# Newest results on pygmy resonances in atomic nuclei


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supported by DFG (ZI 510/4-1 and INST 216/544-1)

# Giant Dipole Resonance (GDR)

**1937:**

## Atomumwandlungen durch γ-Strahlen.

Von **W. Bothe** und **W. Gentner** in Heidelberg.

*Z. Phys.* ***106*** *(1937) 236*

### 6. *Diskussion.*

Die beschriebenen Versuche zeigen, daß bei gewissen Elementen der Prozeß $(\gamma, n)$ verhältnismäßig leicht beobachtbar ist.

... Vielleicht spielen hierbei Resonanzverhältnisse eine entscheidende Rolle, ...

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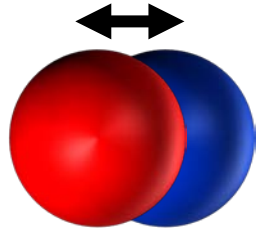
**1944:**

**QUADRUPOLE AND DIPOLE γ-RADIATION OF NUCLEI**

By **A. MIGDAL**



*J. Phys. (USSR)* ***8*** *(1944) 331*

**1947:**

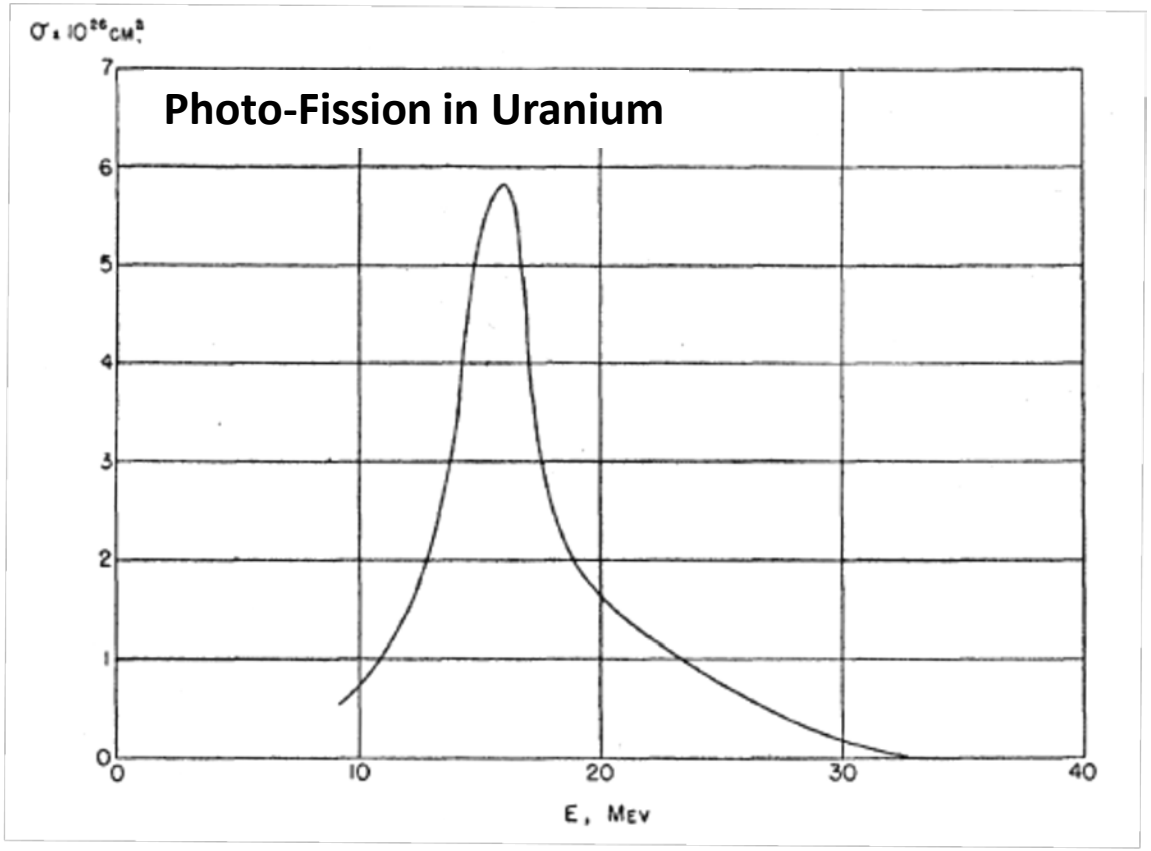
**Photo-Fission in Heavy Elements***

G. C. BALDWIN AND G. S. KLAIBER

*Research Laboratory, General Electric Company, Schenectady, New York*

*Phys. Rev.* ***71*** *(1947) 3*

# Giant Dipole Resonance (GDR)

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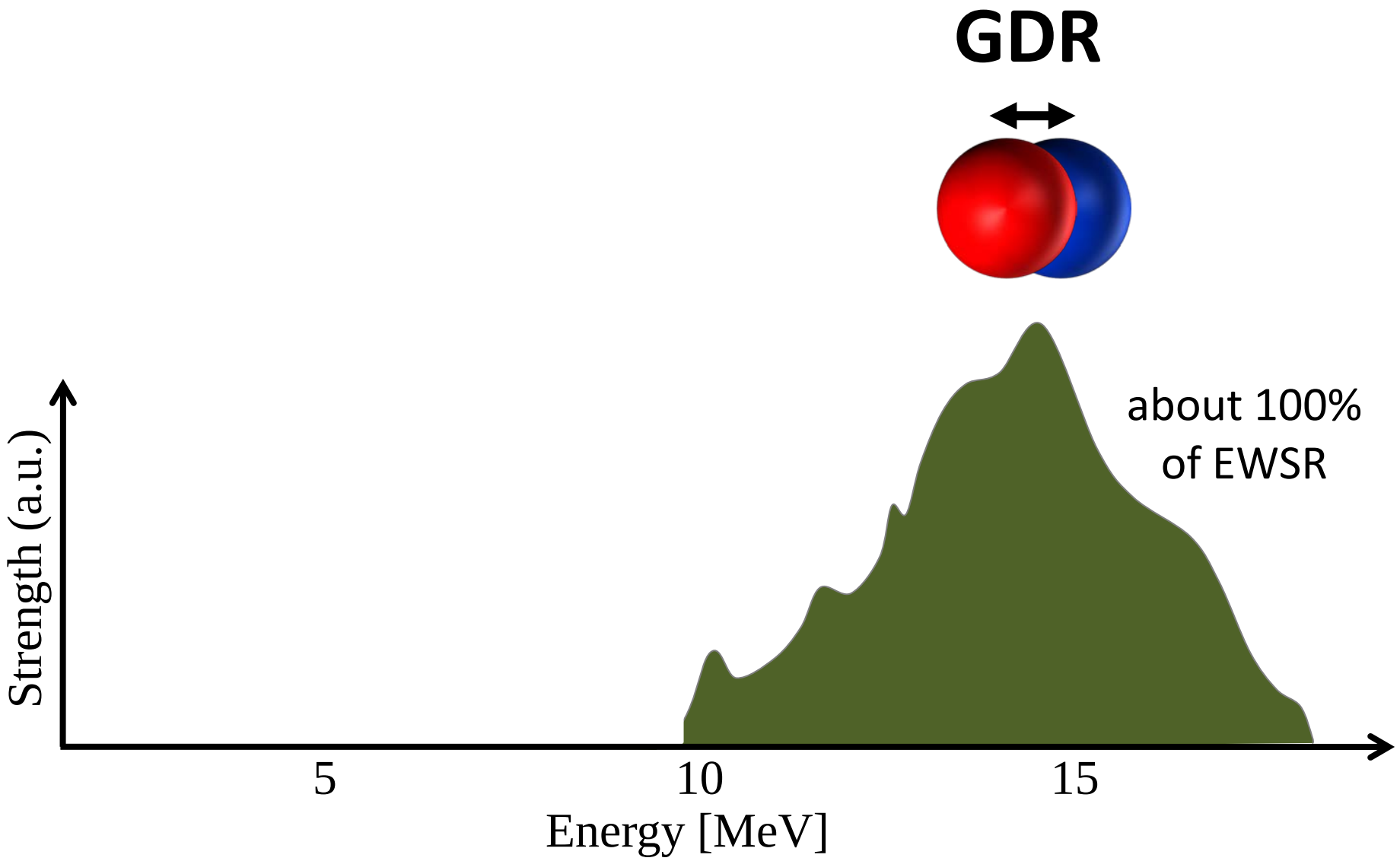


# Pygmy Dipole Resonance (PDR)

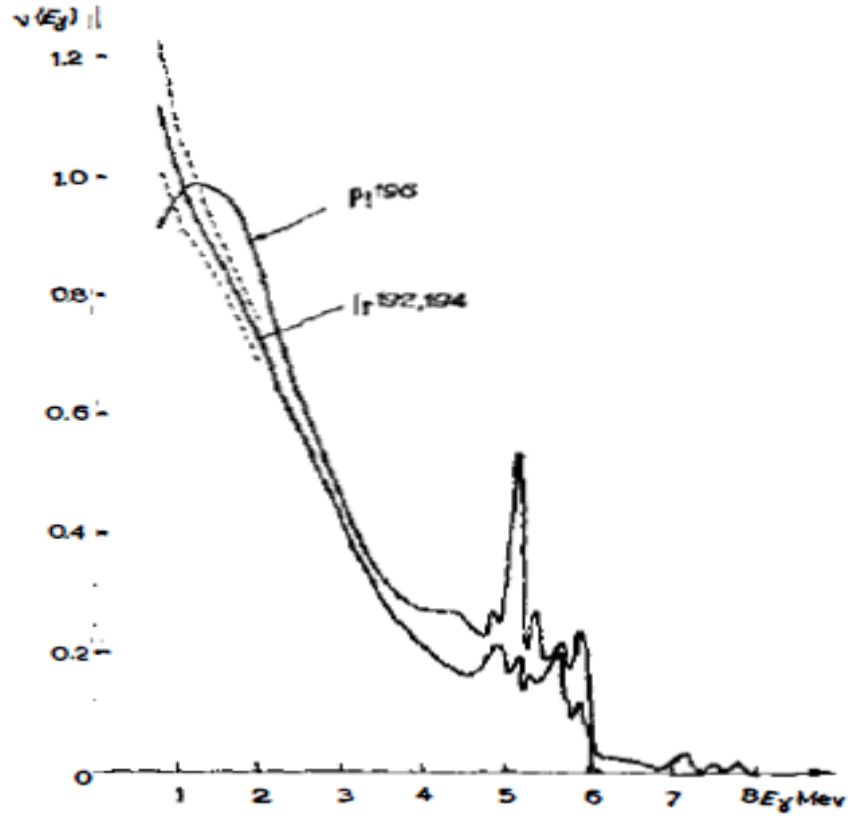
**1961:**

NEUTRON CAPTURE GAMMA RAYS[1]

