

# The Pygmy Dipole Resonance – status and new developments

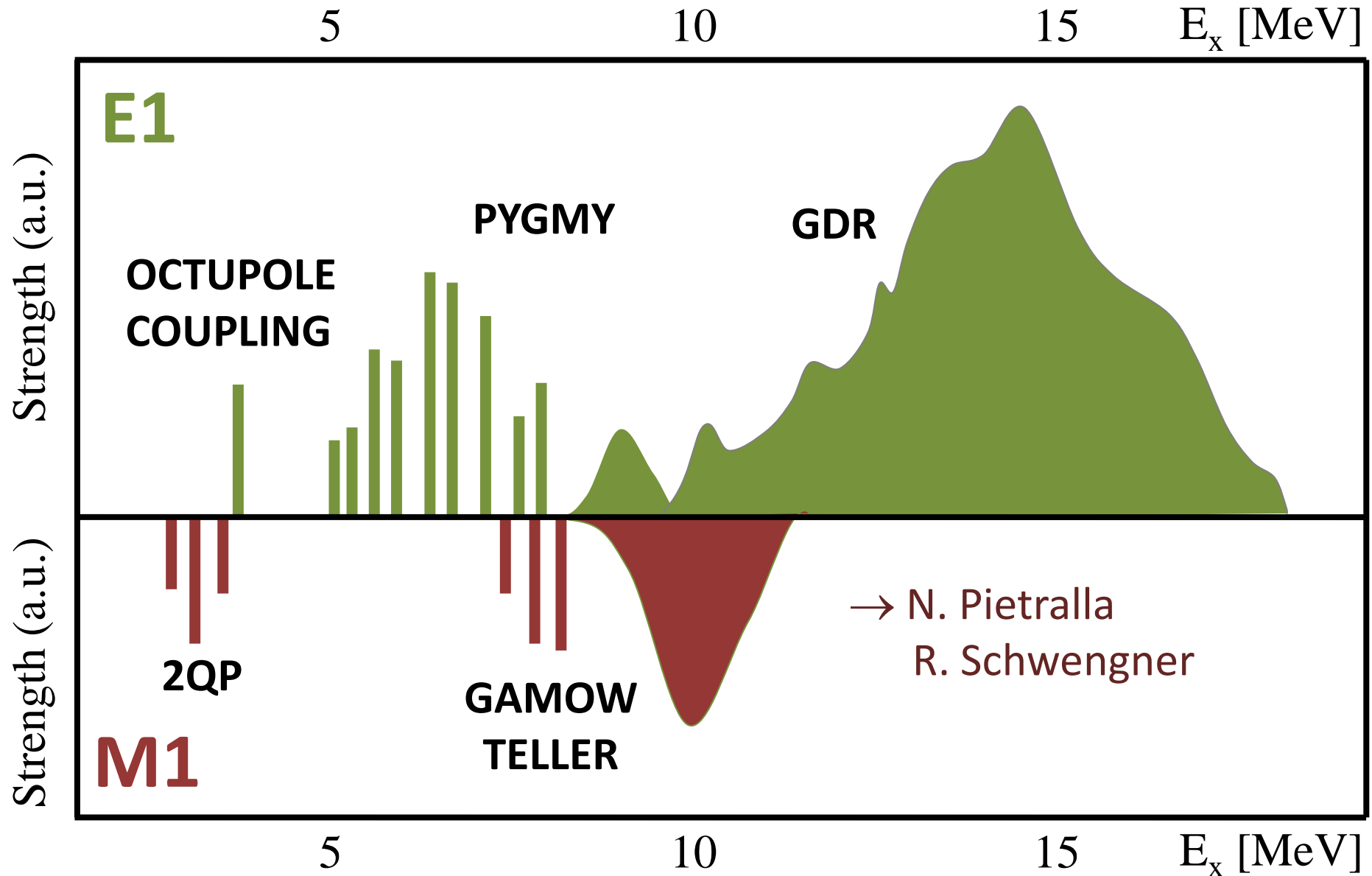
- From Giants to Pygmies – a short history
- Electromagnetic and hadronic interaction:  
Methods and experimental status
- Open questions and new experiments



Andreas Zilges  
University of Cologne



# Dipole response of atomic nuclei



# Giant Dipole Resonance (GDR)

**1937:**

**Atomumwandlungen durch  $\gamma$ -Strahlen.**

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

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

75 years ago

## 1938: Nuclear Photo-effects

THE beautiful experiments of Bothe and Gentner<sup>1</sup> on the ejection of neutrons from heavier nuclei by means of  $\gamma$ -rays with energy of about 17 M.v. resulting from impact of protons on lithium, have revealed a remarkable selectivity of these nuclear photo-effects. ...

N. BOHR.

Universitetets Institut  
for Teoretisk Fysik,  
Copenhagen, ø  
Jan. 31.

*nature* **141** (1938) 326

# Giant Dipole Resonance (GDR)

**1937:**

**Atomumwandlungen durch  $\gamma$ -Strahlen.**

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

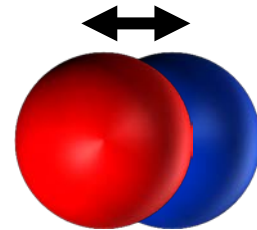
*Z. Phys.* **106** (1937) 236

**1944:**

**QUADRUPOLE AND DIPOLE  $\gamma$ -RADIATION OF NUCLEI**

By **A. MIGDAL**

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



# Giant Dipole Resonance (GDR)

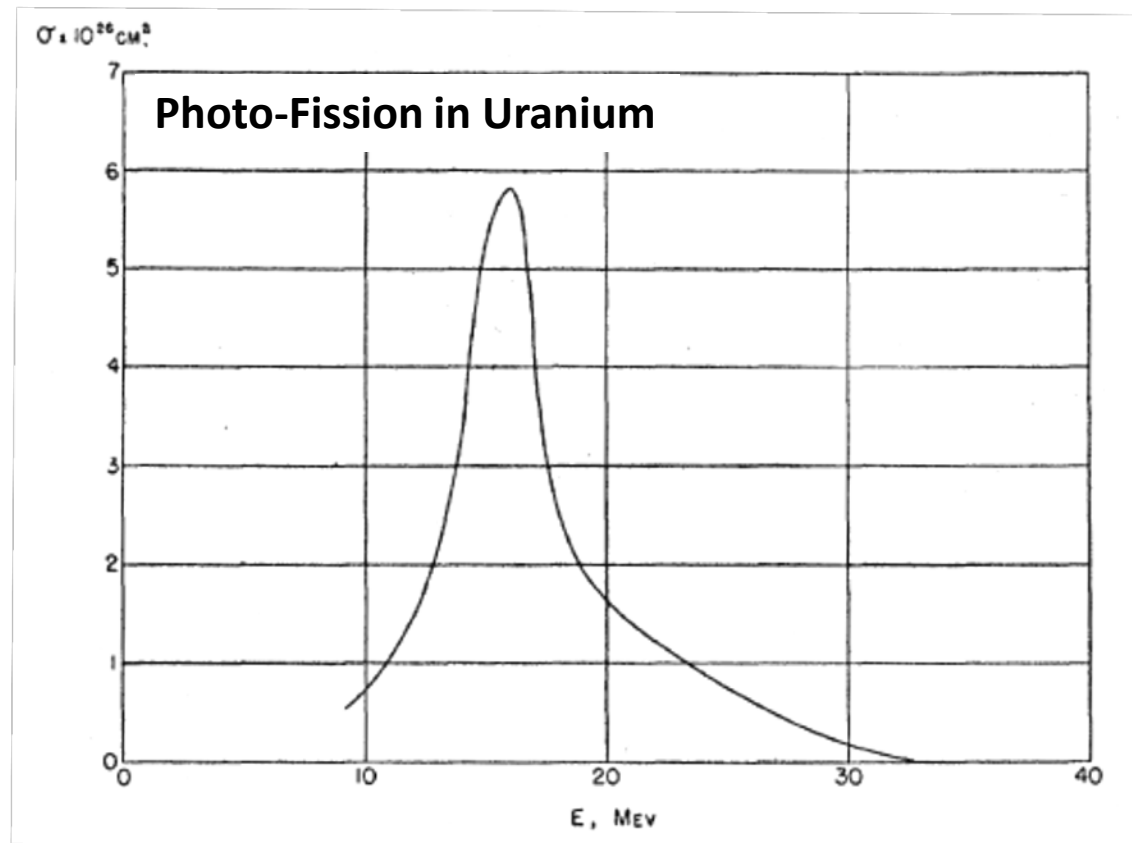
1947:

