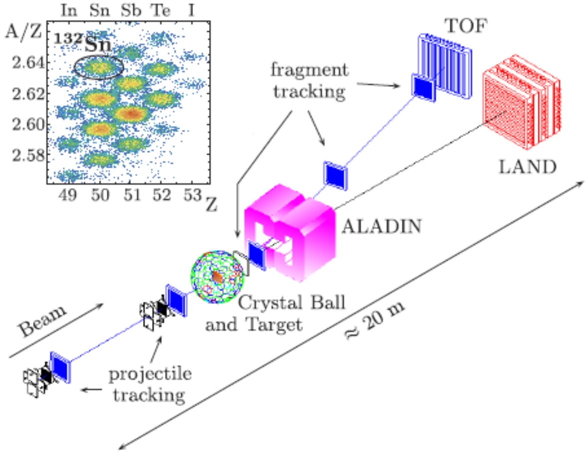


D. Savran et al.,
Progress in Particle and Nuclear Physics 70 (2013) 210

Pygmy Dipole Resonance Strength

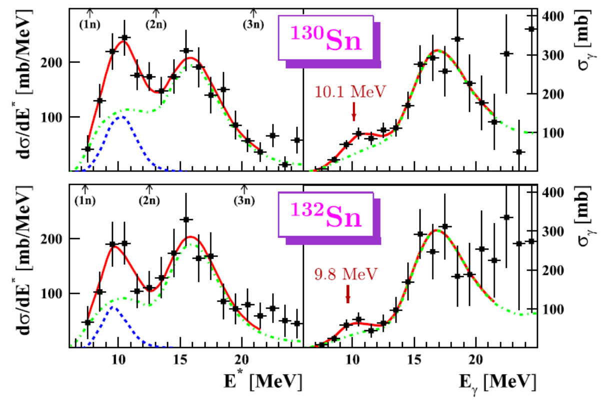
Z=50

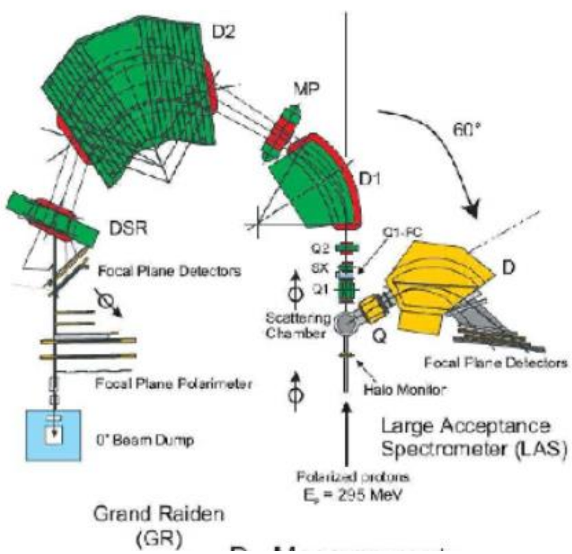
N=82



LAND-FRS facility at GSI, Darmstadt

Neutron-rich unstable nuclides

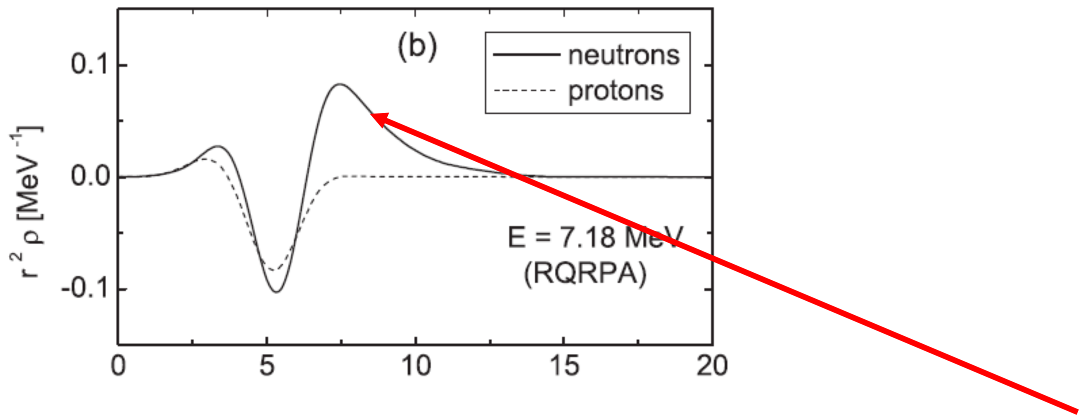




The corresponding photo-absorption cross section exhausts about 10% of the GDR in neutron-rich unstable nuclides and up to 1% in stable nuclides.

Grand Raiden facility at RCNP, Osaka (Japan

Pygmy Dipole Resonance Strength



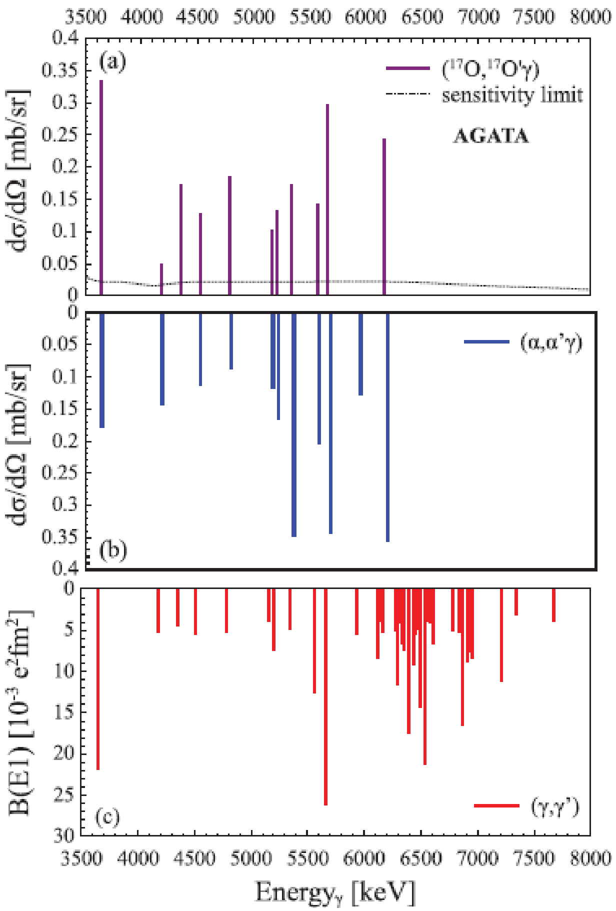
Many modern theoretical models (QRPA, QPM…..:) neutron skin

PDR investigation provide the **Neutron skin thickness** $\delta R_{n,p}$:
linked to symmetry energy parameters (L,J) of the equation state of the neutron-rich matter.
related to the Polarisability α_D which can be extracted by integration of the PDR strength.

Exhausting a considerable fraction (up to 10%) of the total E1 strength in nuclei, The PDR gamma-ray strength may strongly enhance the radiative neutron capture rates in the r- and p-process responsable for the **nucleosynthesis of heavy elements.**

- The properties of the PDR are a good test for modern nuclear structure models.