By G. A. Bartholomew

*Neutron Physics Branch, Chalk River Project, Atomic Energy of Canada Limited*

*Ann. Rev. Nucl. Sci.* ***11*** *(1961) 259*



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*Ann. Rev. Nucl. Sci.* ***11*** *(1961) 259*

**1969:**

**Effect of the pigmy resonance on the calculations of the neutron capture cross section**

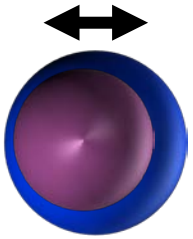
J. S. Brzosko, E. Gierlik, A. Soltan, Jr., and Z. Wilhelmi

*Can. J. Phys.* ***47*** *(1969) 2850*

**1971:**

Three-Fluid Hydrodynamical Model of Nuclei*

*R. Mohan, M. Danos, and L.C. Biedenharn,*
*Phys. Rev. C* ***3*** *(1971) 1740*



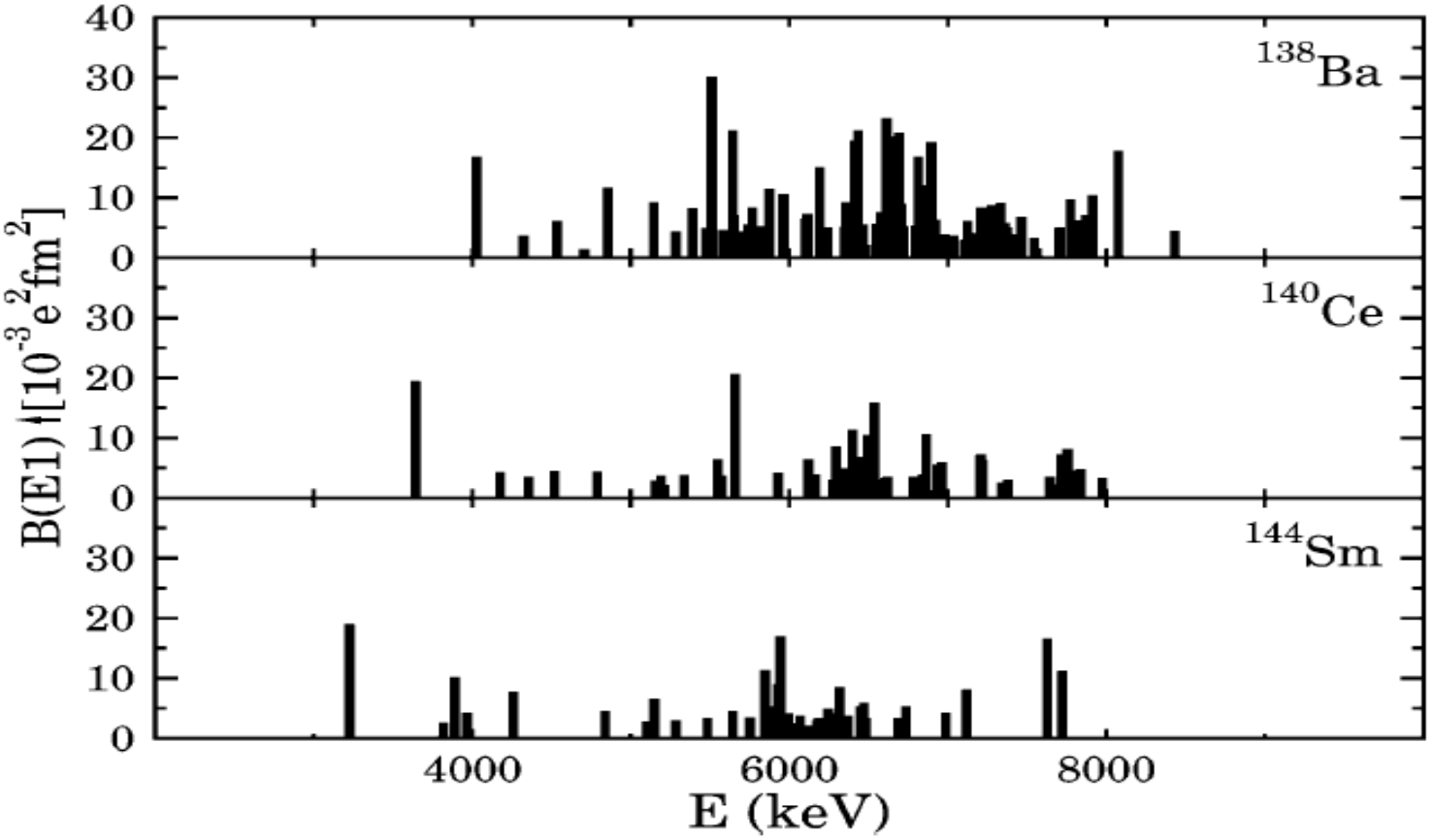
**Z protons, Z neutrons, N-Z excess neutrons**

# Pygmy Dipole Resonance (PDR)

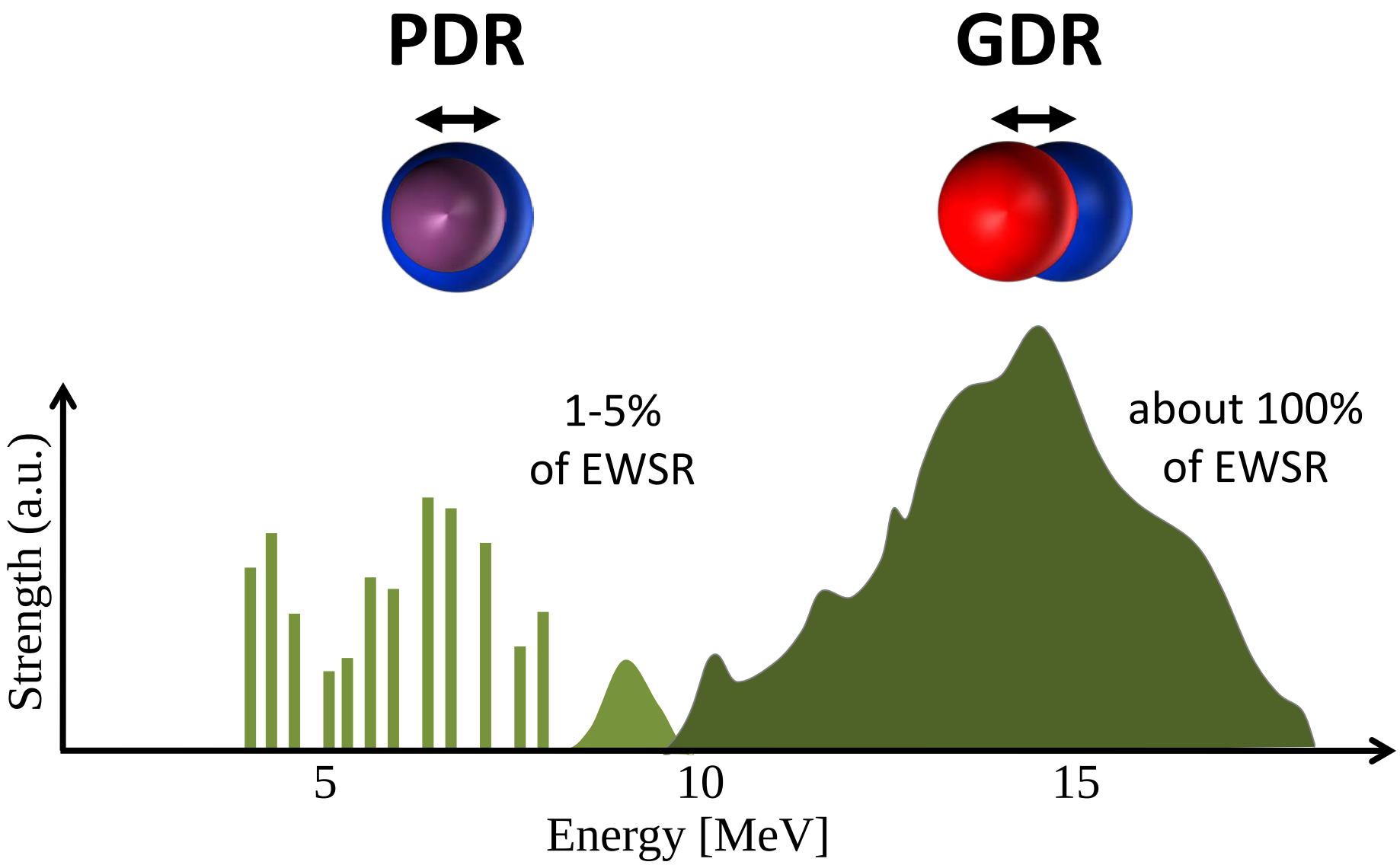
**2002:** Concentration of electric dipole strength below the neutron separation energy in $N = 82$ nuclei