## 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*

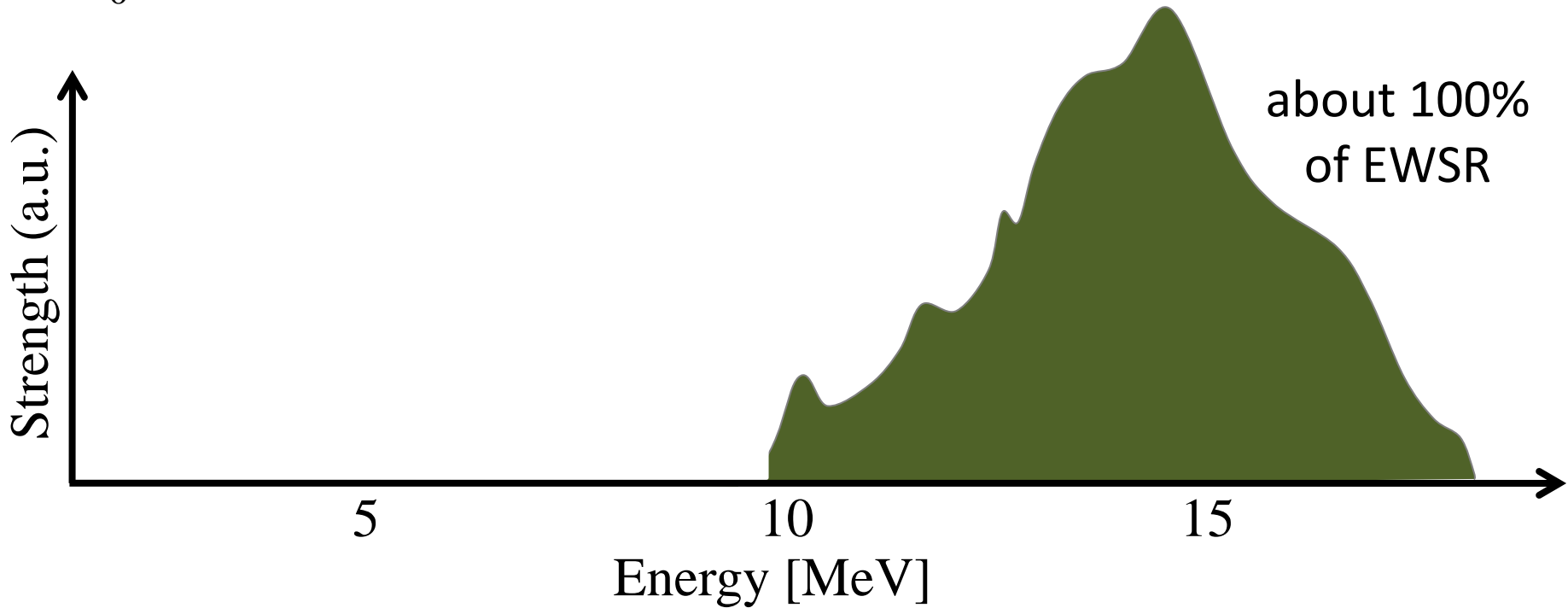
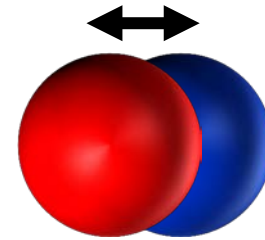


# Giant Dipole Resonance (GDR)

$$E_x = 31 A^{-1/3} + 21 A^{-1/6}$$

$$\int_0^{\infty} \sigma(E) dE = 60 \frac{NZ}{A} \text{MeV} \cdot \text{mb}$$

**GDR**



# Pygmy Dipole Resonance (PDR)

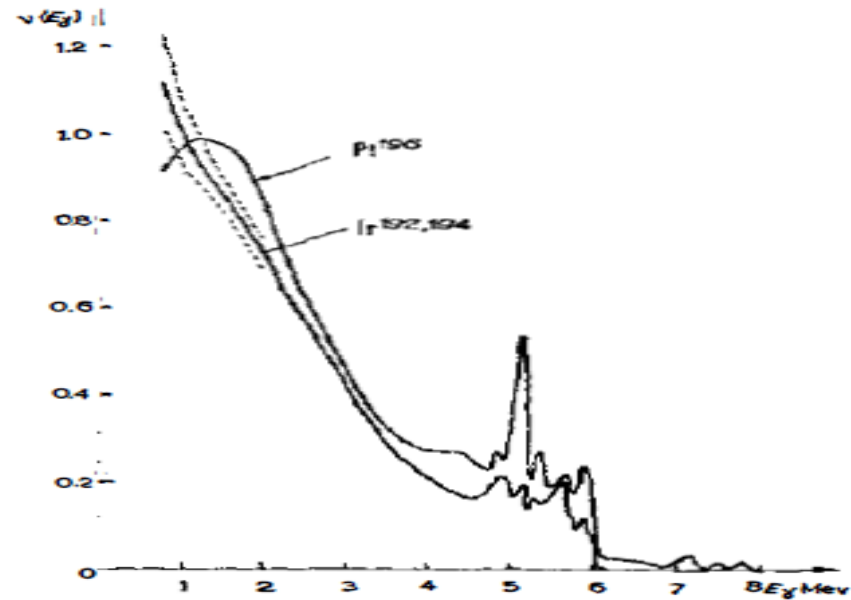
1961:

## NEUTRON CAPTURE GAMMA RAYS<sup>1</sup>

By G. A. BARTHOLOMEW

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

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





# Pygmy Dipole Resonance (PDR)

**1961:**

NEUTRON CAPTURE GAMMA RAYS<sup>1</sup>

BY G. A. BARTHOLOMEW

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

*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. WILHELM

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

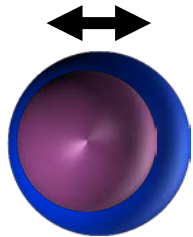
# Pygmy Dipole Resonance (PDR)

**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



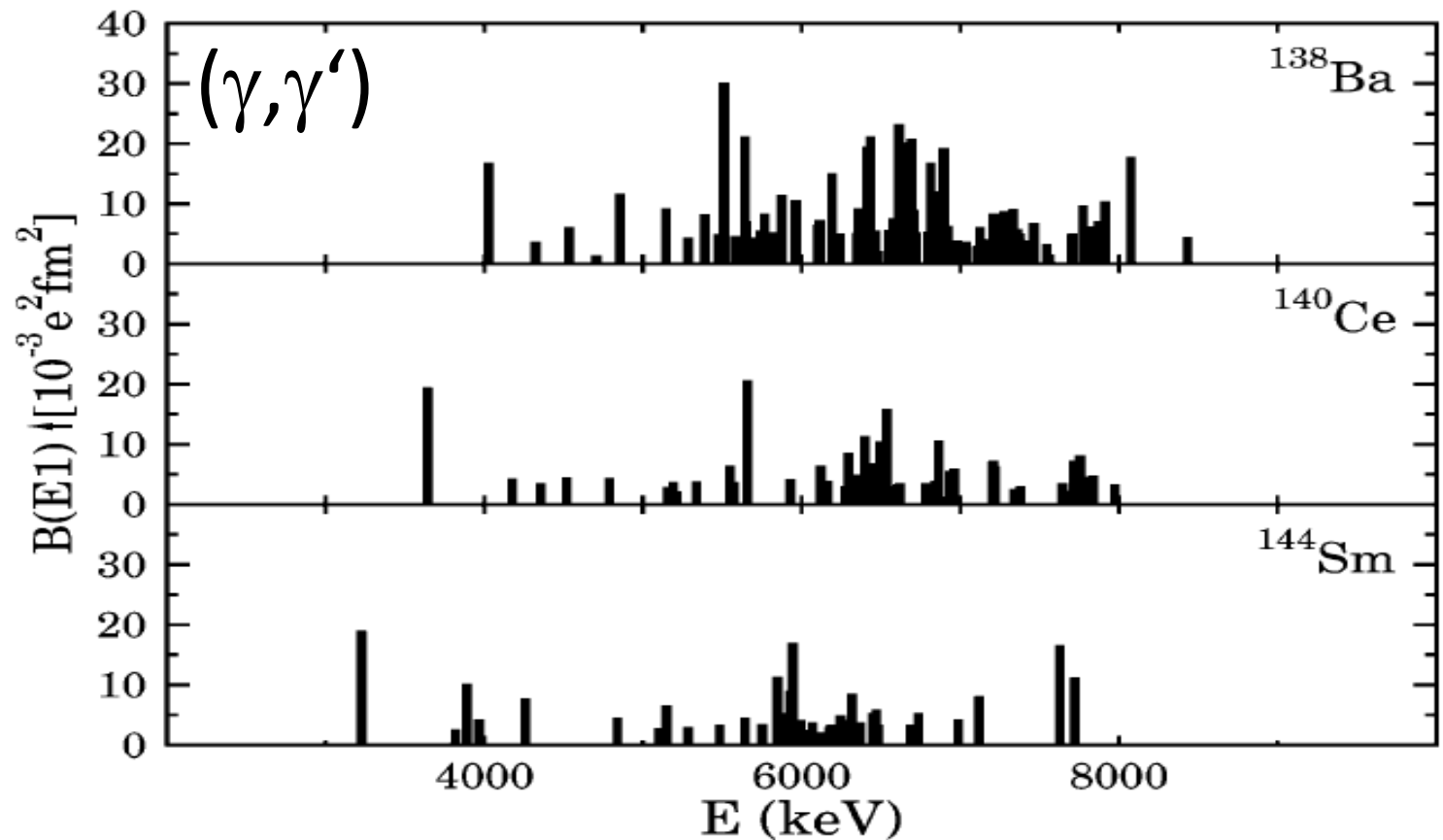
# Pygmy Dipole Resonance (PDR)

**2002:**

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

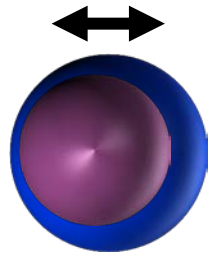
A. Zilges, S. Volz, M. Babilon, T. Hartmann, P. Mohr, K. Vogt