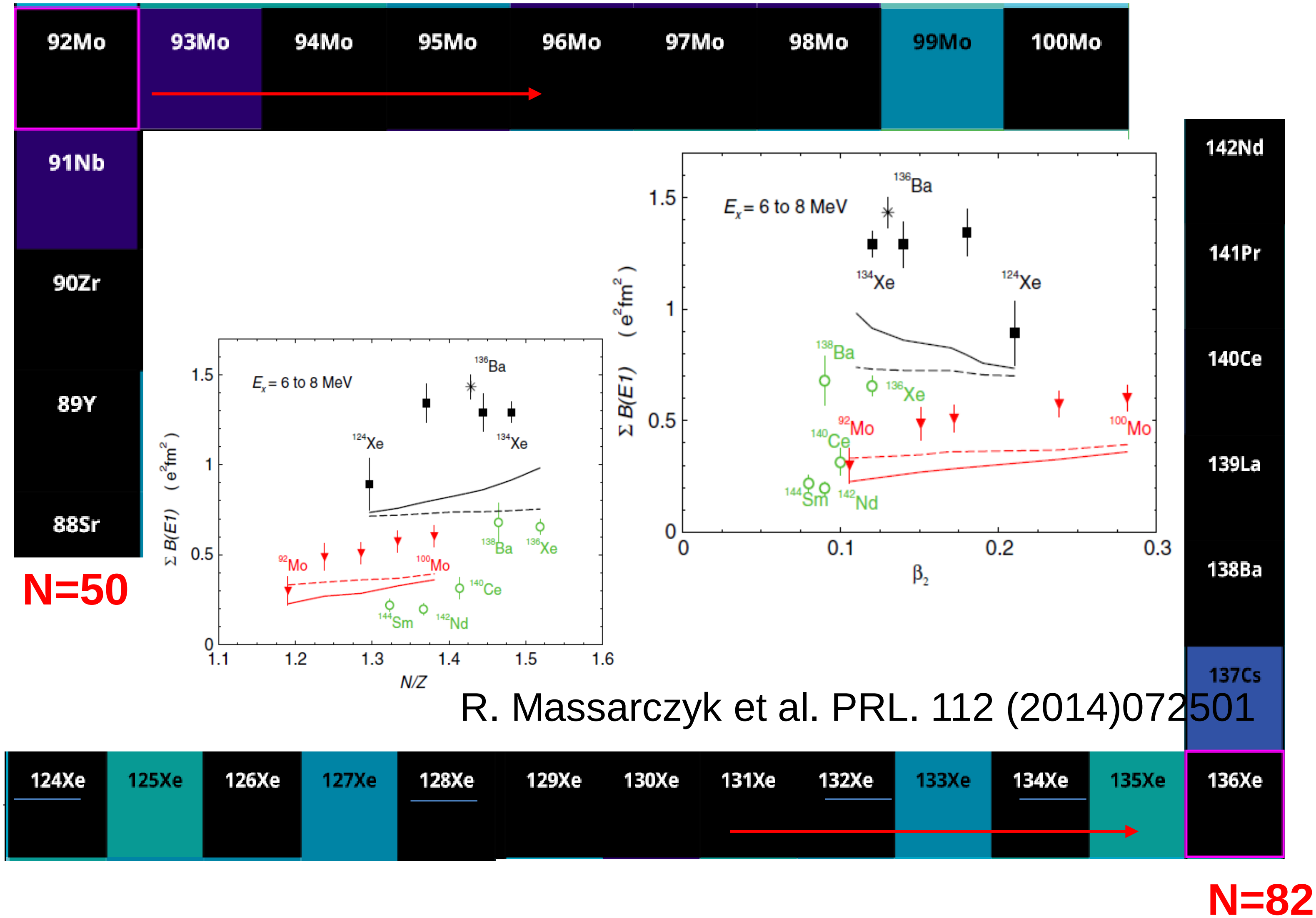
Pygmy Dipole Resonance Strength



PDR strength splits into 02 parts:
*one lower part of isoscalar character (T=0) and can be excited by both photon and hadron probes,
*a higher part of isovector character (T=1) observed only in photon scattering.