A. Zilges, S. Volz, M. Babilon, T. Hartmann, P. Mohr, K. Vogt

*Phys. Lett. B* ***542*** *(2002) 43*



# From giants to pygmies



# Pygmy Dipole Resonances in atomic nuclei

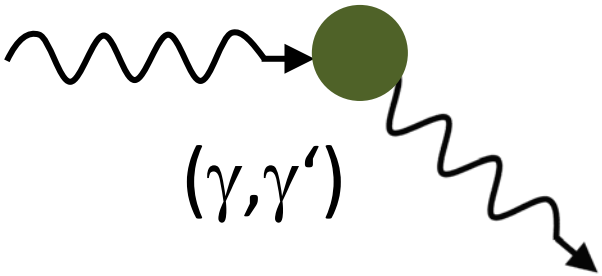
- Tools to investigate the PDR

- Selected results:
  - PDR and neutron excess
  - Splitting of the PDR

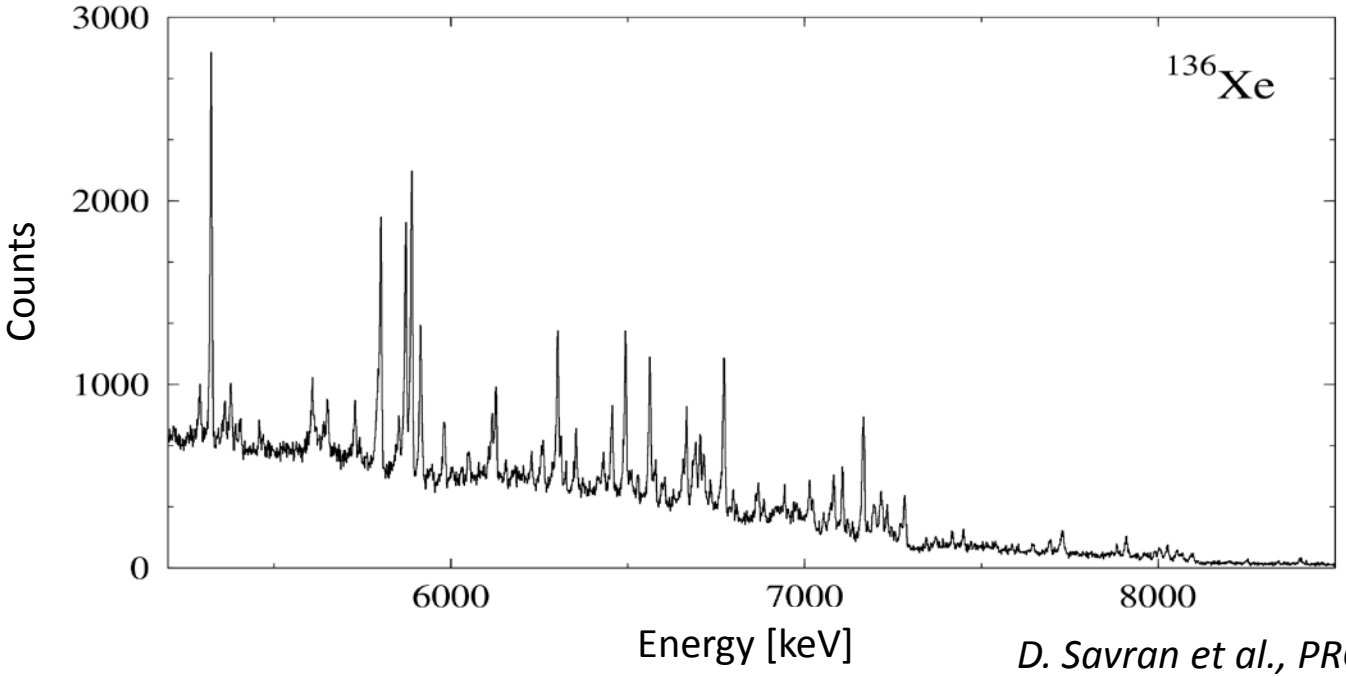
- Open questions

- Theoretical interpretation:
  Next talk (Nadia Tsoneva)

# Tools: Photon scattering (γ,γ')



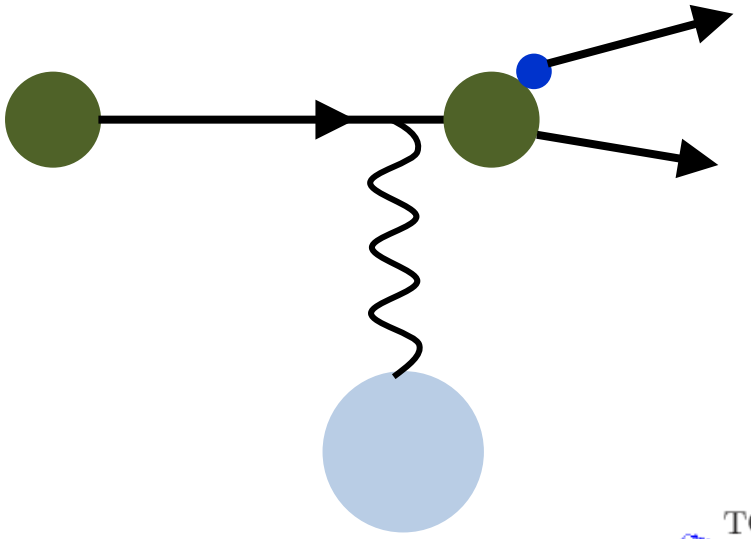

- $E_\gamma$ = 0-10 MeV (below $S_n$)
- very selective excitation
- energy resolution $\Delta E$=5-10 keV
- complex sensitivity limit
- only stable nuclei can be studied



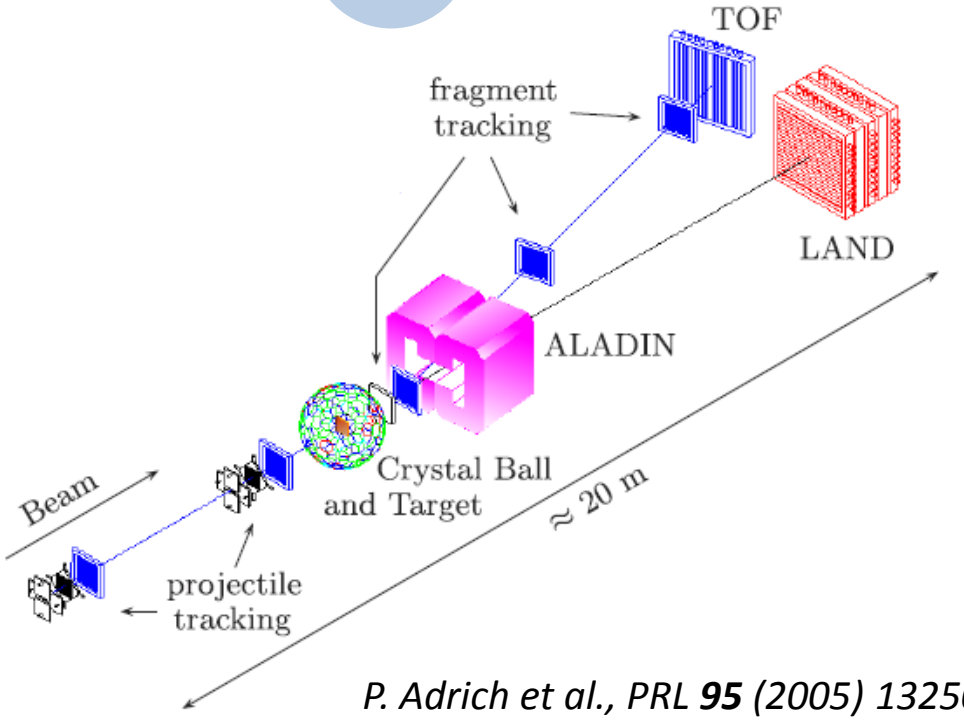

S-DALINAC@TUD
ELBE@HZDR
HIGS@DUKE

*D. Savran et al., PRC* ***84*** *(2011) 024326*

# Tools: Coulomb excitation/dissociation



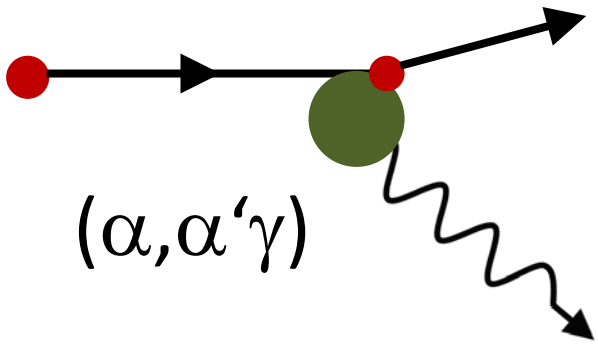
- $E_{cm}$ = few 100 MeV/A
- selective excitation
- energy resolution $\Delta E$=30-500 keV
- radioactive nuclei can be studied in inverse kinematics



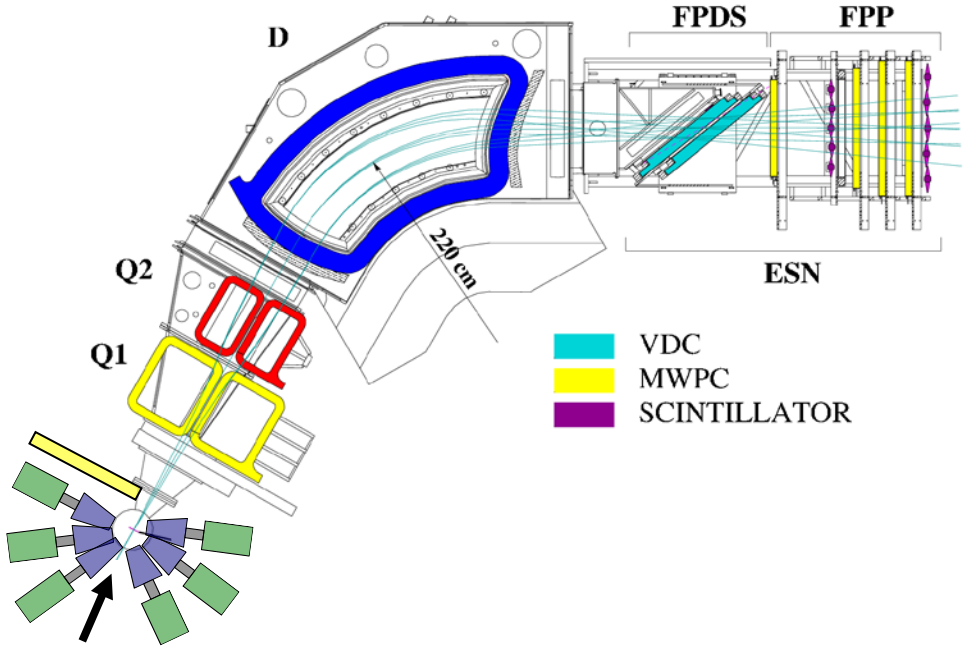

LAND@FRS@GSI
RISING@FRS@GSI
GRAND RAIDEN@RCNP

*P. Adrich et al., PRL **95** (2005) 132501*

# Tools: Hadronic interaction




- $E_{cm}$ = 30-200 MeV/A
- structural information (e.g. isospin)
- γ-decay channel can be selected
- radioactive nuclei can be studied in inverse kinematics