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

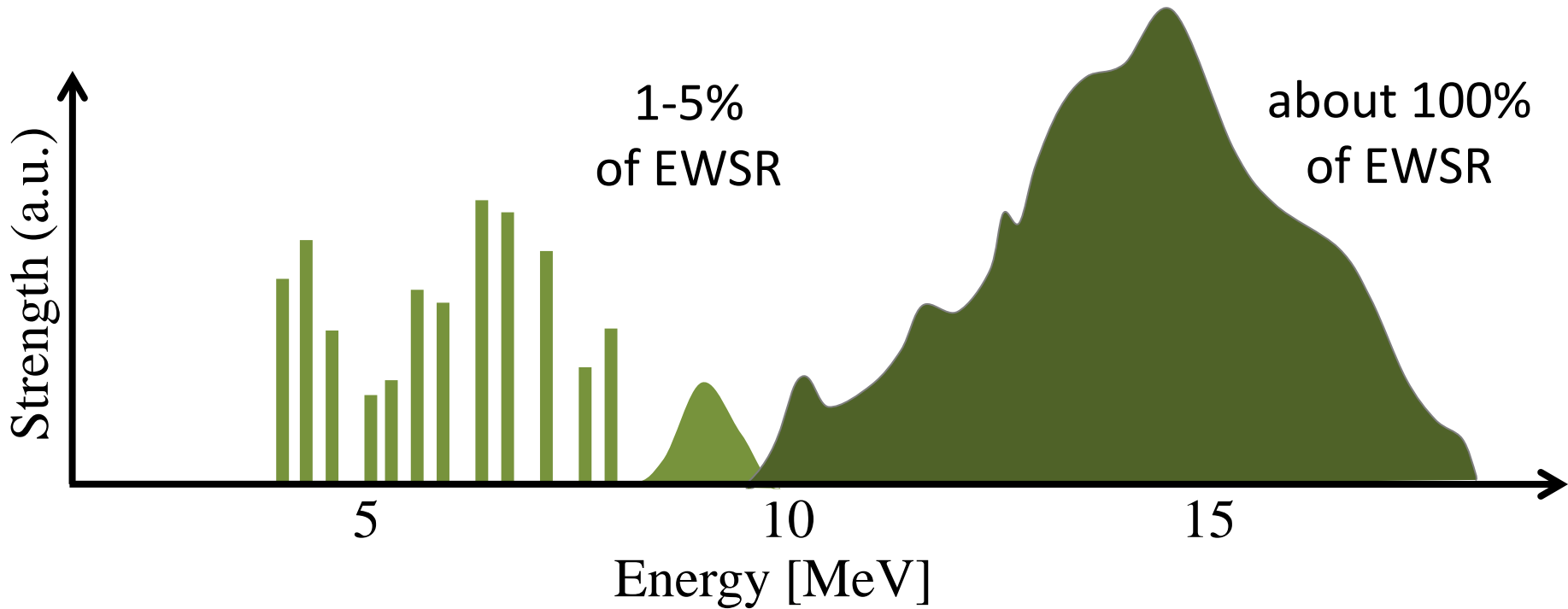
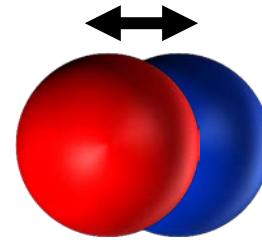


# From giants to pygmies

**PDR**

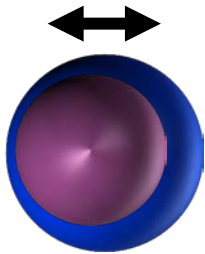


**GDR**

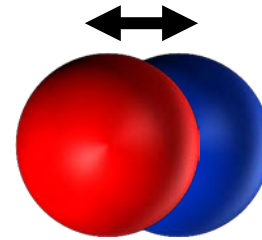


# From giants to pygmies

**PDR**



**GDR**



Strength (a.u.)

5

10

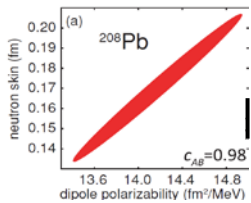
15

Energy [MeV]

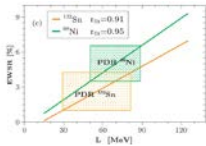


# Relevance of low-lying E1 strength

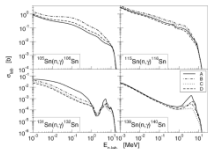
- PDR as a universal „collective“ excitation mode
- Connection to neutron skin, neutron star radius
- Slope of symmetry energy in EoS
- Impact on nucleosynthesis



*P.-G. Reinhard and W. Nazarewicz, PRC **81** (2010) 051303(R)*  
*J. Piekarewicz et al., PRC **85** (2012) 041302(R)*  
*J. Erler et al., PRC **87** (2013) 044320*

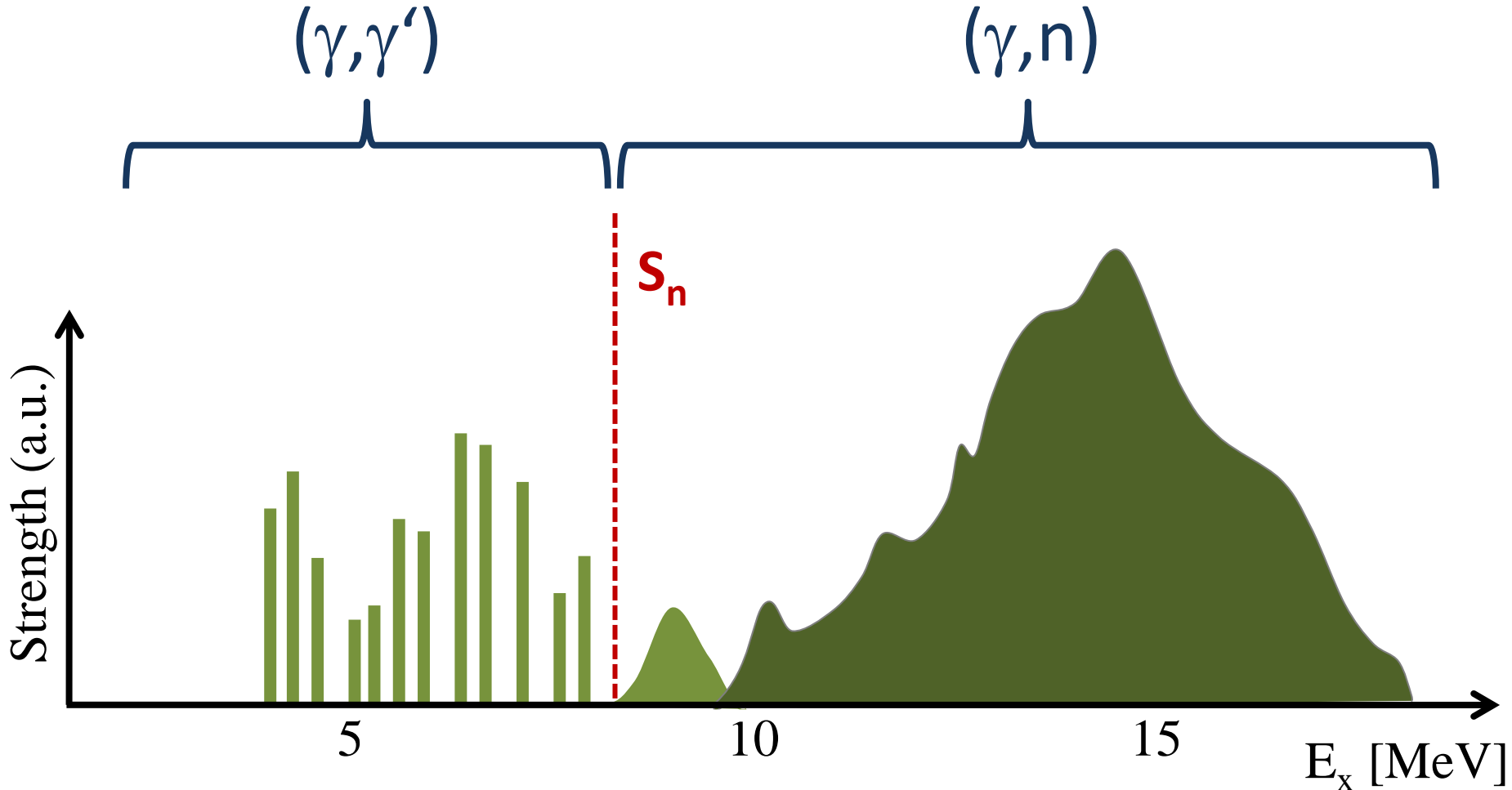


*A. Carbone et al. PRC **81** (2010) 041301(R)*  
*B.A. Brown and A. Schwenk, PRC **89** (2014) 011307(R)*



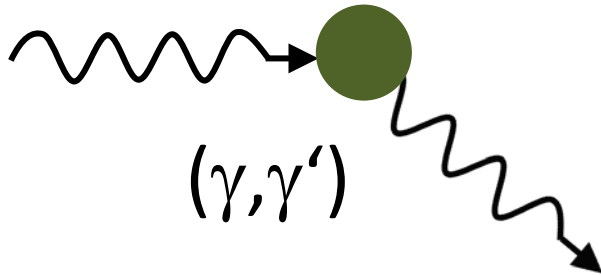
*S. Goriely, PLB **436** (1998) 10*  
*E. Litvinova et al., NPA **823** (2009) 26*

# Study of the E1 strength distribution via electromagnetic interaction

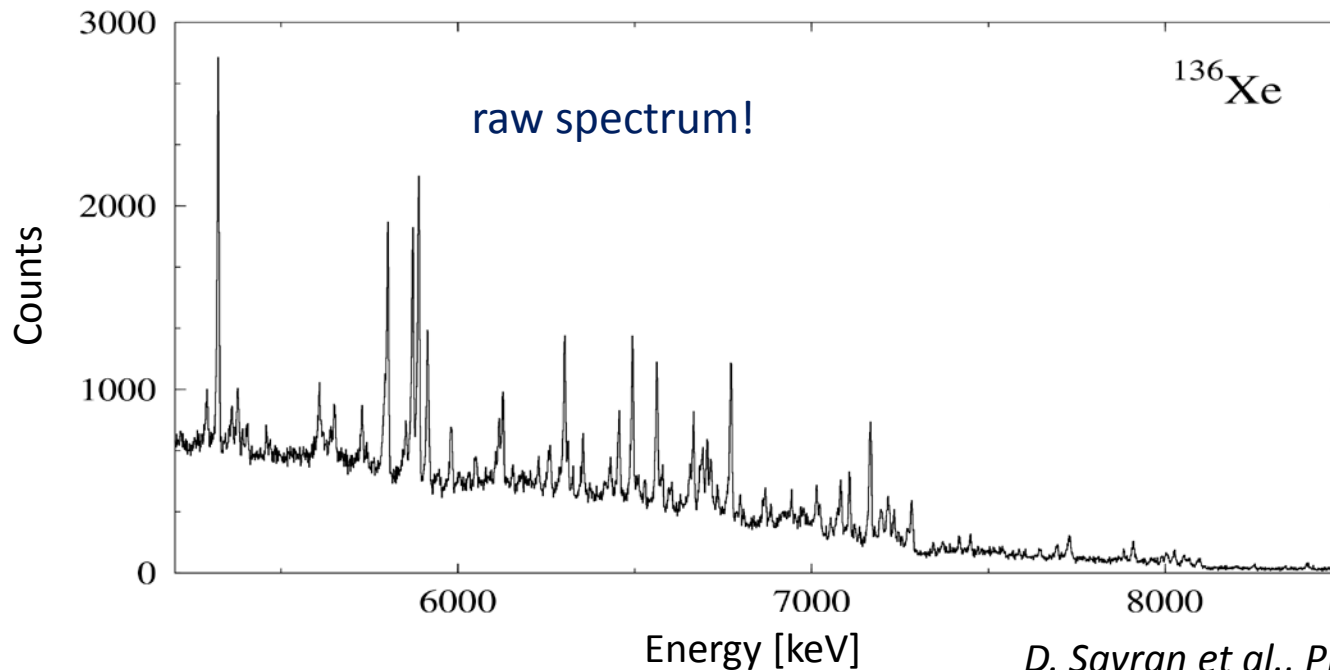


The photons can be real or virtual!