Pygmy Dipole Resonance Strength

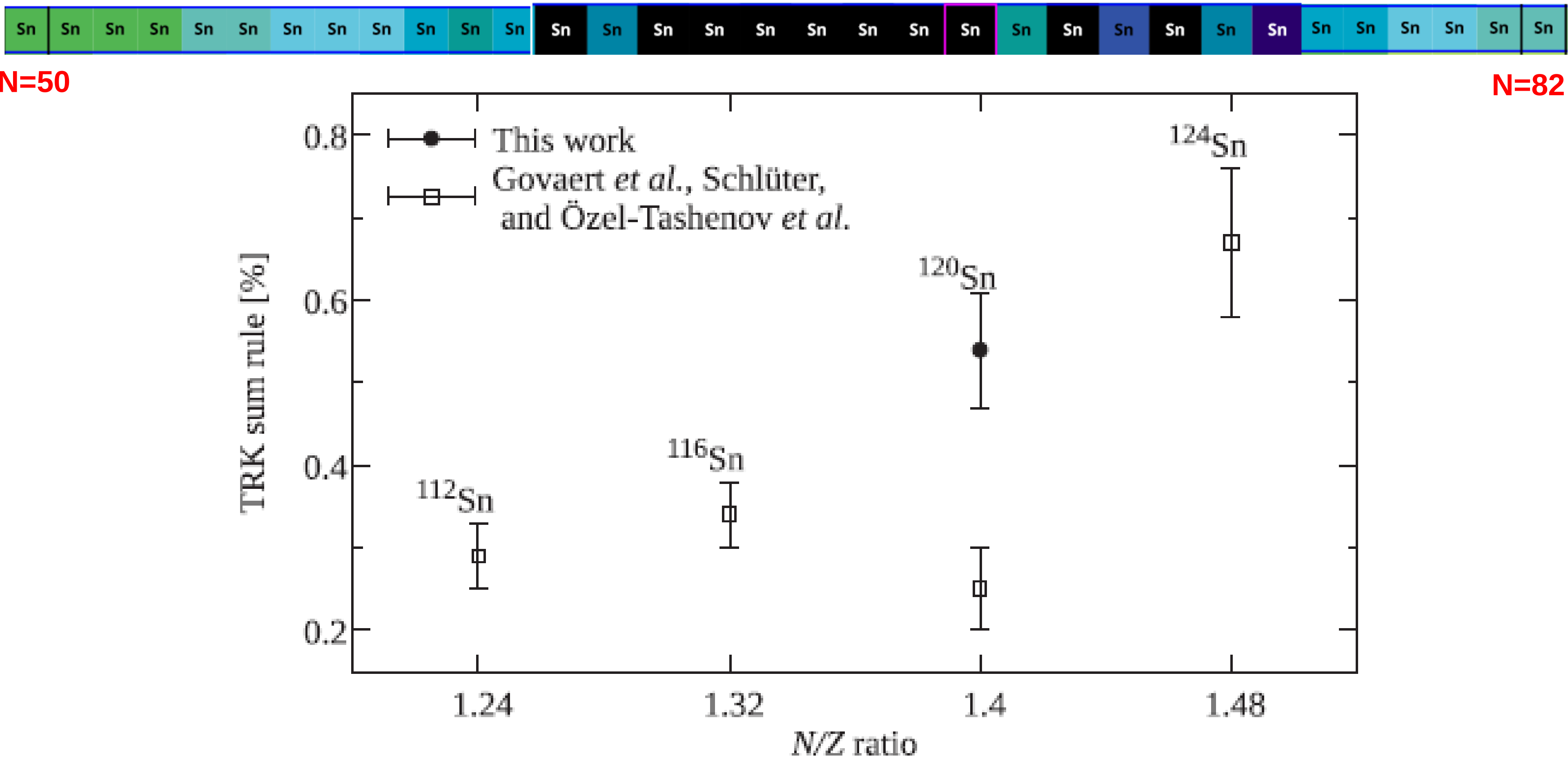
isotonic and isotopic chains



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

Deformation Minor effect, Neutron excess (neutron skin thickness) principle role

Chain far away beyond the neutron shell-closure



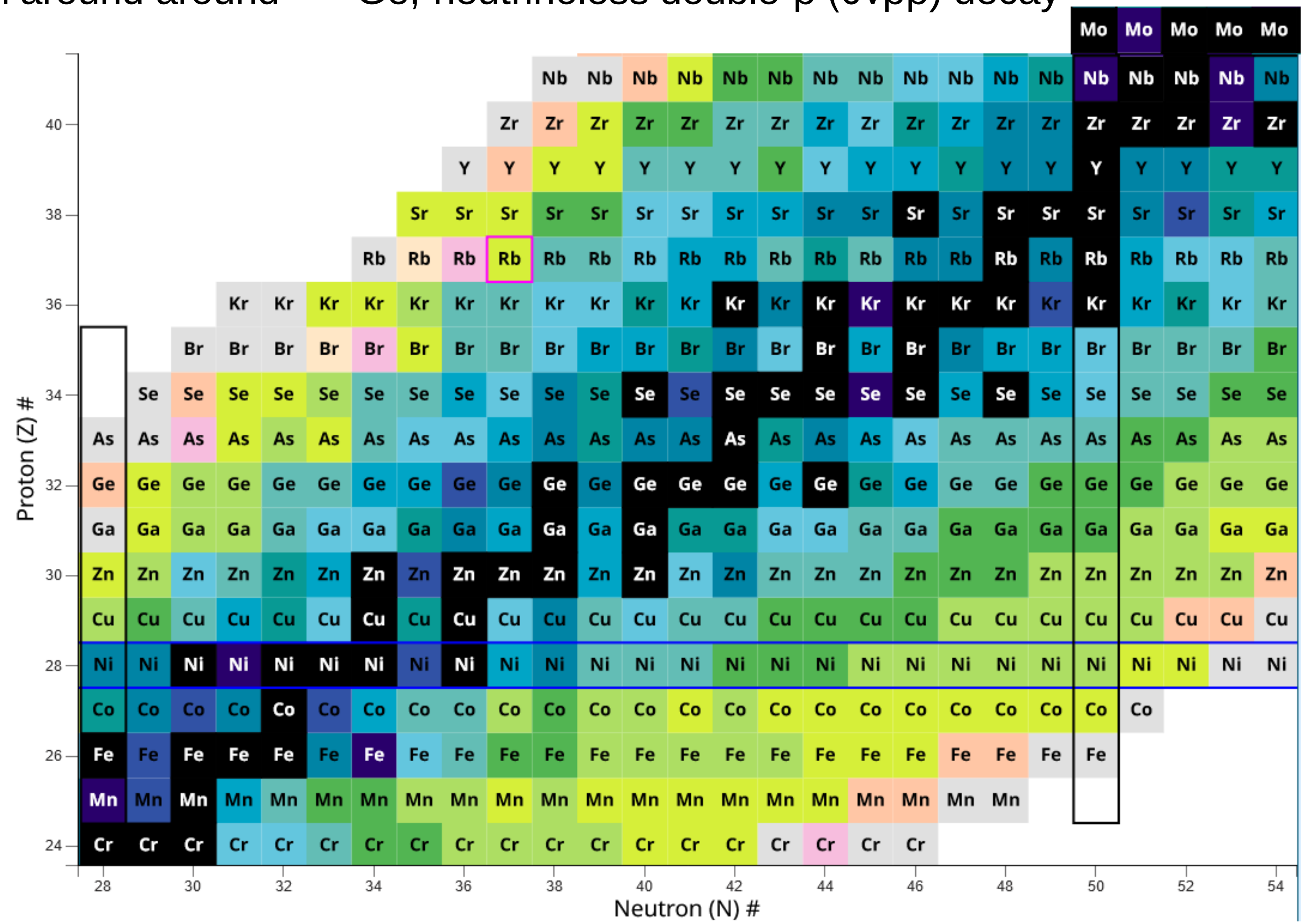
$\beta = 0.123$ $\beta = 0.09$

Neutron excess effect

M. Müscher et al, PRC 102; 014317(2020)

Germanium chain (Z=32) **pfg shell**

The low-lying states are characterized by a rich nuclear structure phenomena represented by a rapid shape evolution from one nucleus to another (structure variation); Shape coexistence and triaxial deformation around around ^{76,78}Ge, neutrinoless double-β (0νββ) decay

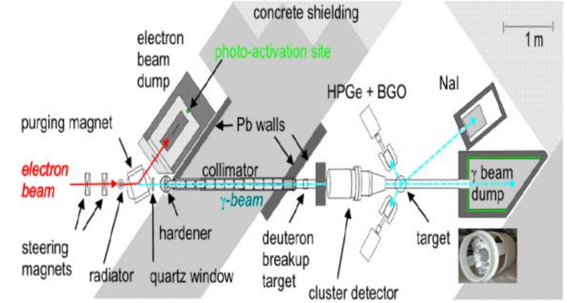


^{74}Ge N= 42: R. Massarczyk et al. , PRC **92**, 044309 (2015)

^{76}Ge N=44: R. Schwengner et al., C **105**, 024303 (2022)

^{70}Ge N=38: Present measurements

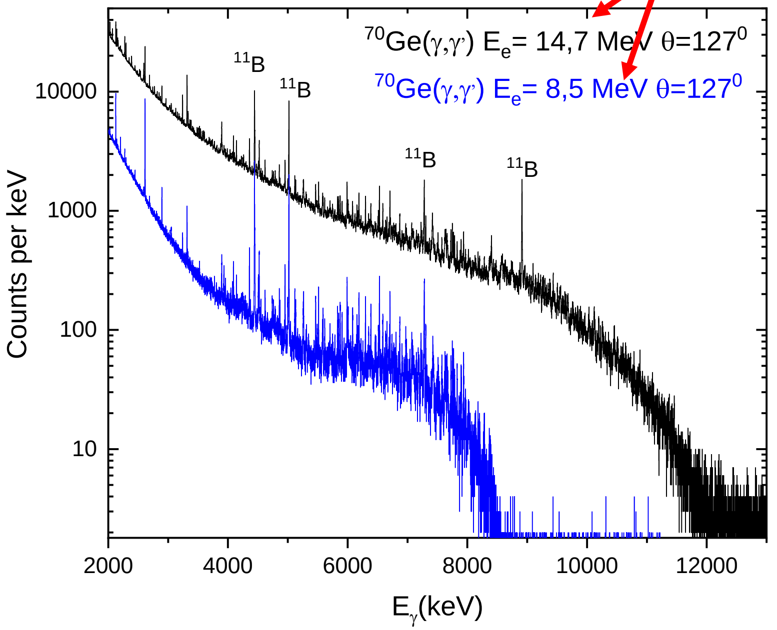
Measurements @ bremsstrahlung facility at the electron accelerator ELBE (HZDR)