BBS@KVI
BigRIPS@RIKEN

*Janis Endres et al., PRL **105** (2010) 112503*

# Pygmy Dipole Resonances in atomic nuclei

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  - Splitting of the PDR
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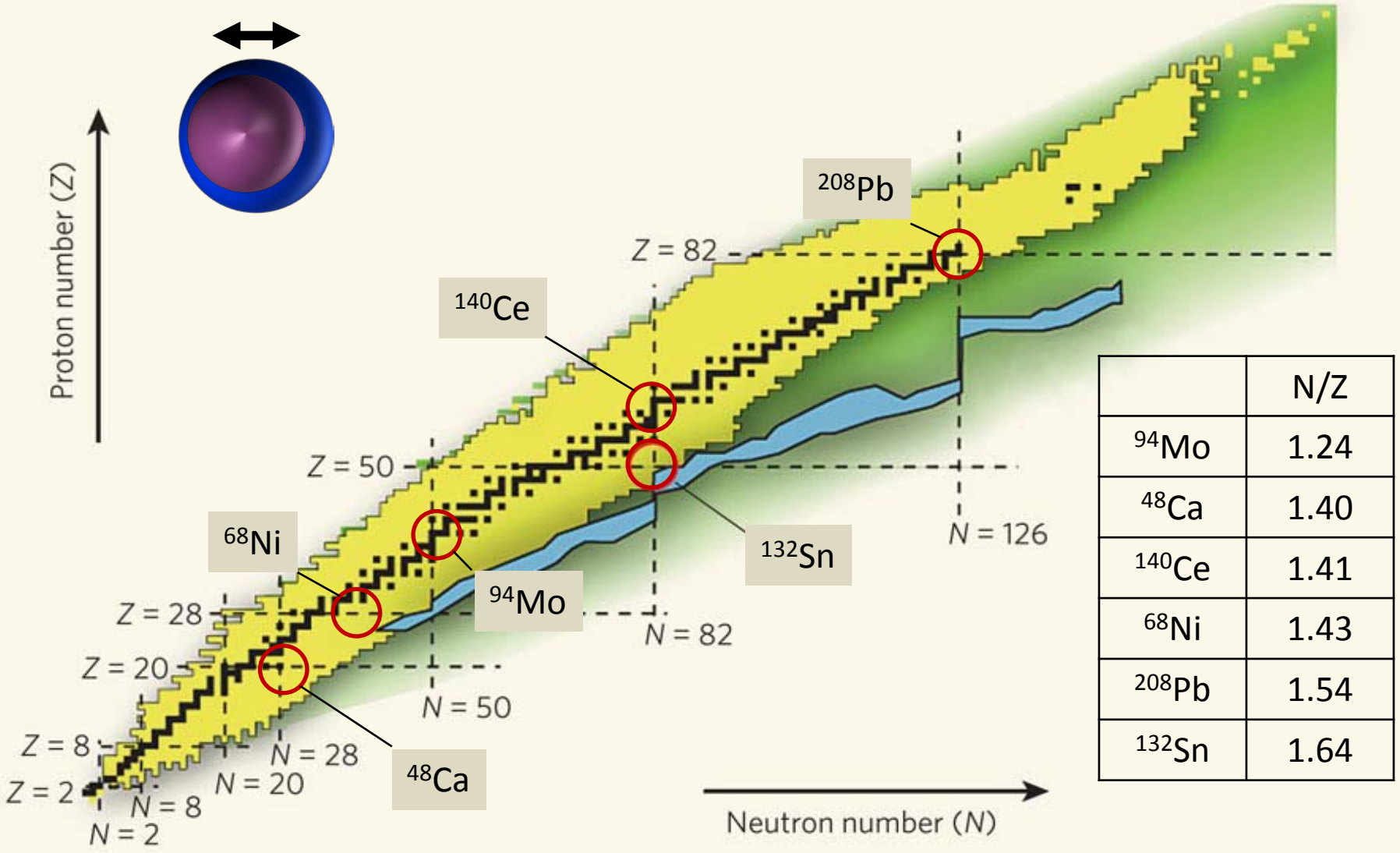
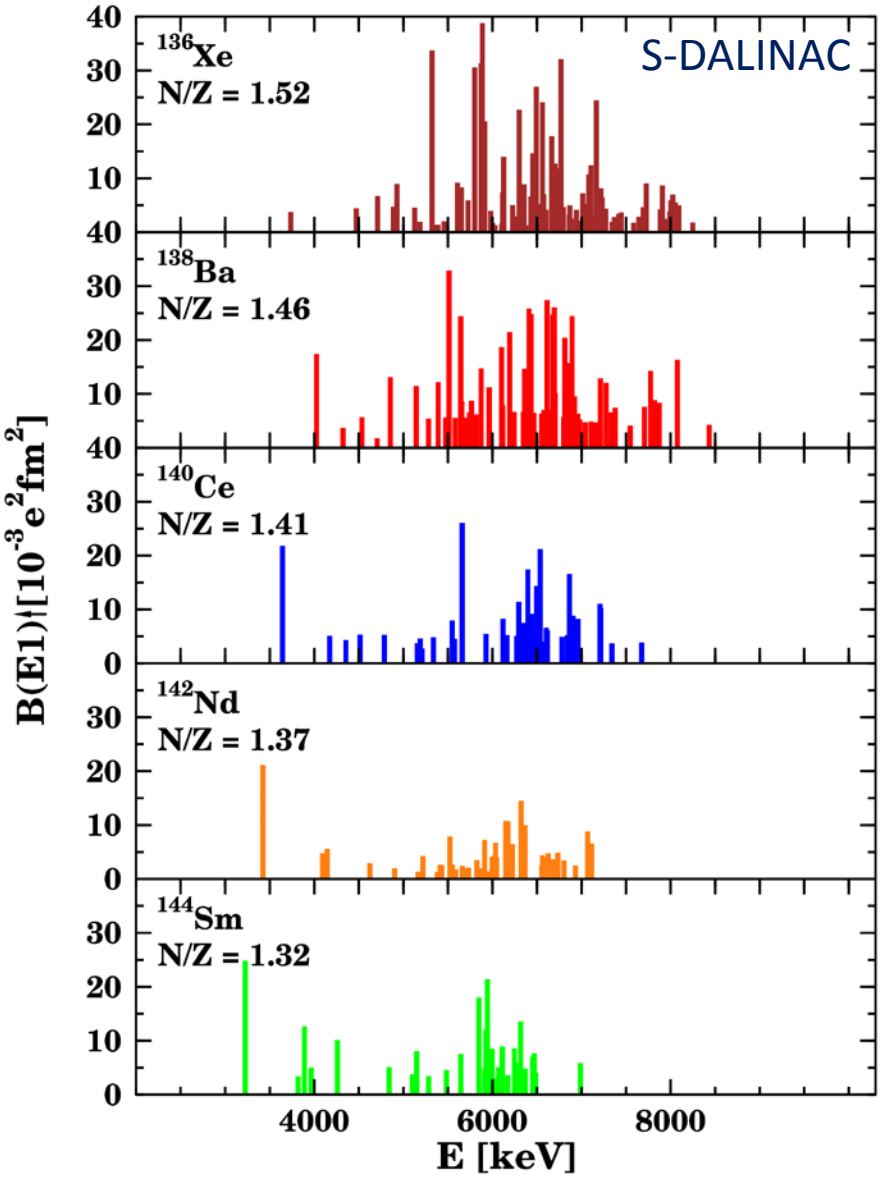
# PDR and neutron excess

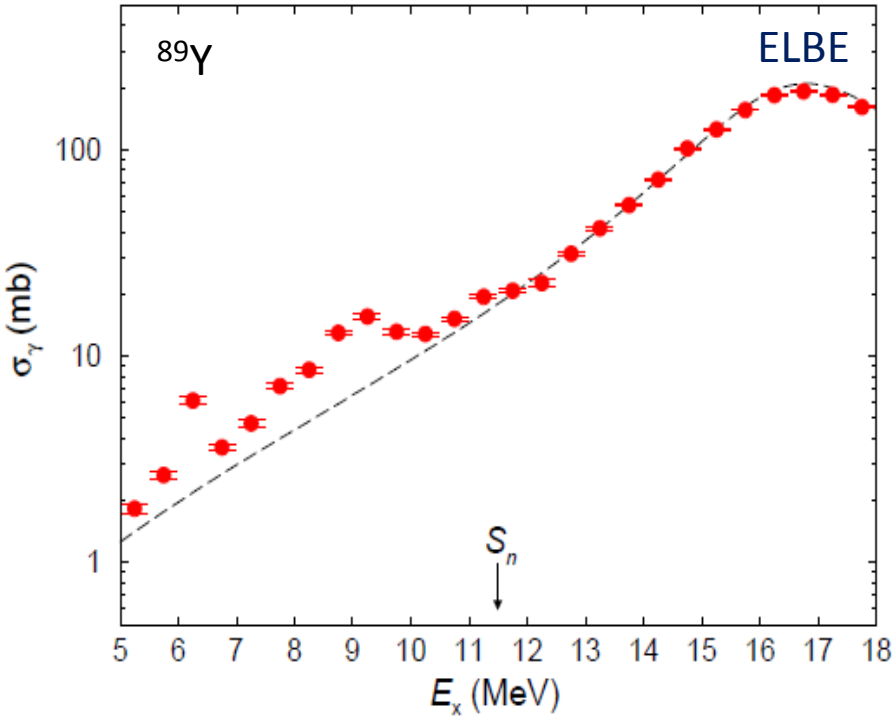



| | N/Z |
|---|---|
| $^{94}$Mo | 1.24 |
| $^{48}$Ca | 1.40 |
| $^{140}$Ce | 1.41 |
| $^{68}$Ni | 1.43 |
| $^{208}$Pb | 1.54 |
| $^{132}$Sn | 1.64 |