# Scattering of real photons ( $\gamma, \gamma'$ )



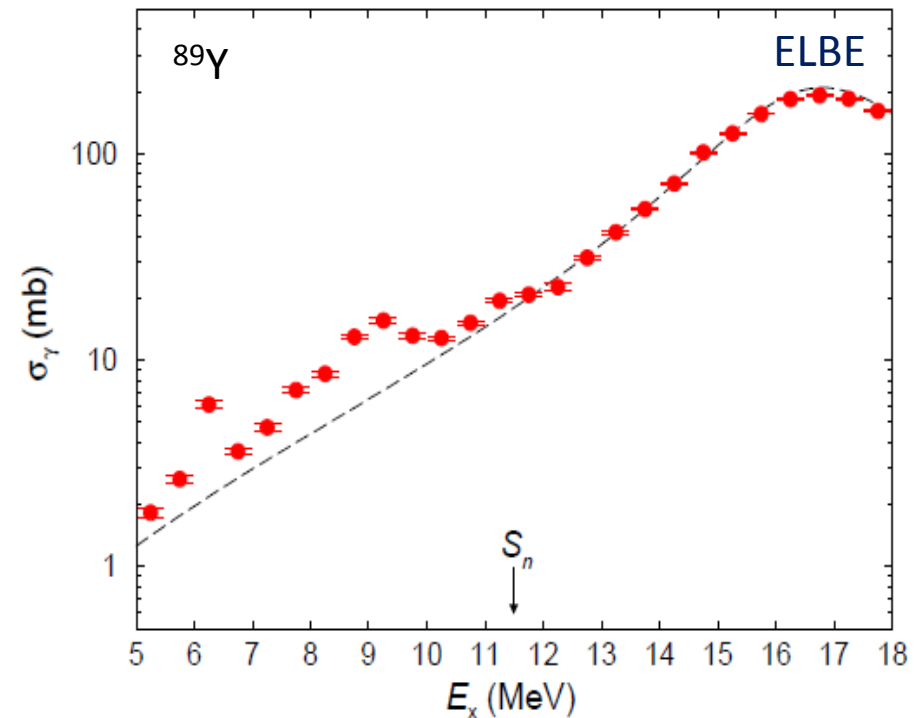
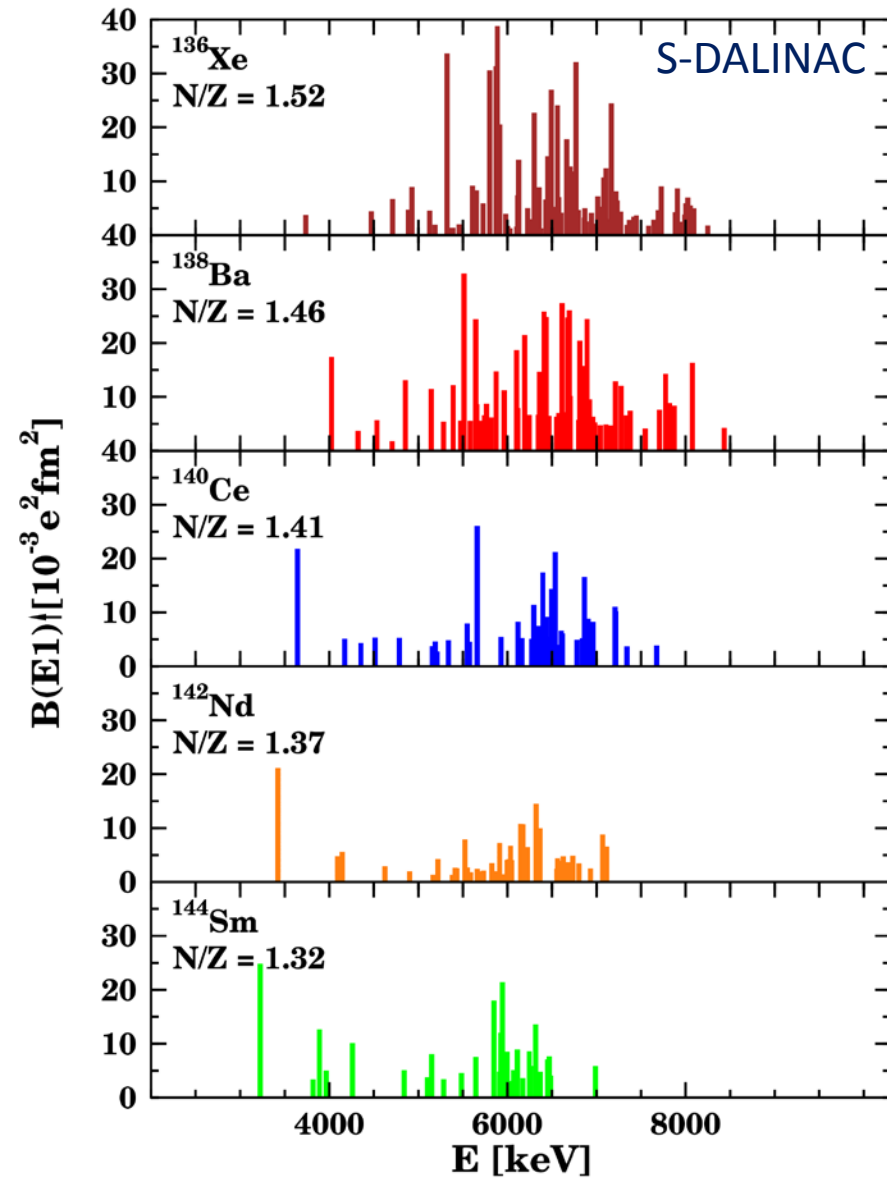
- $E_\gamma = 0 - S_n$
- very selective excitation ( $\Delta J=1$  or  $2$ )
- energy resolution  $\Delta E=5-10$  keV
- complex sensitivity limit
- only stable nuclei can be studied



S-DALINAC@TUD  
ELBE@HZDR  
HIGS@DUKE  
ELI@Bukarest



# E1 distribution in stable nuclei: ( $\gamma, \gamma'$ )



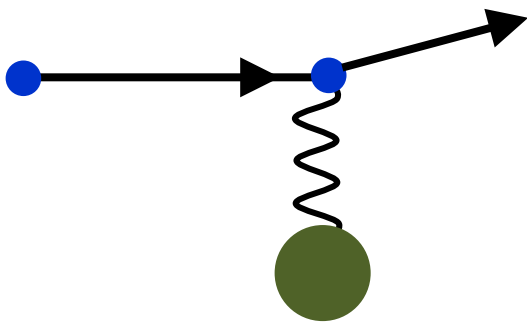
*N. Benouaret et al., PRC 79 (2009) 014303*