Accelerator parameters:

- Maximum electron energy: 18 MeV
- Maximum average current: 0.8 mA
- Micro-pulse rate:13 MHz
- Micro-pulse length:

Feeding effect and to distinguish the inelastic transitions

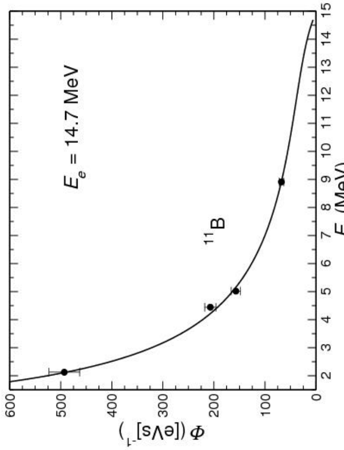


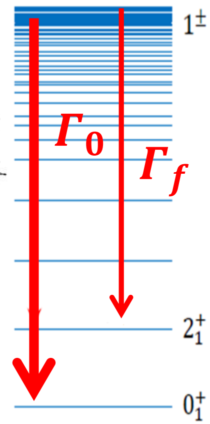
*Target (20mm diameter): 1508.8 mg of oxyde of germanium enriched to 97.7% in ^{70}Ge, combined with 300 mg of Boron, enriched to 99,5 % in **^{11}B** (known cross sections to determine the **photon flux)**

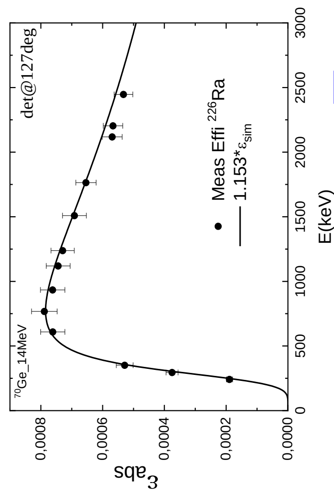
* Spectra of scattered photons were measured for 105 h and 148 h in the experiments at 8.5 MeV and 14. 7MeV electron energy, respectively

NRF experiments Analysis

Bremsstrahlung Photons *->Low angular population of dipole statesmomentum transfert ->*







Measured Integral scattering cross section

$$\frac{I_s(E_x)}{I_s(E_x^{\mathrm{B}})} = \left(\frac{I_\gamma(E_\gamma,\theta)}{W(E_\gamma,\theta)\Phi_\gamma(E_x)N_N}\right) \times \left(\frac{I_\gamma(E_\gamma^{\mathrm{B}},\theta)}{W(E_\gamma^{\mathrm{B}},\theta)\Phi_\gamma(E_x^{\mathrm{B}})N_N^{\mathrm{B}}}\right)^{-1}$$

Integrated scattering cross section

$$I_s = \int \sigma_{\gamma\gamma}\, dE = \frac{2J_x+1}{2J_0+1}\left(\frac{\pi\hbar c}{E_x}\right)^2 \frac{\Gamma_0}{\Gamma}\Gamma_0$$

$$b_0 = \frac{\Gamma_0}{\Gamma} = \frac{1}{1+\sum_{f>0}\frac{\Gamma_f}{\Gamma}} \qquad \frac{\Gamma_f}{\Gamma} = \frac{A_{i,f}}{\sum_f A_{i,f}}$$

Transition strength for photo absorption

$$B(E1)\uparrow = 0.9554\left(\frac{g\Gamma_0}{{E_\gamma}^3}\right)(10^{-3}e^2fm^2)$$

Transition multipolariy: $\frac{W(90^0)}{W(127^0)} = \begin{cases} 0.76 & 0\rightarrow 1\rightarrow 0 \\ 2.260 & \rightarrow 2\rightarrow 0 \end{cases}$

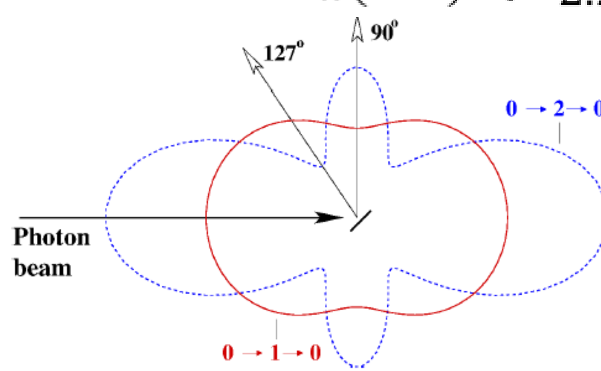
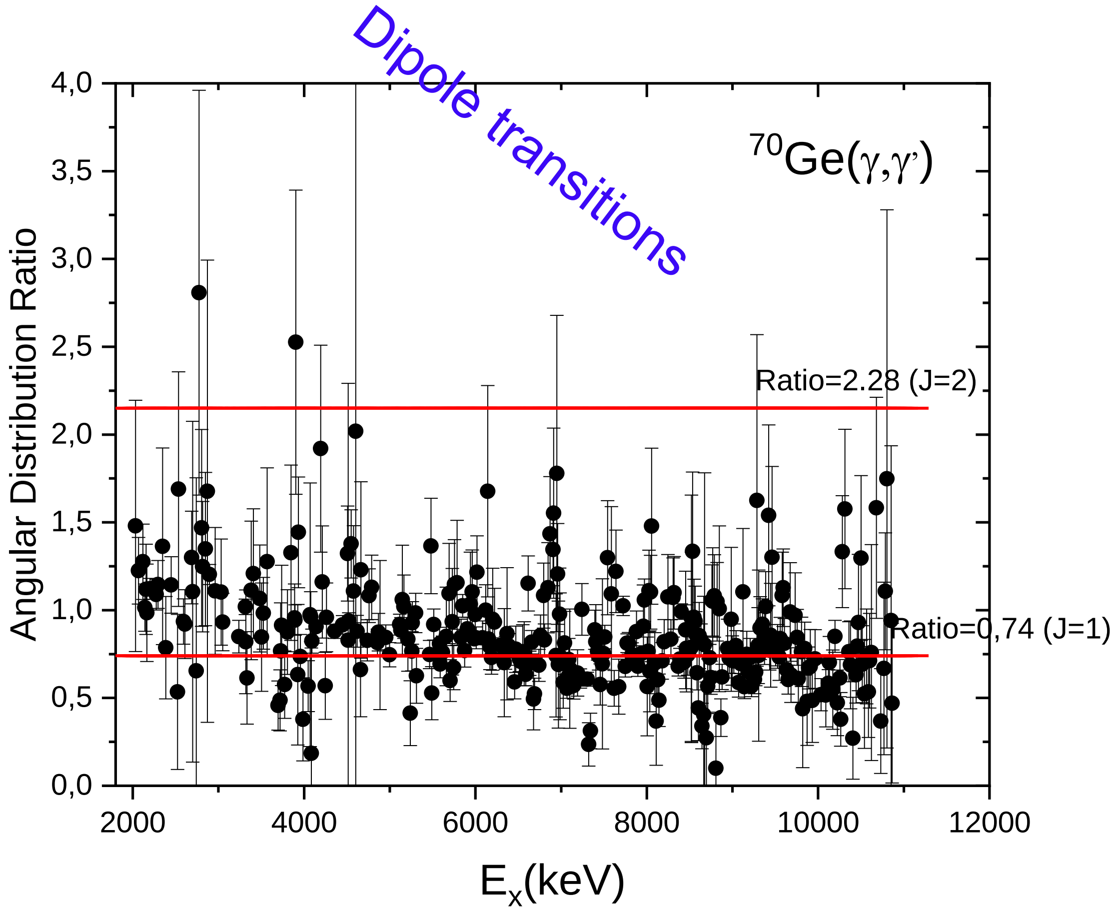