*chart of nuclides from: P.D. Cottle, nature **465** (2010) 430*

# PDR in stable nuclei: (γ,γ‘)

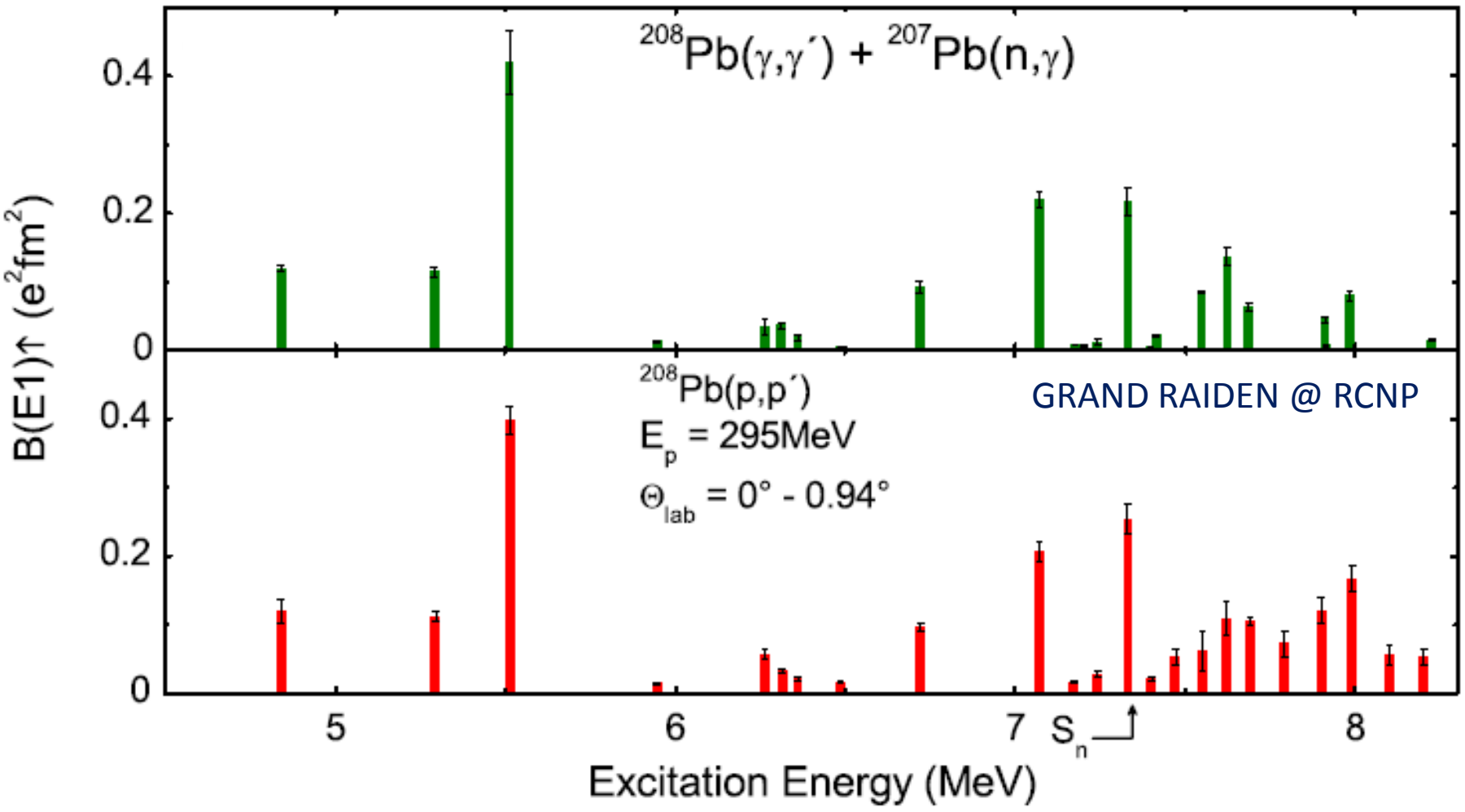




*N. Benouaret et al., PRC **79** (2009) 014303*
*D. Savran et al., PRC **84** (2011) 024326*
*S. Volz et al., NPA **779** (2006) 1*
*A. Zilges et al., PLB **542** (2002) 43*