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

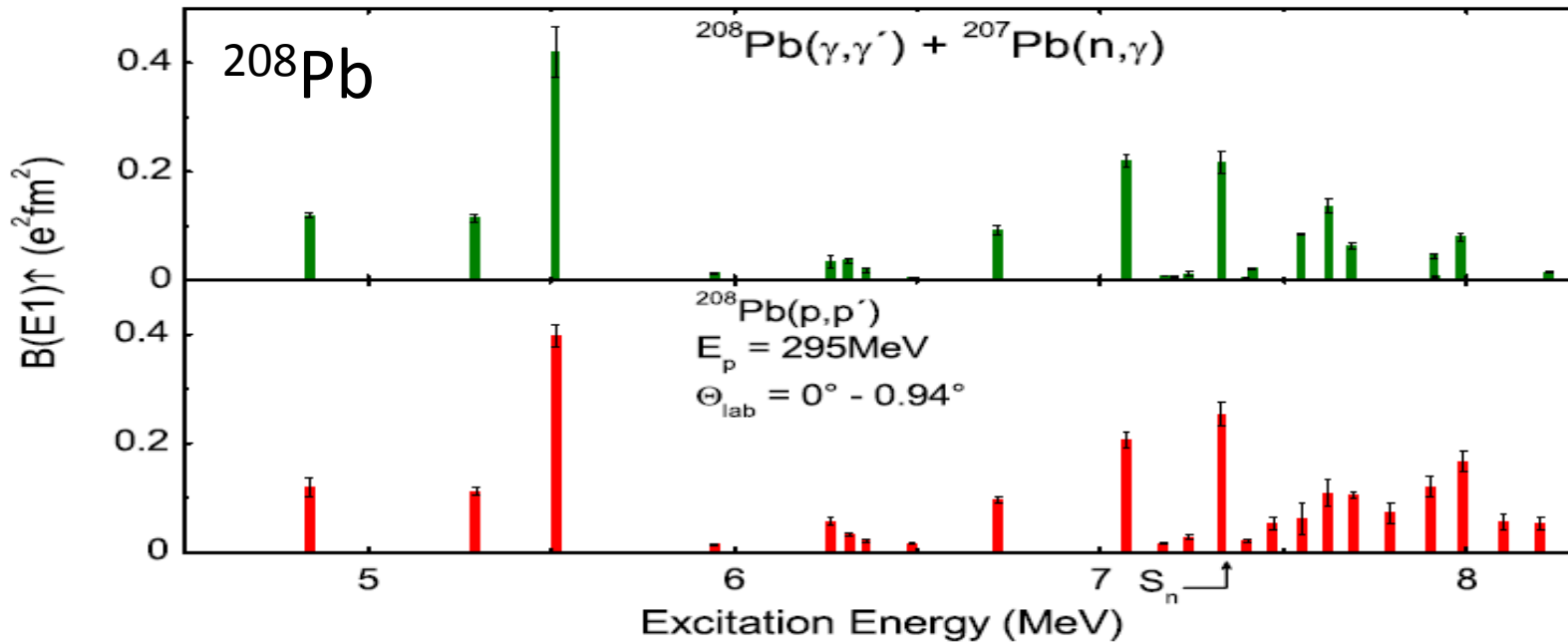
*S. Volz et al., NPA 779 (2006) 1*

*A. Zilges et al., PLB 542 (2002) 43*

# Scattering of virtual photons via (p,p') at 0°



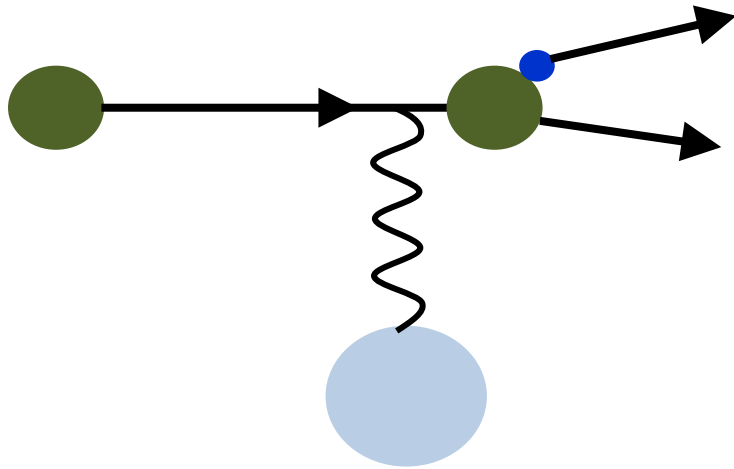
- $E_x = 0 - 25$  MeV
- energy resolution  $\Delta E = 25$  keV
- less selective, complex disentanglement
- only stable nuclei can be studied



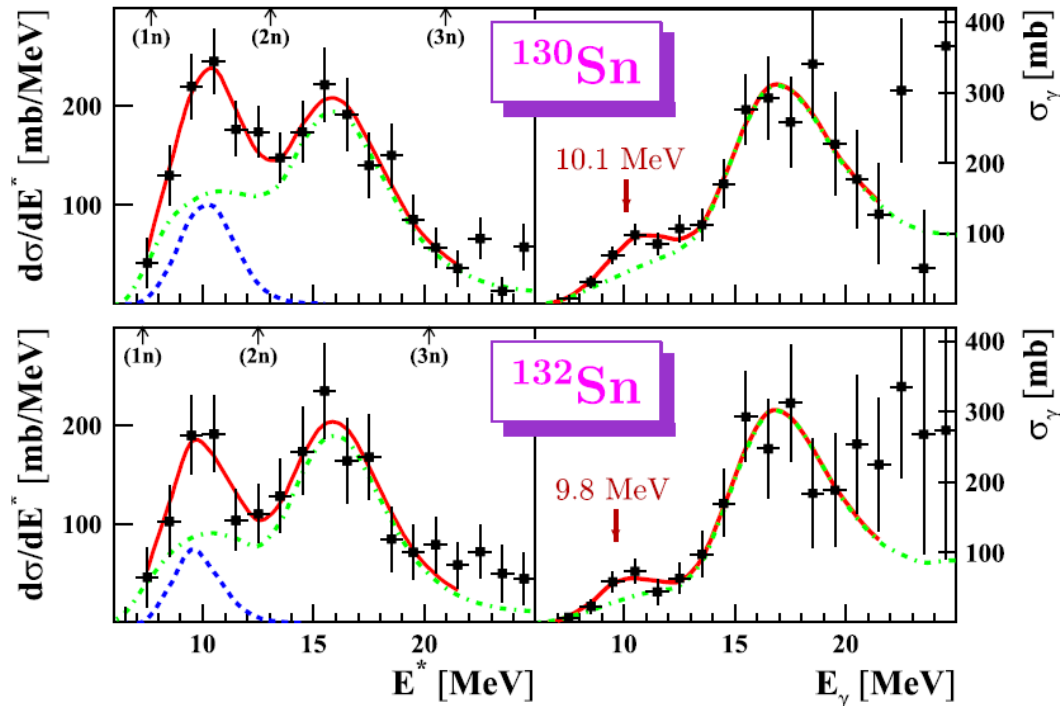
GRAND  
RAIDEN  
@RCNP

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

# Coulomb interaction in inverse kinematics



- $E_{\text{cm}} = \text{few } 100 \text{ MeV/A}$
- radioactive nuclei can be studied
- energy resolution  $\Delta E = 500 \text{ keV}$
- complex data evaluation



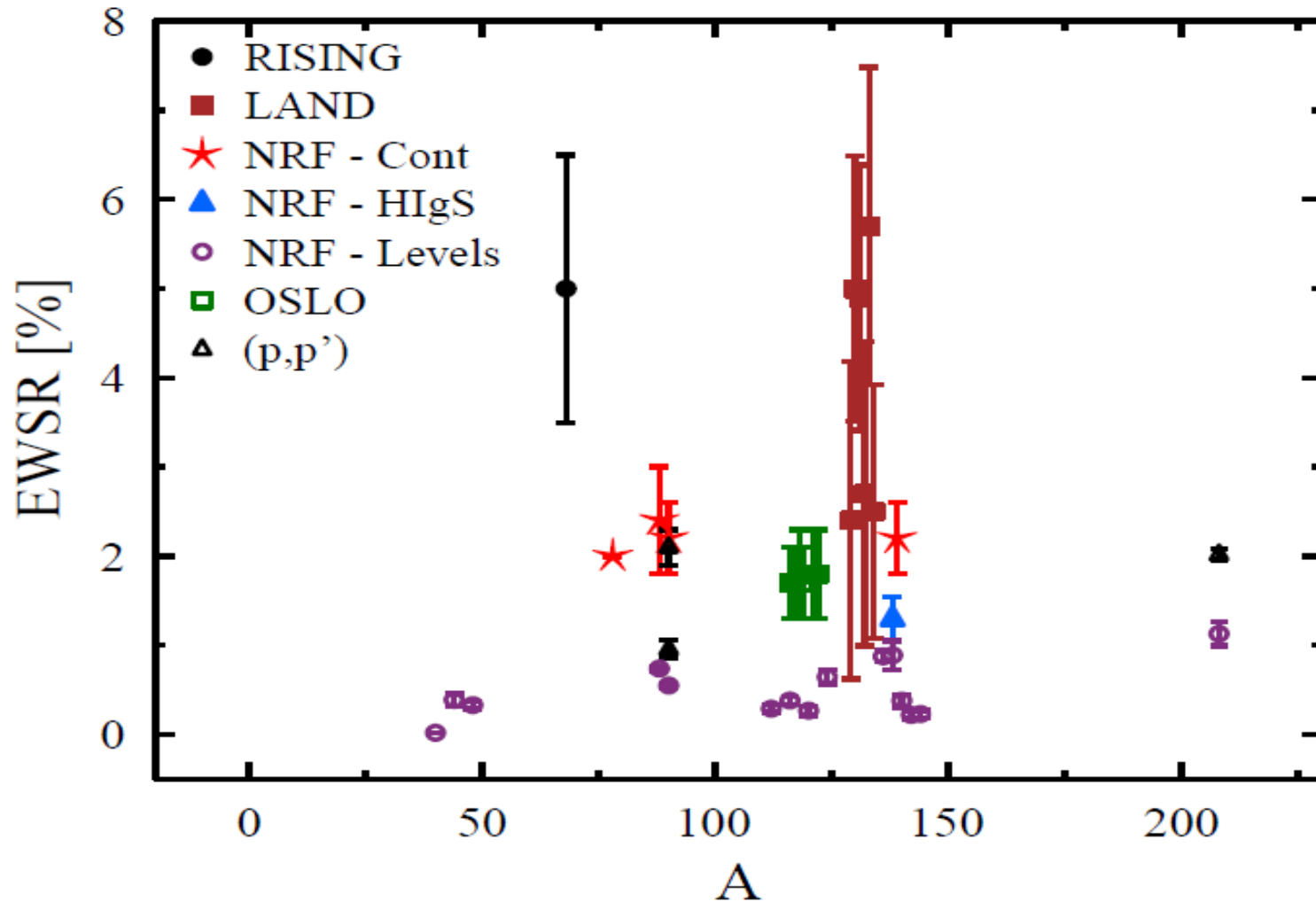
LAND@FRS@GSI

NeuLAND@R3B@FAIR

...