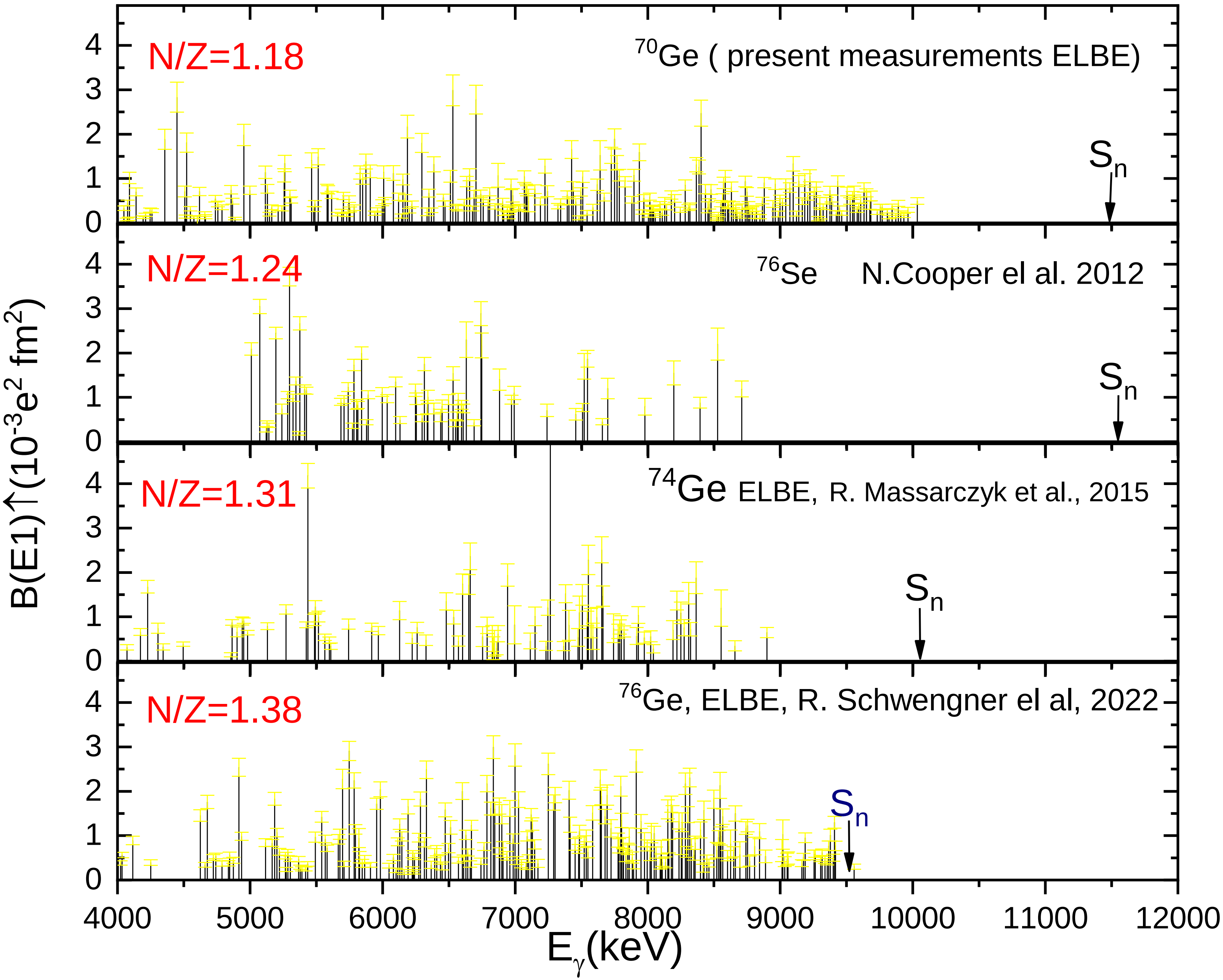
Photo absorption cross section:

$$\sigma_\gamma = \sigma_{\gamma\gamma}\left(\frac{\Gamma_0}{\Gamma}\right)^{-1}$$