# PDR in stable nuclei: (γ,γ‘) and (p,p‘)

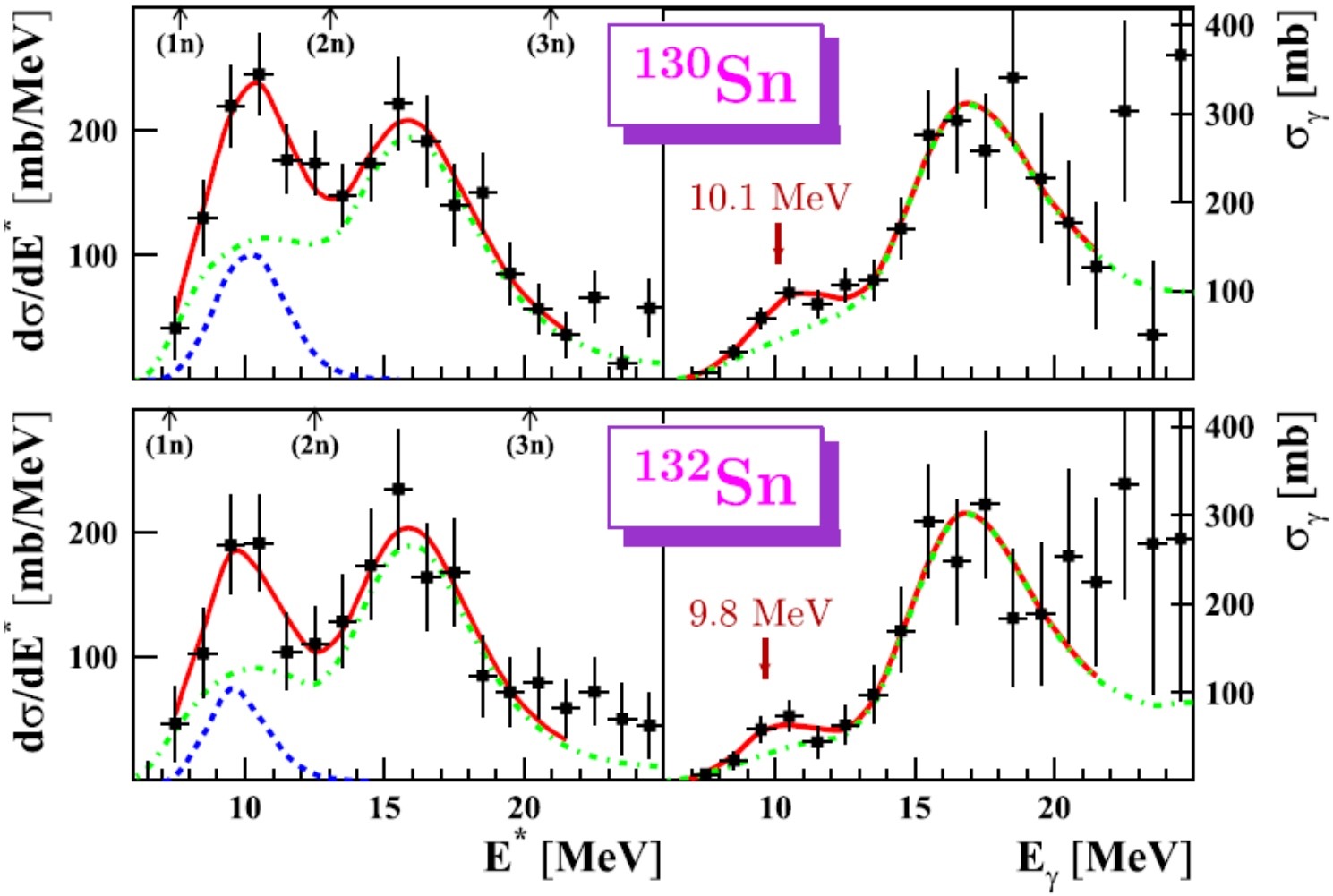



*A. Tamii et al., PRL **107** (2011) 062502*

# PDR in radioactive nuclei

$^{130,132}$Sn @ 500 MeV/A on Pb

LAND plus ALADIN plus Crystal Ball

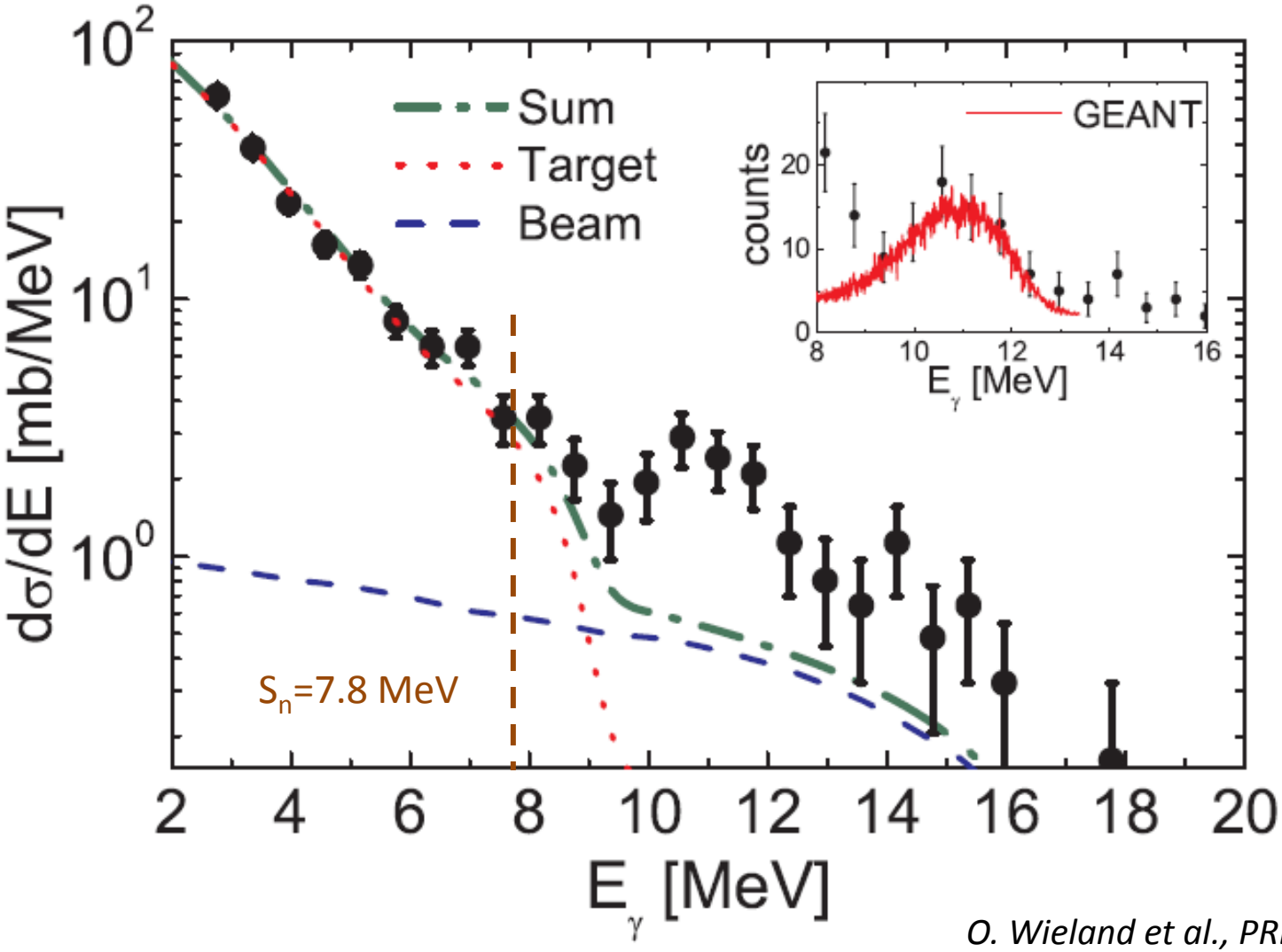



*P. Adrich et al., PRL **95** (2005) 132501*

# PDR in radioactive nuclei

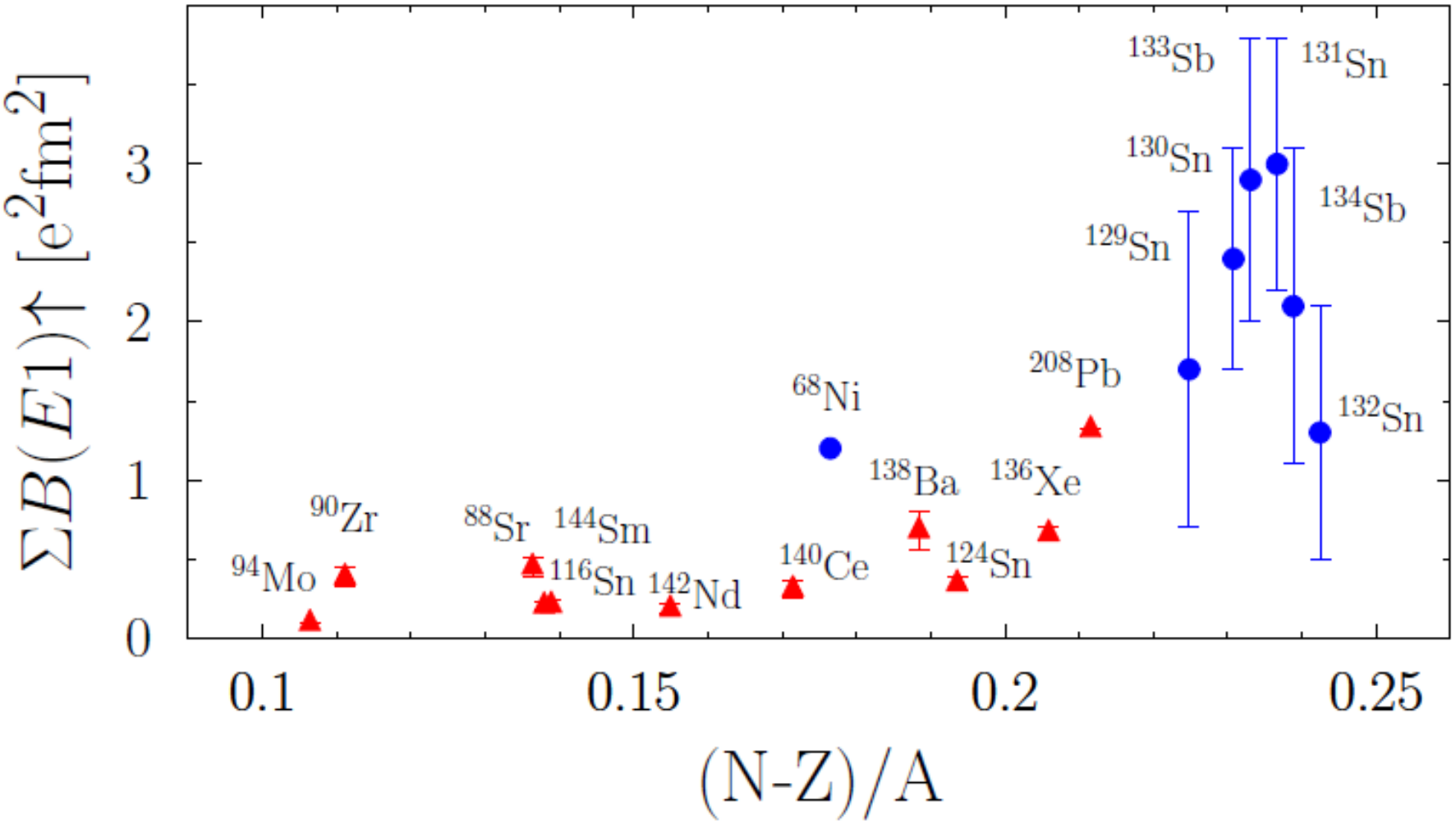
$^{68}$Ni @ 600 MeV/A on Au

RISING HPGe array, HECTOR $BaF_2$ array



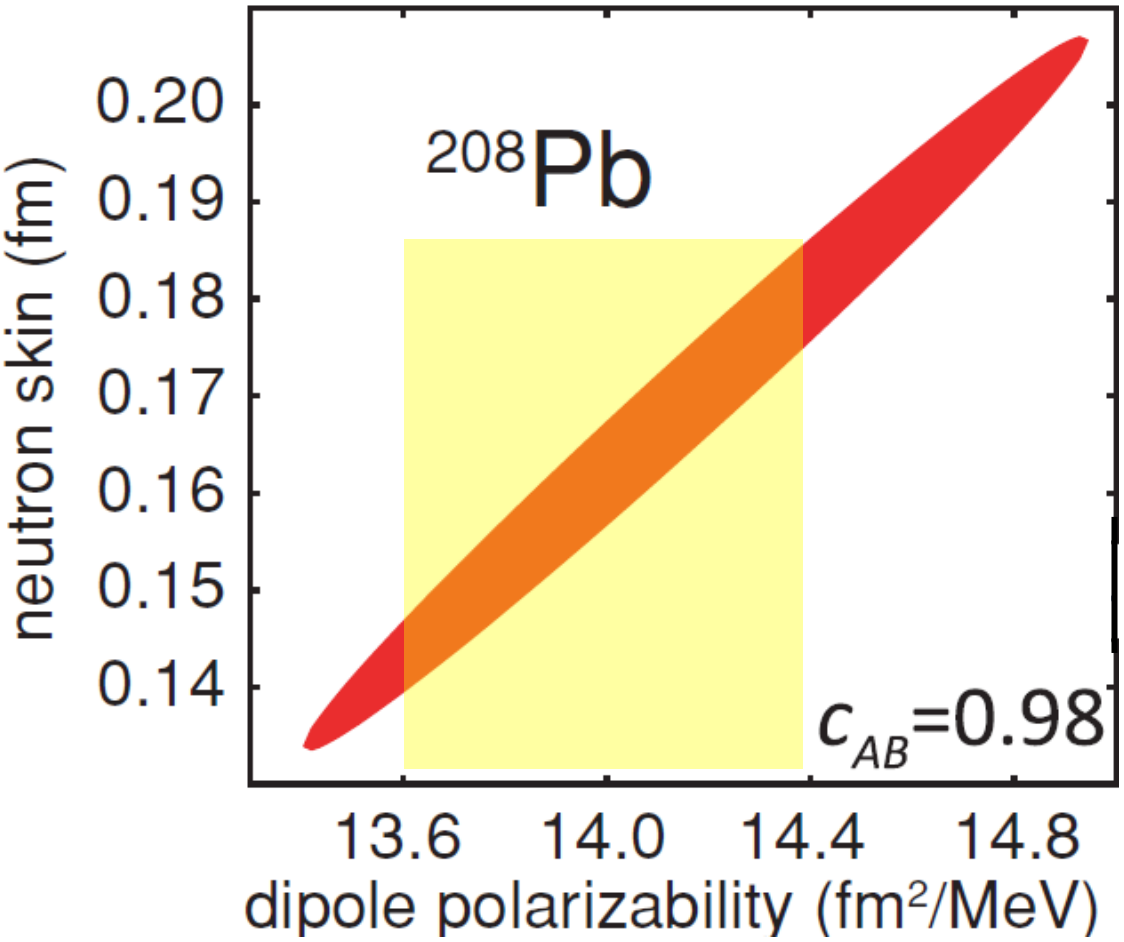

*O. Wieland et al., PRL **102** (2009) 092502*

# Summed PDR strength and neutron excess




*V. Derya et al., to be published*

# Electric dipole strength ⟷ neutron skin

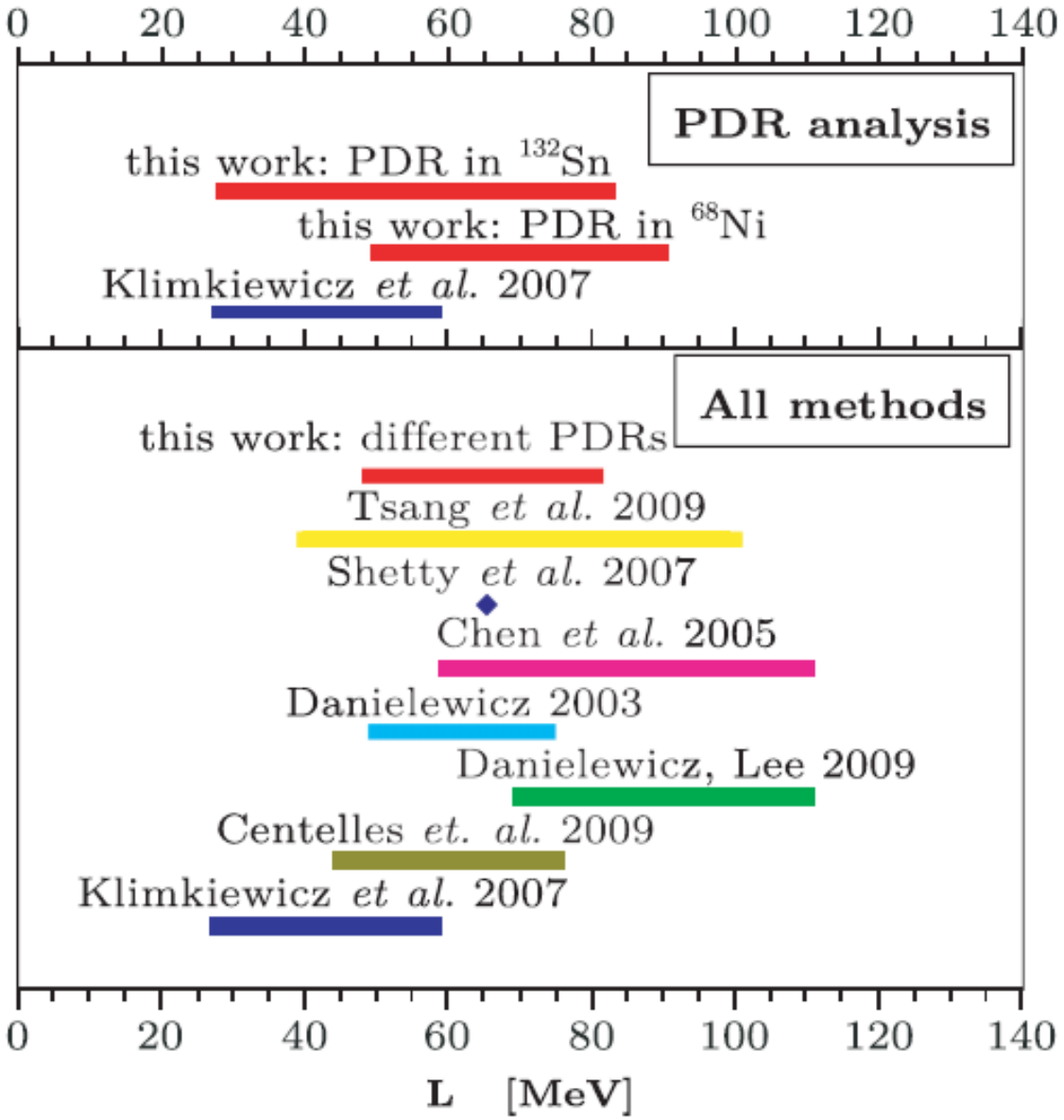



dipole polarizability

$$\alpha_D \propto \int \frac{\sigma_{absorpt.}}{E_\gamma^2} \mathrm{d}E_\gamma$$