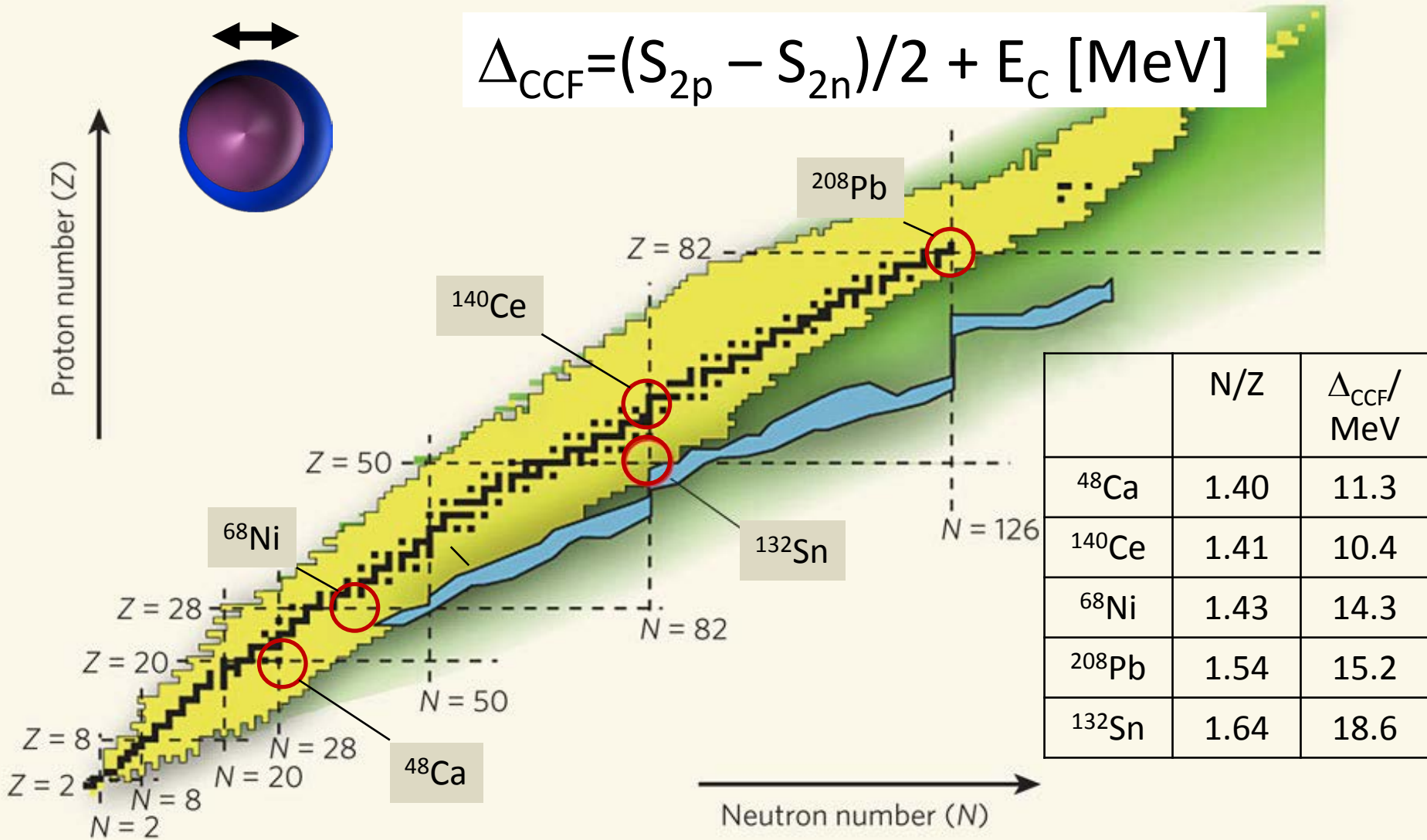
→ talk by O. Wieland

# Summed B(E1) strength of Pygmy Dipole Resonance



*D. Savran, T. Aumann, and A. Zilges, PPNP 70 (2013) 210*

# Parametrization of „exoticity“





# PDR or GDR ?

- Electromagnetic probes yield mainly distribution of E1 strength (and – sometimes – branching ratios)
- Is there an alternative experimental approach to separate the low-lying dipole strength (or PDR) from the GDR ?

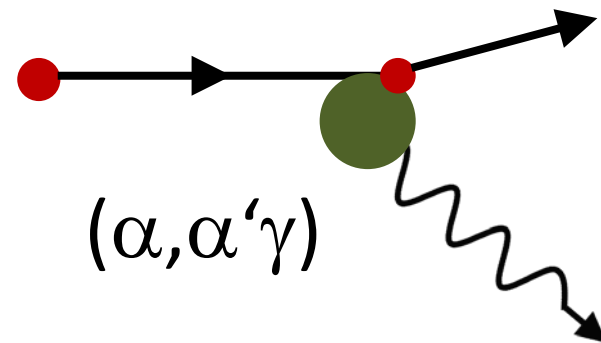
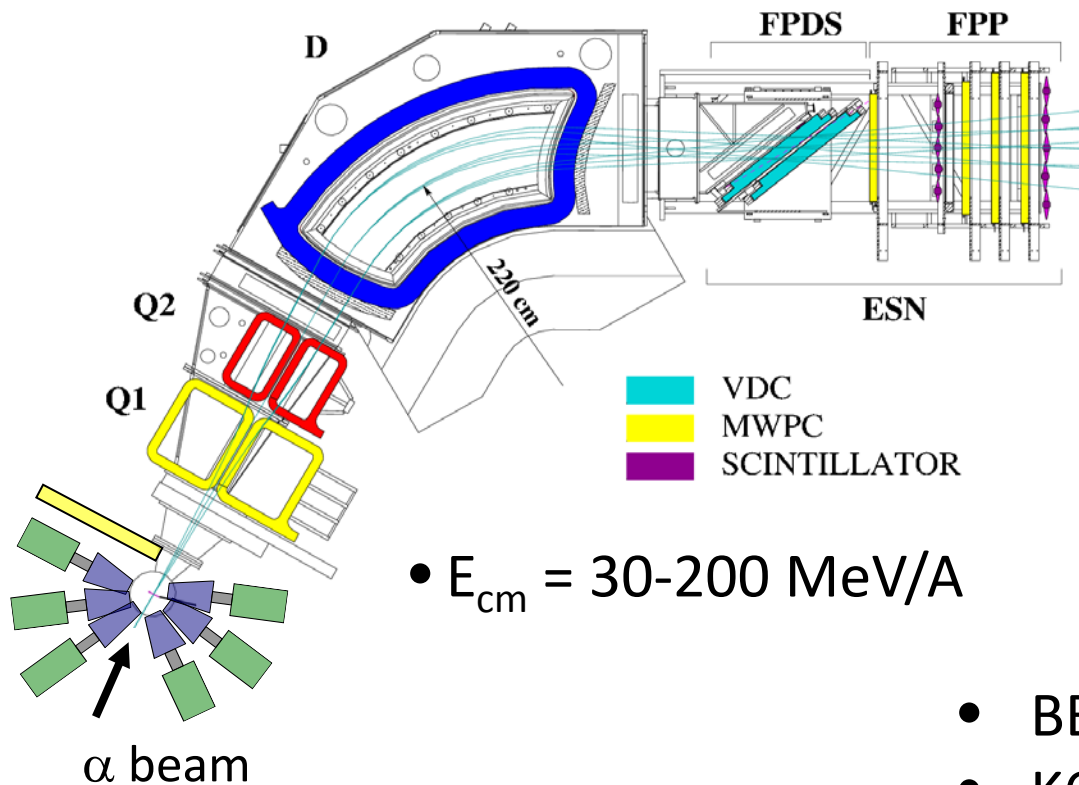
# Structure of the PDR: $(\gamma, \gamma')$ vs. $(\alpha, \alpha')$

	$(\gamma, \gamma')$ or Coulex	$(\alpha, \alpha')$ @ 30 MeV/A
Interaction	electromagnetic	strong
Location of interaction	whole nucleus	surface
Isospin	isovector E1 excitations	dominant isoscalar
Multipolarity	E1, M1, E2	E0, E1, E2, E3, ...
$\Delta E$	<u>3</u> -500 keV	50-200 keV

A coincident detection of the  $\gamma$  decay enhances the selectivity and energy resolution of  $(\alpha, \alpha') \rightarrow (\alpha, \alpha' \gamma)$



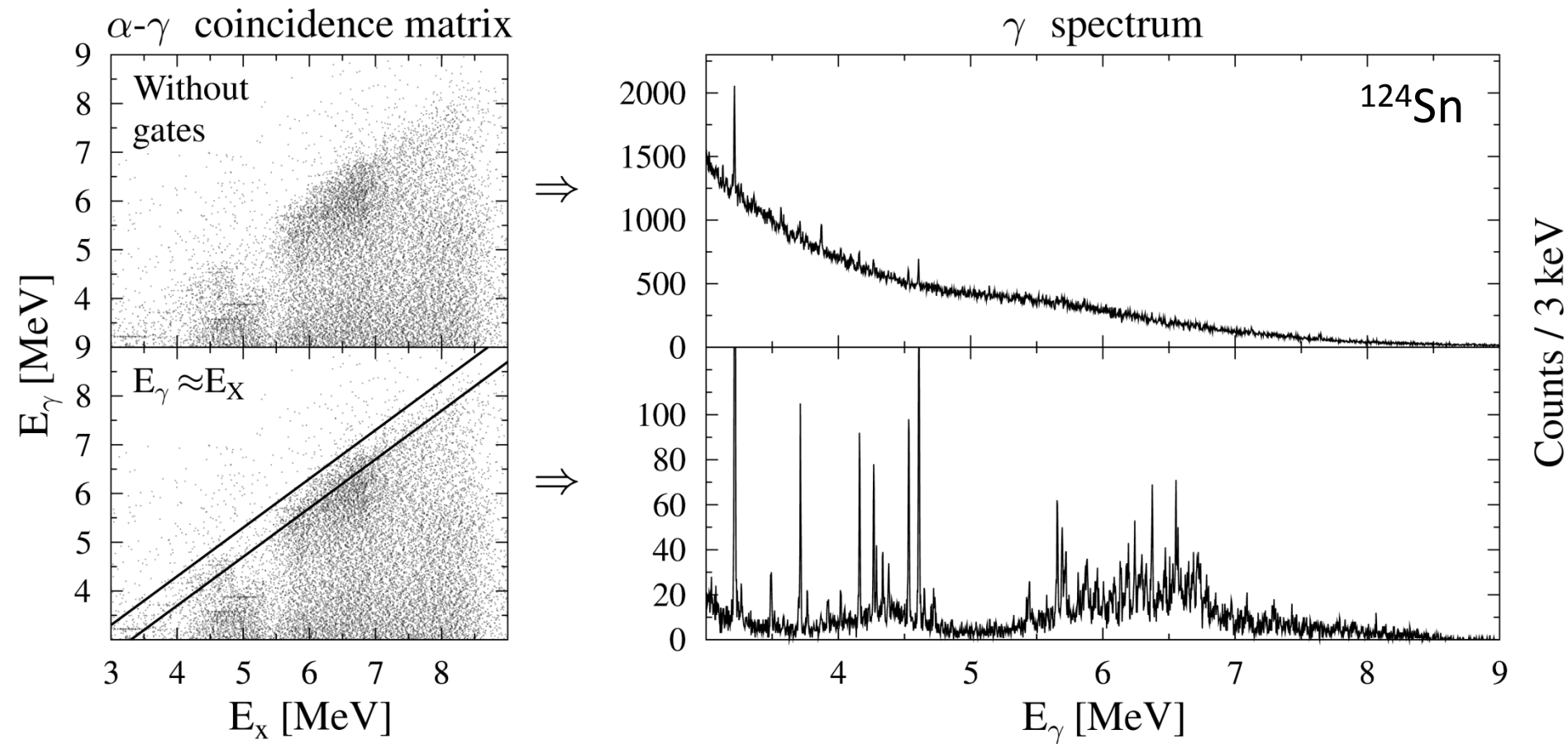
# $(\alpha, \alpha'\gamma)$ and $(p, p'\gamma)$ experiments