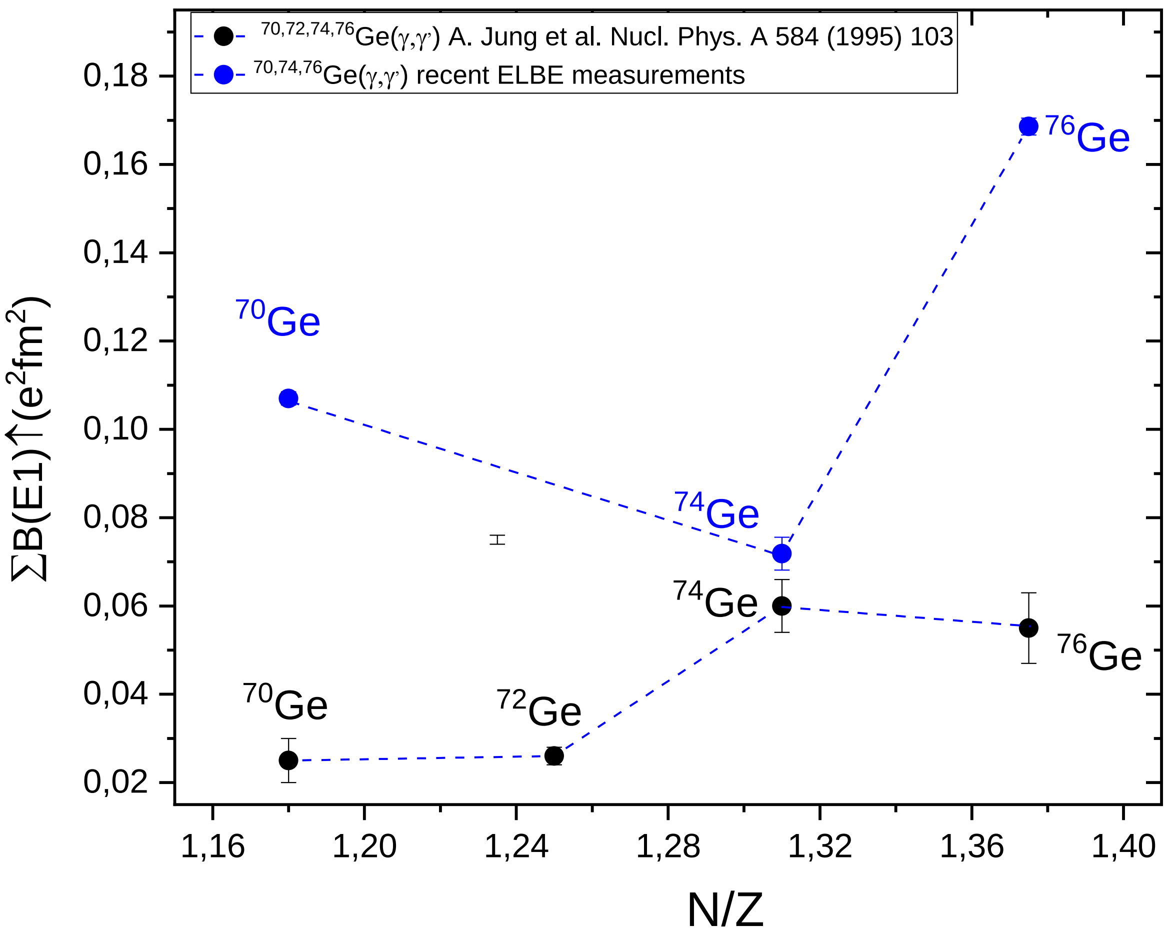
$^{70}Ge\ (\gamma, \gamma')$ Results



^{70}Ge (γ, γ') Results

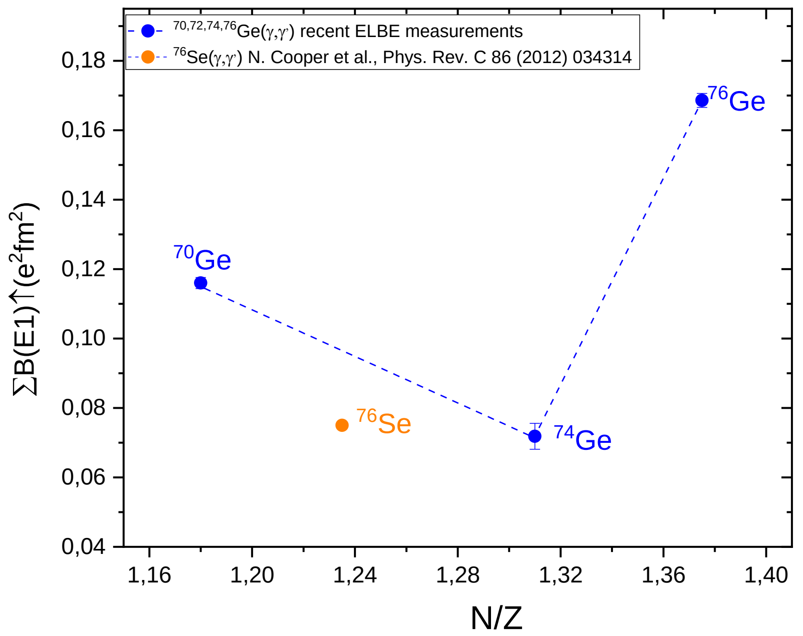


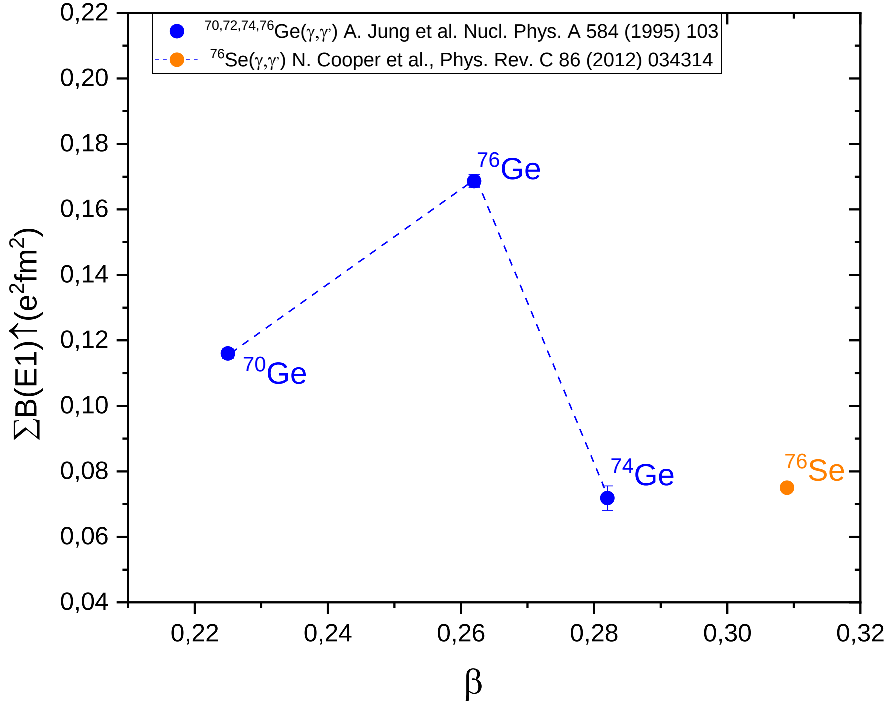
^{70}Ge (γ,γ') Results (Resolved transition strengths)



*The dipole transition strengths assumed E1 are summed in the energy region 5 MeV to 9 MeV as from A. Jung measurements

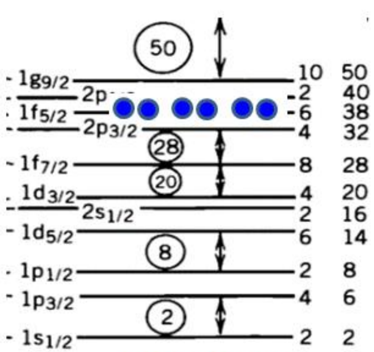
^{70}Ge (γ,γ') Results (Resolved transition strengths)



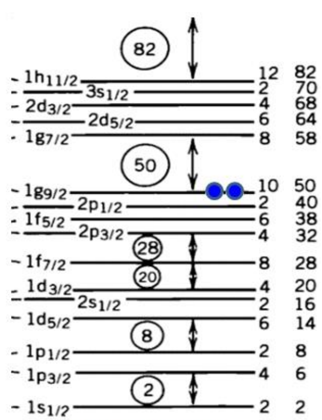


*The dipole transition strengths assumed E1 are summed in the energy region from 5 MeV up to neutron threshold 9.4 MeV of ^{76}Ge

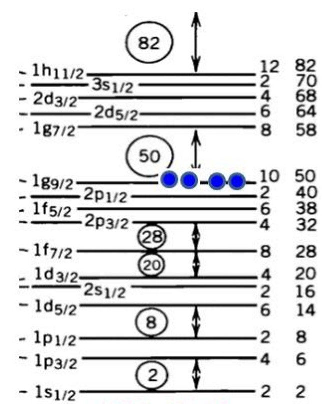
.