*P.-G. Reinhard and W. Nazarewicz, PRC **81** (2010) 051303(R)*
*A. Tamii et al., PRL **107** (2011) 062502*

# Neutron skin ⟷ symmetry energy




L= slope parameter of symmetry energy

*A. Carbone et al., PRC **81** (2010) 041301(R)*

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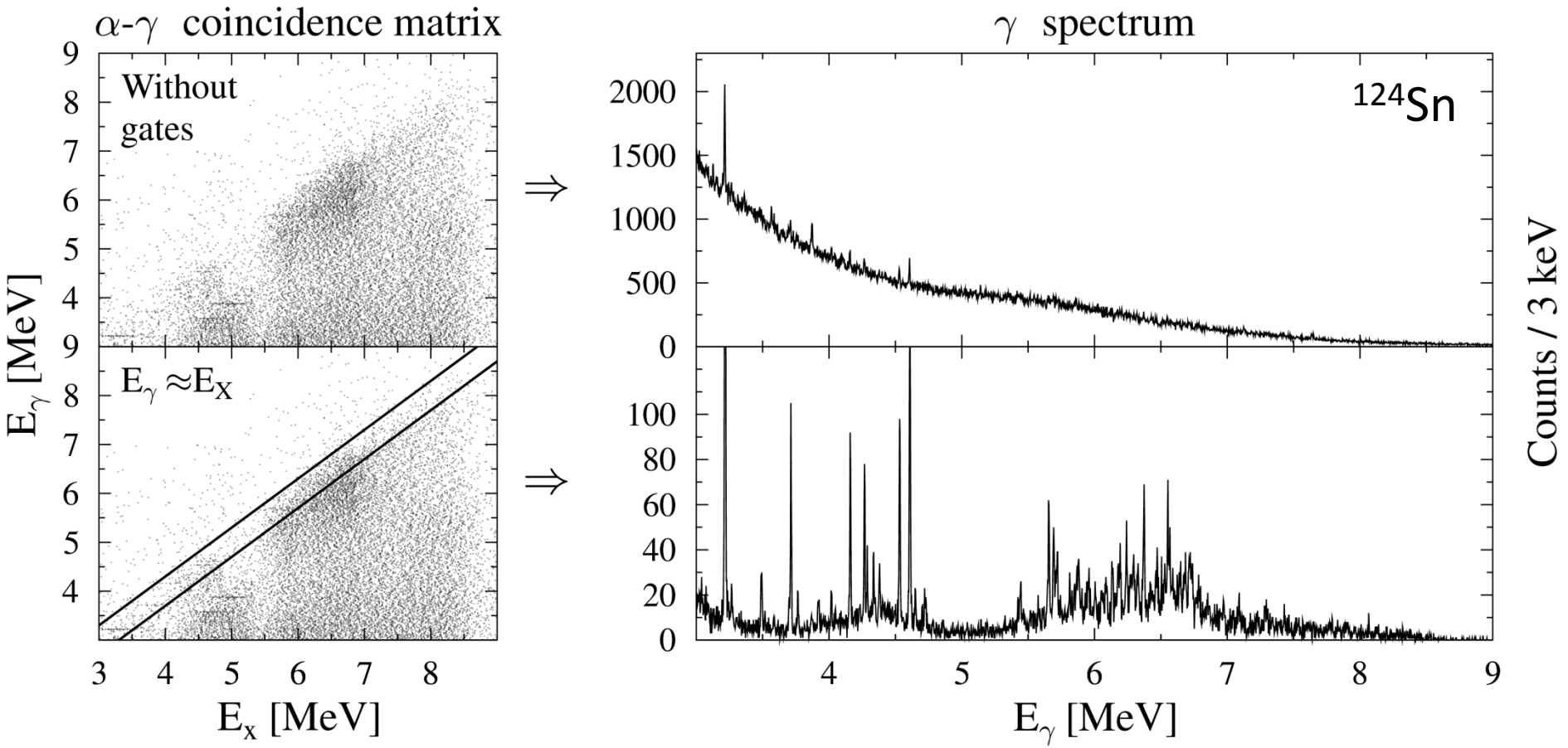
# Structure of the PDR: (γ,γ‘) vs. (α,α‘)

| | (γ,γ') |
|---|---|
| Interaction | Electromagnetic |
| Location of interaction | Whole nucleus |
| Isospin | Isovector E1 excitation |
| Multipolarity | E1, M1, E2 |

A coincident detection of the γ decay enhances the selectivity and energy resolution of (α,α‘) → (α,α‘γ)

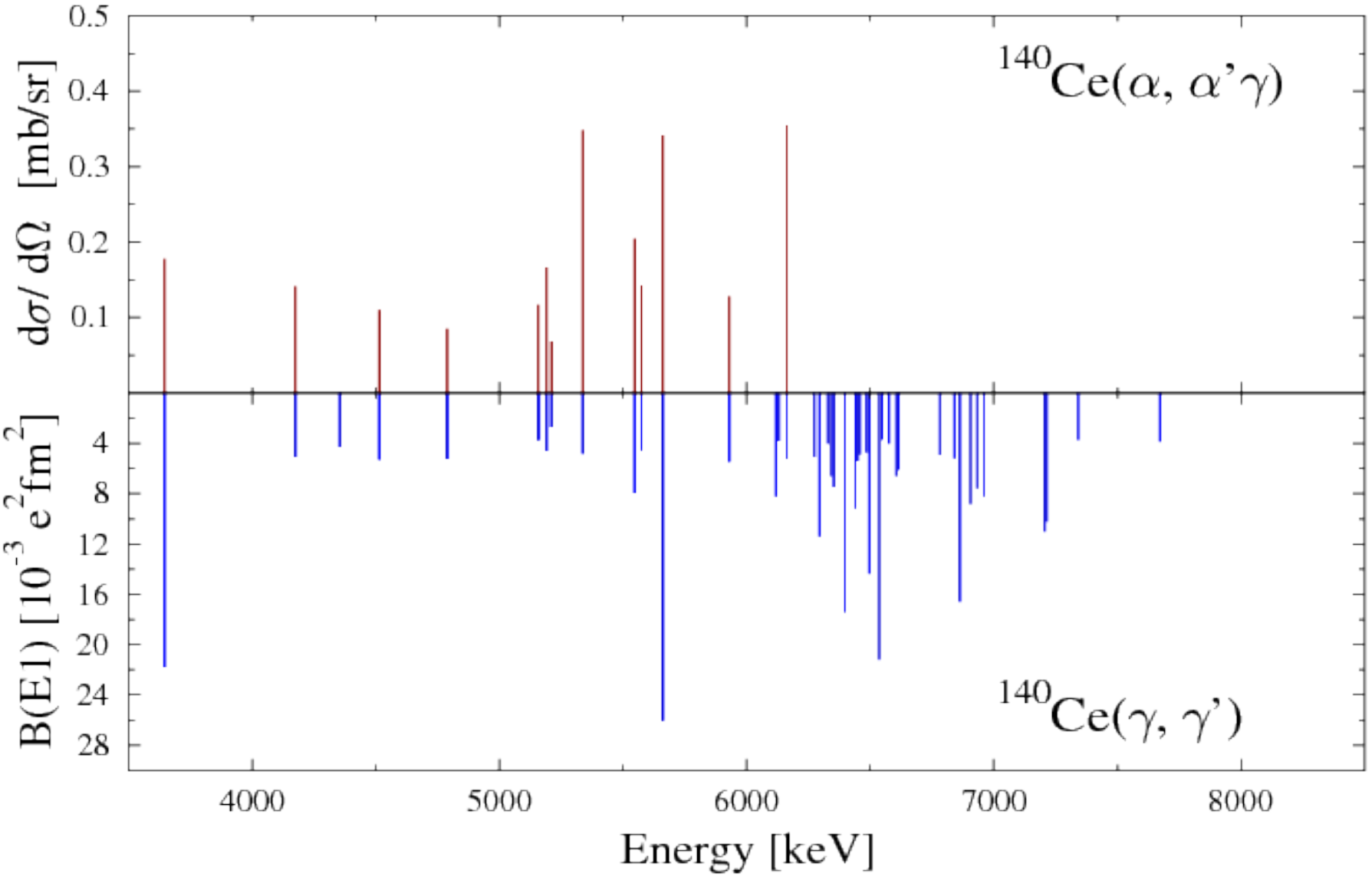
*T.D. Poelhekken et al., PLB **278** (1992) 423*