*D. Savran et al.,  
NIM A 564 (2006) 267*

- BBS@KVI (deceased 15/11/12)
- K600 @ iThemba LABS
- CAGRA campaign @ RCNP
- BigRIPS@RIKEN

# Structure of the PDR: ( $\alpha, \alpha'\gamma$ ) experiments

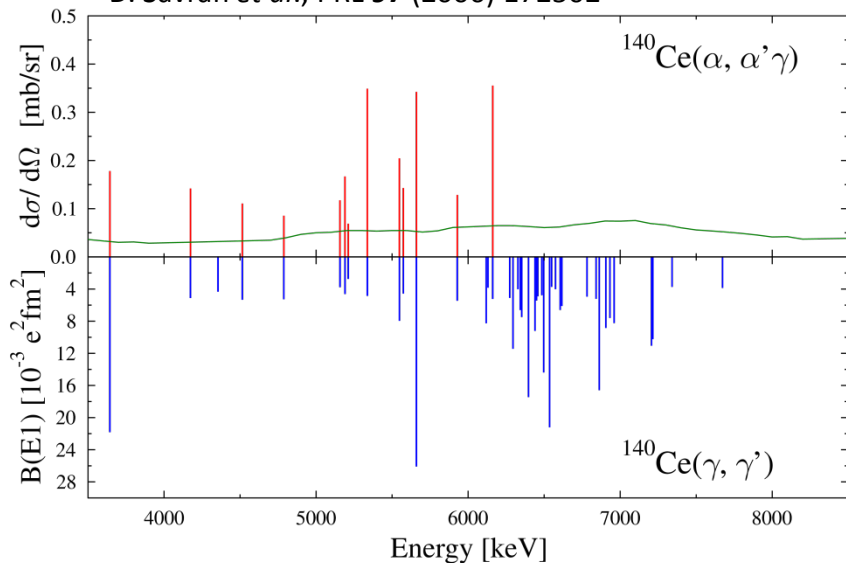


Janis Endres et al., PRL **105** (2010) 112503

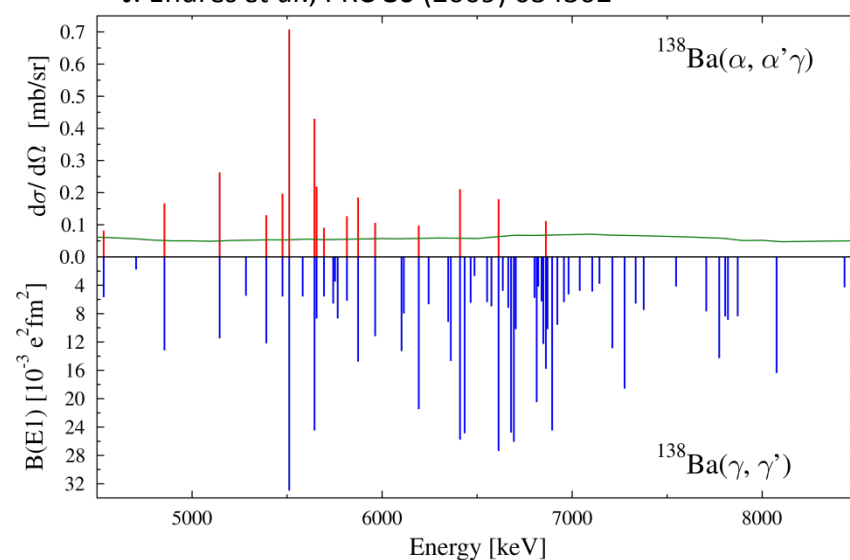
Janis Endres et al., PRC **85** (2012) 064331

# Splitting of strength: Experimental results

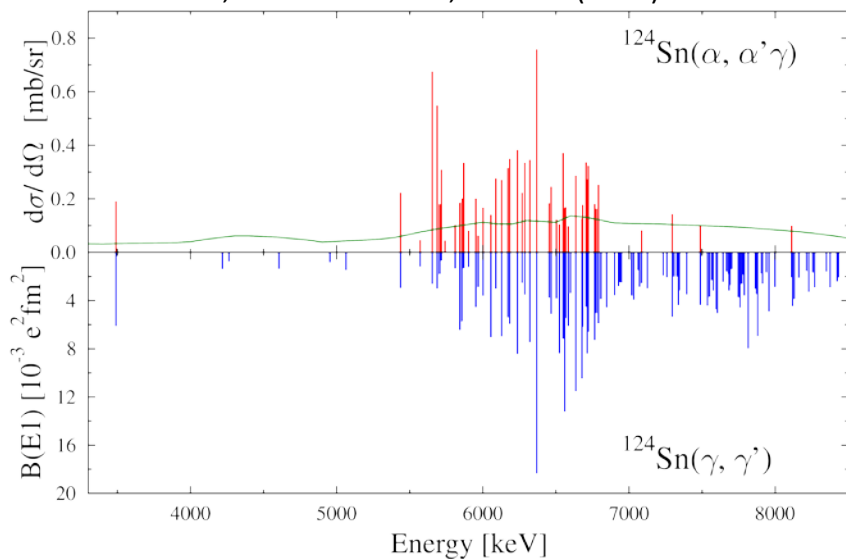
D. Savran *et al.*, PRL **97** (2006) 172502



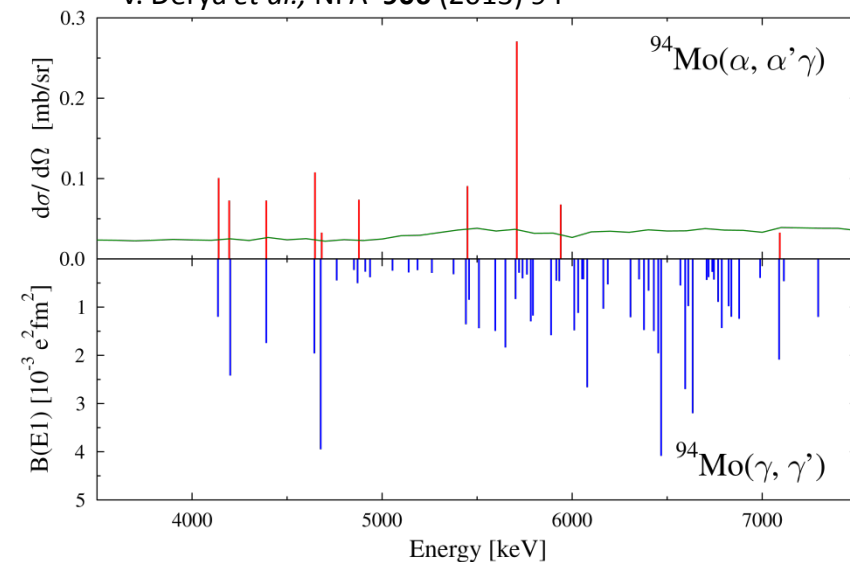
J. Endres *et al.*, PRC **80** (2009) 034302



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

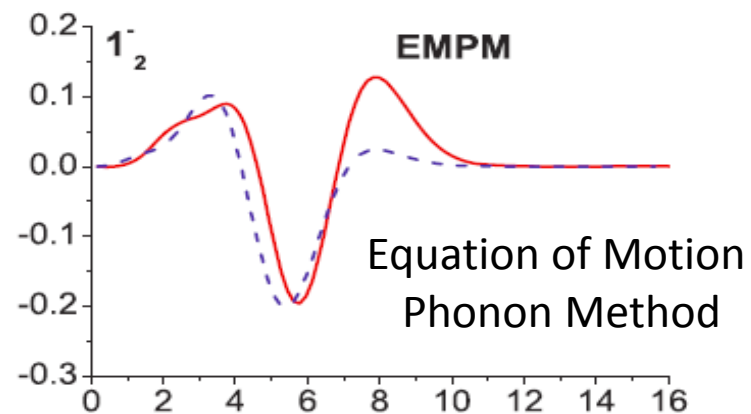
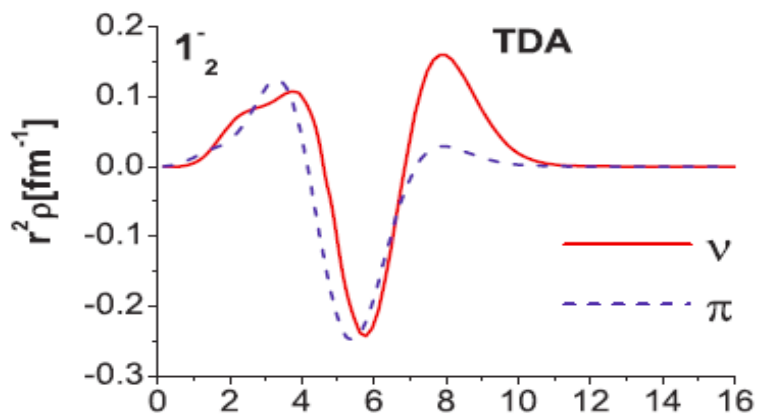