70Ge N=38



74Ge N= 42



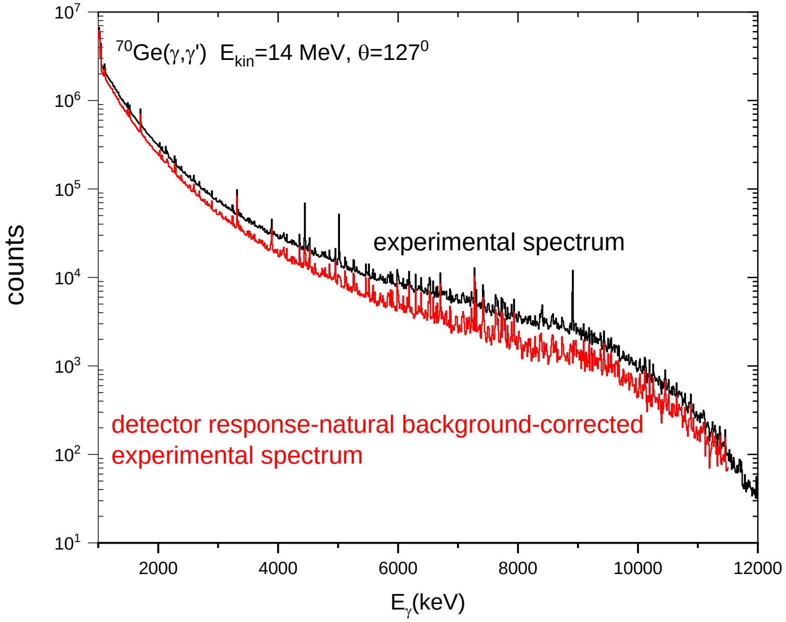
76Ge N=44

^{70}Ge (γ, γ')Results (Unresolved transition strengths: quasi continuum)

we applied statistical methods to estimate the intensities of branching transitions and thus to correct the dipole-strength distribution.

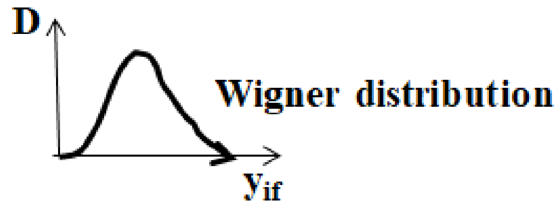
$\gamma DEX\ code$: simulations of $\gamma ray\ cascades$ from the levels.

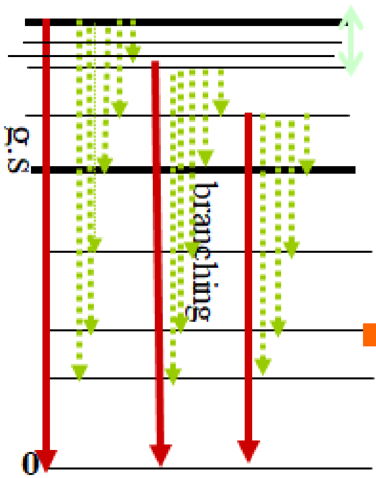
Level scheme are constructed in Δ =200 keV energy bins



^{70}Ge (γ,γ')Results (Unresolved strengths: quasi_continuum)

$\gamma DEX\ code$: simulations of $\gamma ray\ cascades$ from the levels.
Level scheme are constructed in $\Delta = 100$ keV energy bins

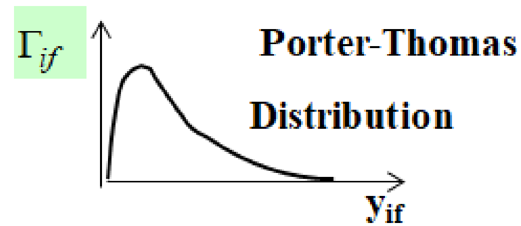




$D = y_{if}\,\rho(E_x, J, a, \sigma, E_1)^{-1}$

level density calculated by using the constant -temperature (CT) model
Level density parameters from T.V. Egidy, PRC 80, 054310 (2009)

$$\Gamma_{if} = y_{if}\bar{\Gamma}_{if} = y_{if}(E_i - E_f)^{2L+1}\frac{f_\gamma^{XL}(E_\gamma)}{\rho(E_x, J_x^\pi)}$$

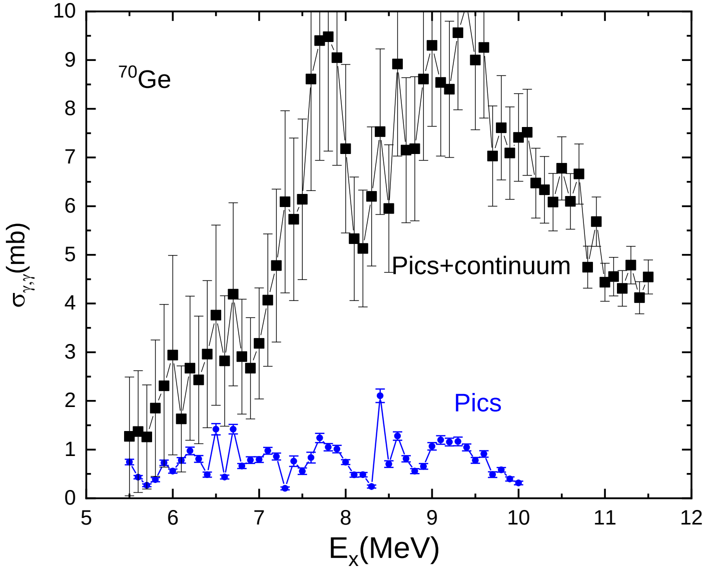


*Photon strength functions approximated by lorentz curves.

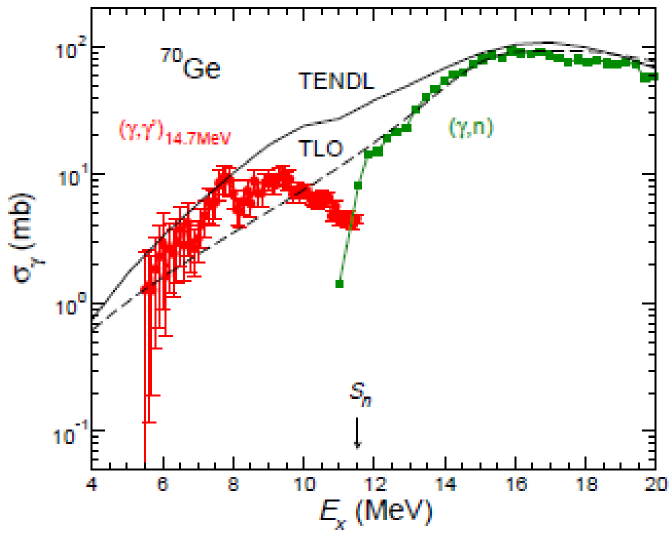
*Substraction of inelastic intensities and correction of intensities of g.s transitions
with calculated branching branching Γ_0/Γ.