# Structure of the PDR: (α,α'γ) experiments




*Janis Endres et al., PRL **105** (2010) 112503*

# Splitting of the PDR




*D. Savran et al., PRL **97** (2006) 172502*

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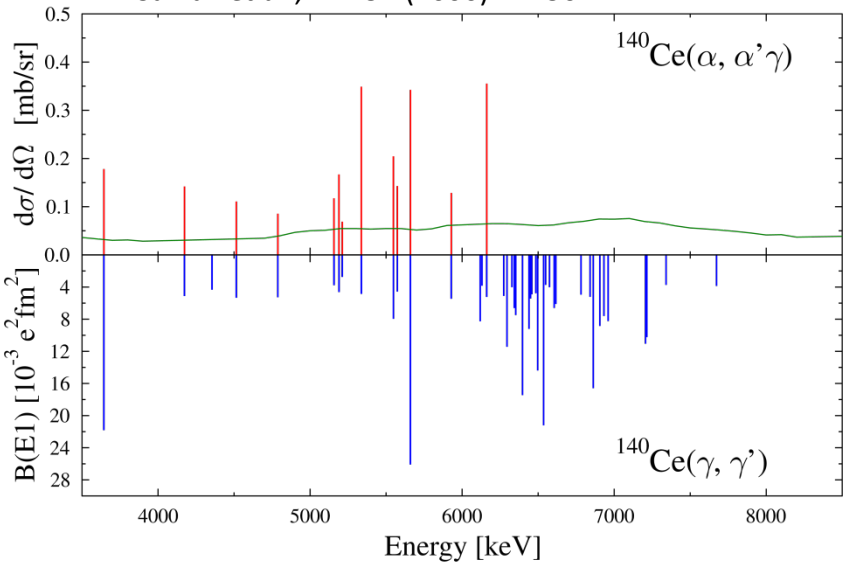
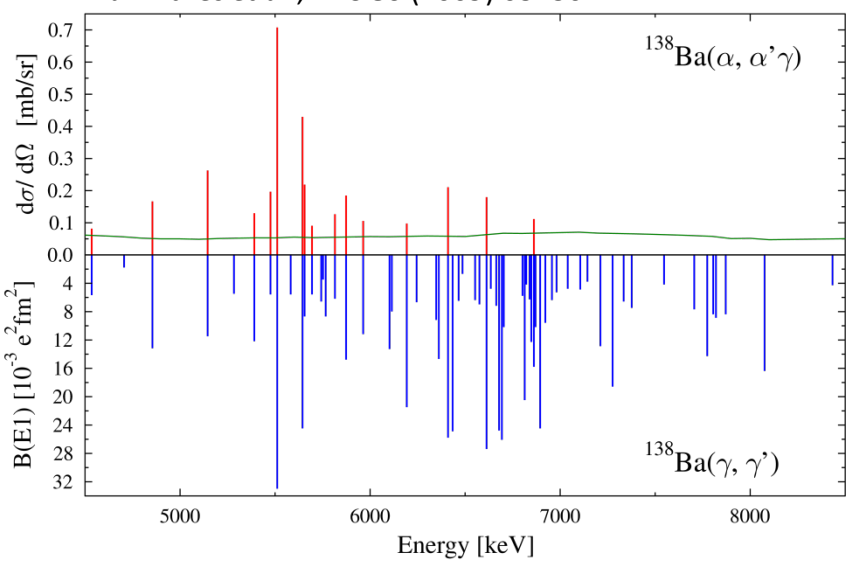
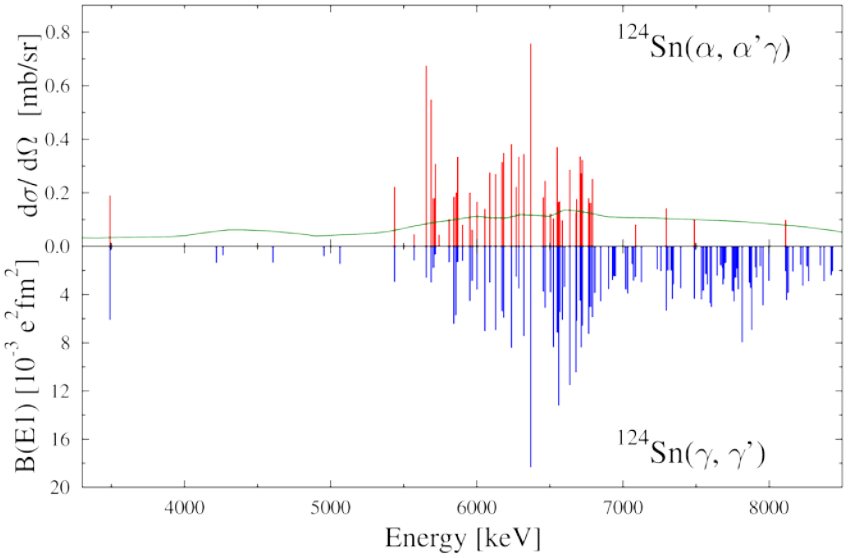
D. Savran *et al.*, PRL **97** (2006) 172502



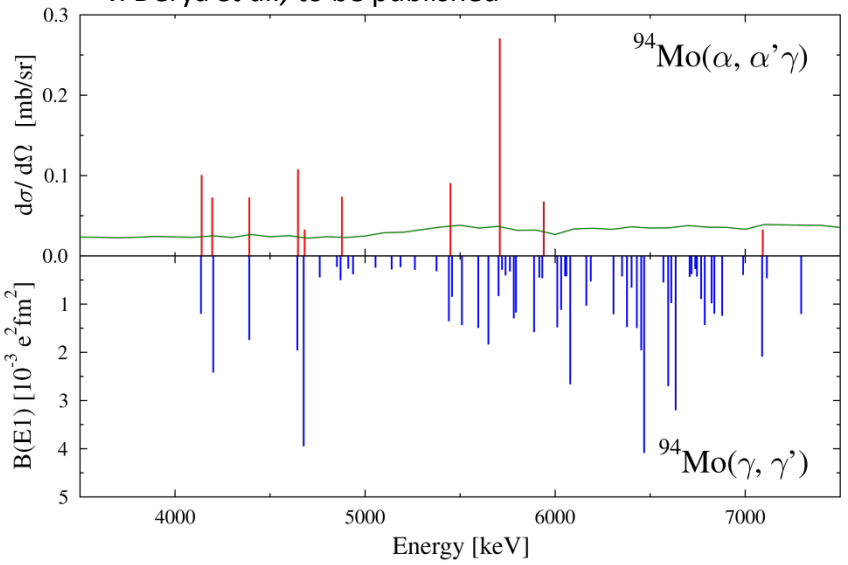

J. Endres *et al.*, PRC **80** (2009) 034302



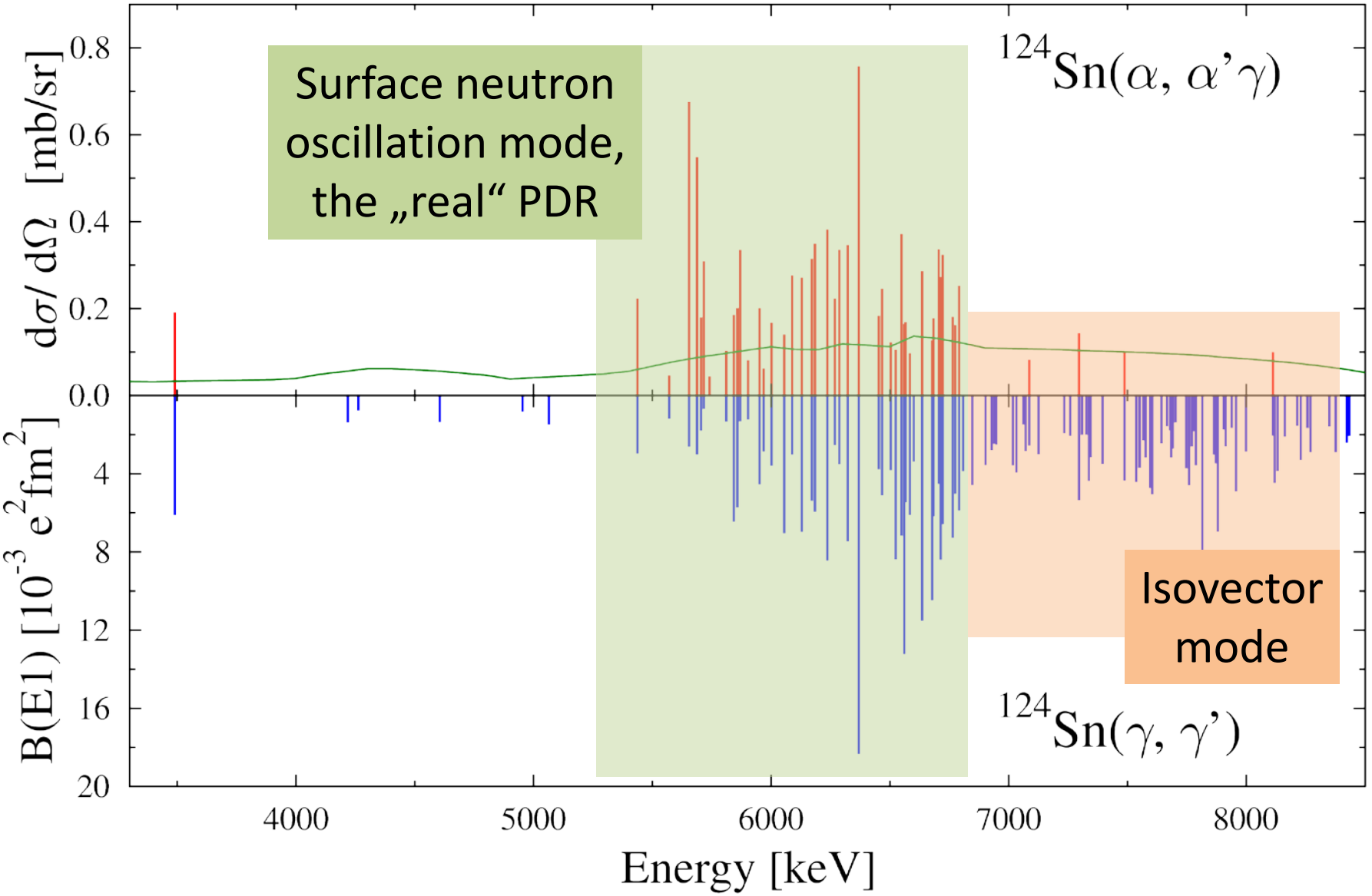

J. Endres, E.Litvinova *et al.*, PRL **105** (2010) 212503




V. Derya *et al.,* to be published



# Splitting of the PDR: Interpretation from RQTBA




*Janis Endres et al., PRL **105** (2010) 112503*
*Janis Endres et al., submitted*

# Some open questions and future plans

**Strength below and above threshold:**

$^{48}$Ca, $^{120}$Sn, $^{144}$Sm @ Grand RAIDEN @ RCNP (data evaluation)

$^{124\text{-}134}$Sn, $^{136}$Xe @ LAND/R3B setup @ GSI (May 2012)

$^{70}$Zn, $^{96}$Mo, $^{130}$Te @ Grand RAIDEN @ RCNP (May 2012)

**Structure of the E1 strength:**

$^{140}$Ce(p,p'$\gamma$) @ BBS @ KVI (April 2012)

$^{124,128}$Sn(d,d') @ LAND/R3B setup @ GSI (May 2012)

$^{124,128,132}$Sn($\alpha$,$\alpha$') @ BigRIPS @ RIKEN (2012)

$^{124}$Sn, $^{140}$Ce($\vec{\gamma}$,$\gamma$') @ $\gamma^3$HIGS @ Duke (2012)

$^{116\text{-}124}$Sn @ NEPTUN @ TU Darmstadt (2013)

# Newest results on pygmy resonances in atomic nuclei

V. Derya, J. Endres, A. Hennig, J. Mayer, L. Netterdon, S. Pascu, S. Pickstone, A. Sauerwein, S. Skalacki, F. Schlüter, P. Scholz, M. Spieker, S. Weber, and A. Z.

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*Extreme Matter Institute EMMI, Darmstadt*

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