$* \ \sigma_\gamma^\Delta = \sigma_{\gamma\gamma}^\Delta / b_0^\Delta$

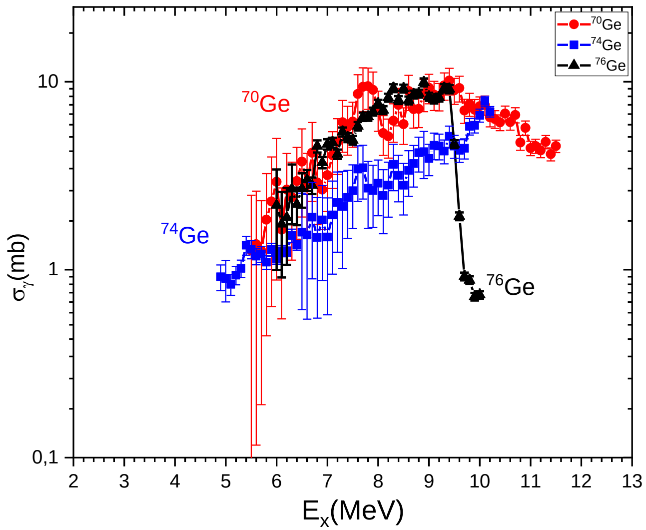
^{70}Ge (γ,γ') Results (Unresolved strength: quasi_continuum)



Continuum contribution is about 6 times the resolved strength



Extra strength in comparison to the Lorentz curve of the GDR which can be attributed to the PDR



Similar PDR strength in $^{70,\ 76}$Ge which seems suppressed in ^{74}Ge

Summary and Conclusion

- Astrophysical and nuclear structure interest of the PDR Strength

- Real Photons enable a complete determination of the dipole Strength

- ^{70}Ge dipole response measurements by photon scattering experiments complementing the systematic of dipole-strength distribution in the Germanium isotopes chain: ^{74}Ge, ^{76}Ge.

- ^{70}Ge resolved dipole strength analysis in the energy range of the PDR as well corrected by the quasi-continuum contribution shows an enhanced summed dipole-strength (photoabsorption cross section) in comparison to ^{74}Ge which means that the evolution of the PDR in the Germanium chain seems not following the known neutron excess trend. This effect could be connected to the nuclear deformation (nuclear structure).

- ^{154}Sm measurements analysis in progress could clarify more this new finding.

Collaborators

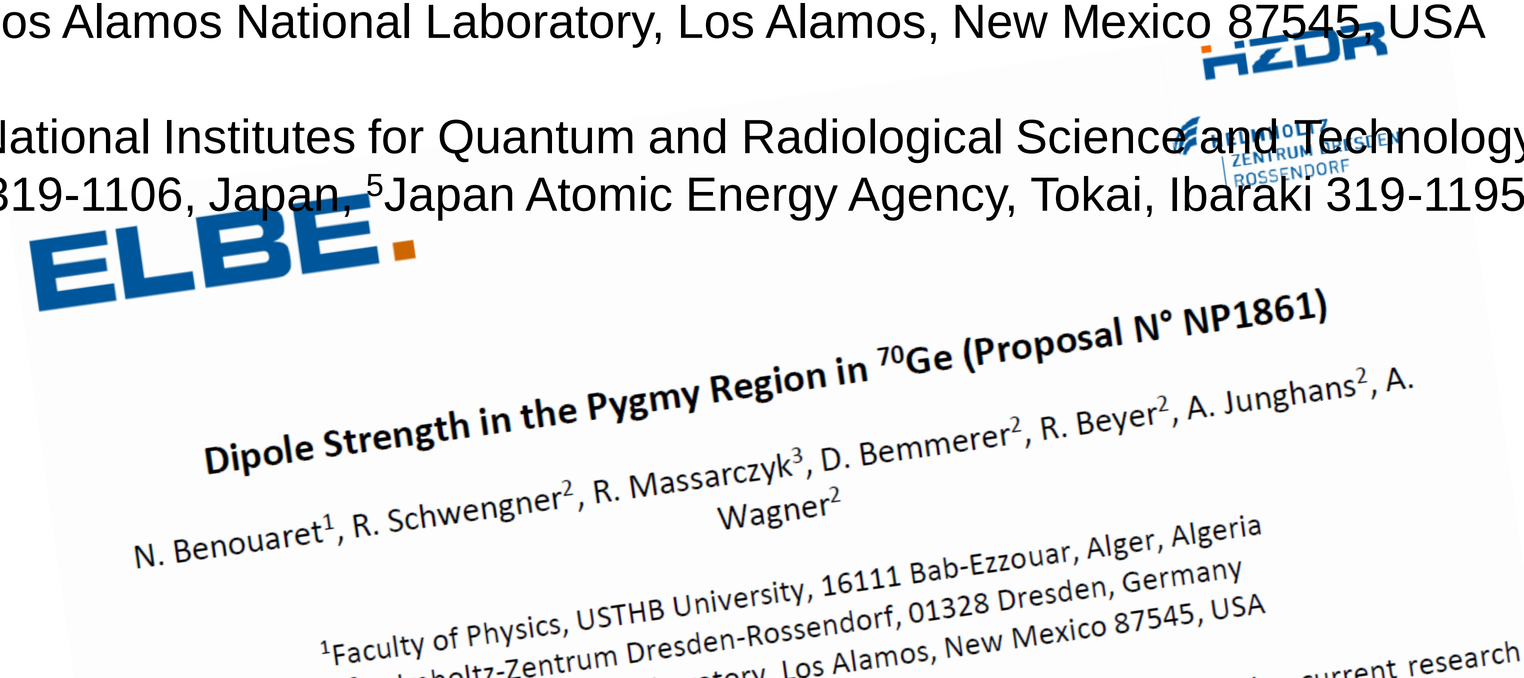
N. Benouaret[1], R. Schwengner[2], R. Massarczyk[3], T. Shizuma[4,5], D. Bemmerer[2], R. Beyer[2], A. Junghans[2], A. Wagner[2]

[1]Faculté de Physique, Université des Sciences et de la Technologie Houari Boumedienne, B.P. 32, El Alia, Bab Ezzouar, 16111, Alger, Algeria

[2]Helmholtz-Zentrum Dresden-Rossendorf, 01328 Dresden, Germany

[3]Los Alamos National Laboratory, Los Alamos, New Mexico 87545, USA

[4]National Institutes for Quantum and Radiological Science and Technology, Tokai, Ibaraki 319-1106, Japan, [5]Japan Atomic Energy Agency, Tokai, Ibaraki 319-1195, Japan


ELBE

Dipole Strength in the Pygmy Region in ^{70}Ge (Proposal N° NP1861)

N. Benouaret[1], R. Schwengner[2], R. Massarczyk[3], D. Bemmerer[2], R. Beyer[2], A. Junghans[2], A. Wagner[2]

[1]Faculty of Physics, USTHB University, 16111 Bab-Ezzouar, Alger, Algeria

...holtz-Zentrum Dresden-Rossendorf, 01328 Dresden, Germany

...tory, Los Alamos, New Mexico 87545, USA

... current research