V. Derya *et al.*, NPA **906** (2013) 94

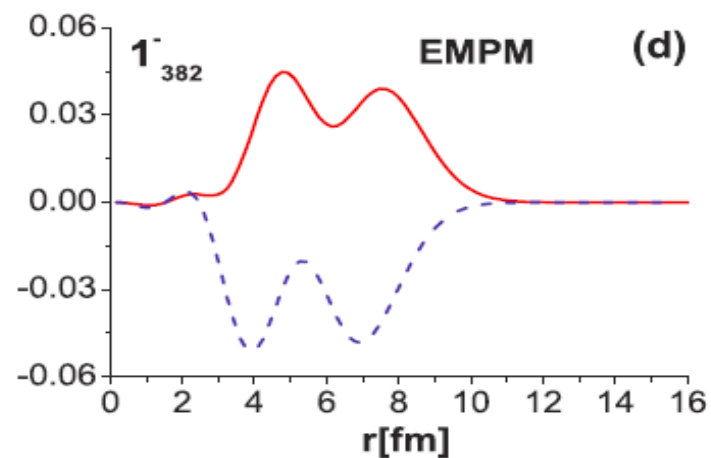
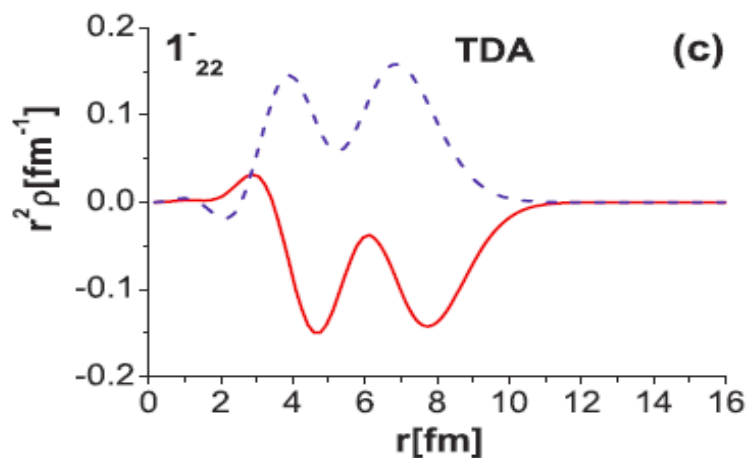


# Transition densities for $1^-$ states in $^{208}\text{Pb}$

PDR  
region



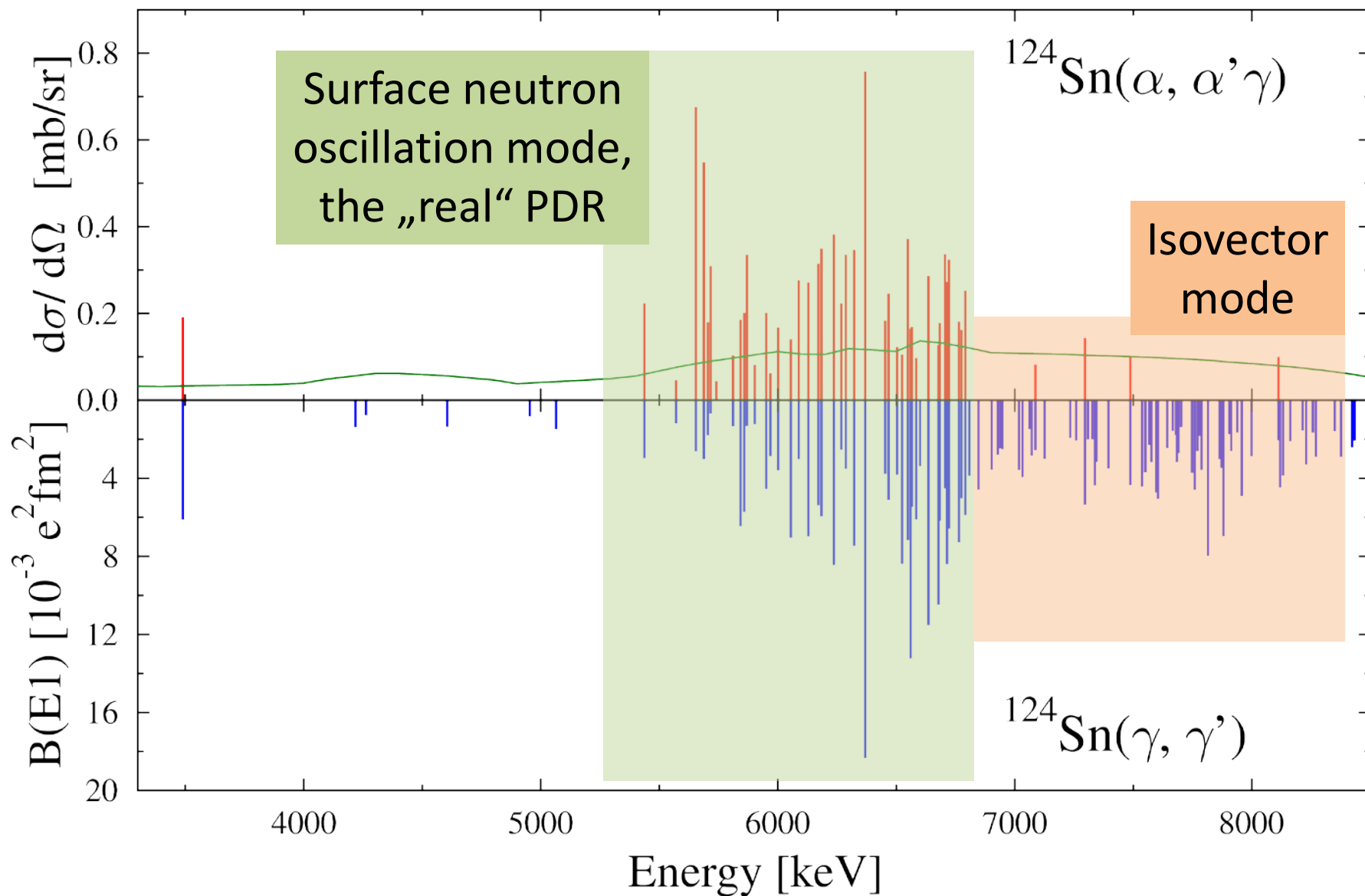
GDR  
region



*D. Bianco, F. Knapp, N. Lo Iudice, F. Andreozzi, A. Porrino, and P. Vesely, PRC 86 (2012) 044327*

→ talk by F. Knapp

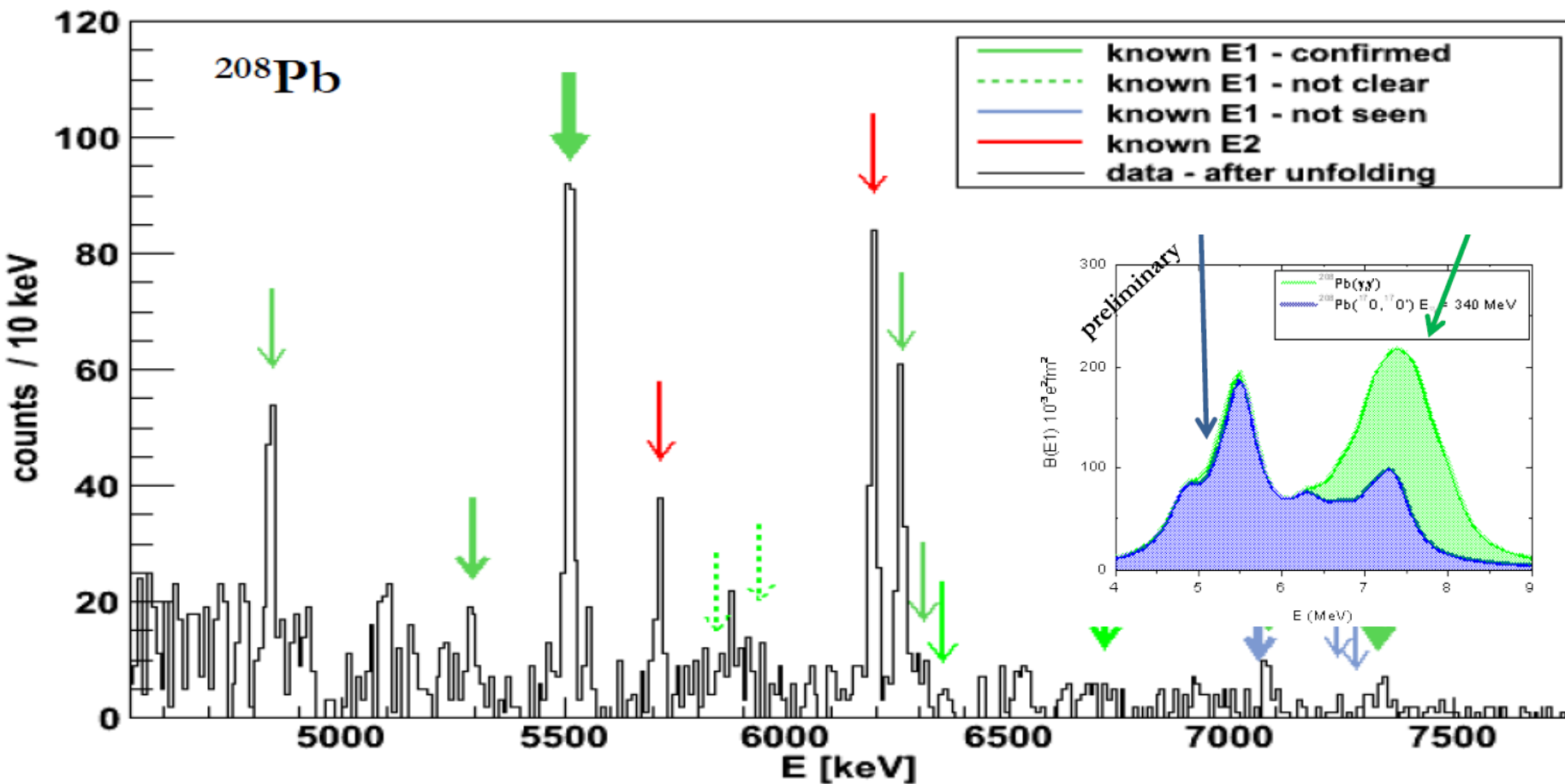
# Splitting of the PDR: Interpretation from RQTBA



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

Janis Endres et al., PRC **85** (2012) 064331

# $\gamma$ decay after inelastic scattering of $^{17}\text{O}$ on $^{208}\text{Pb}$



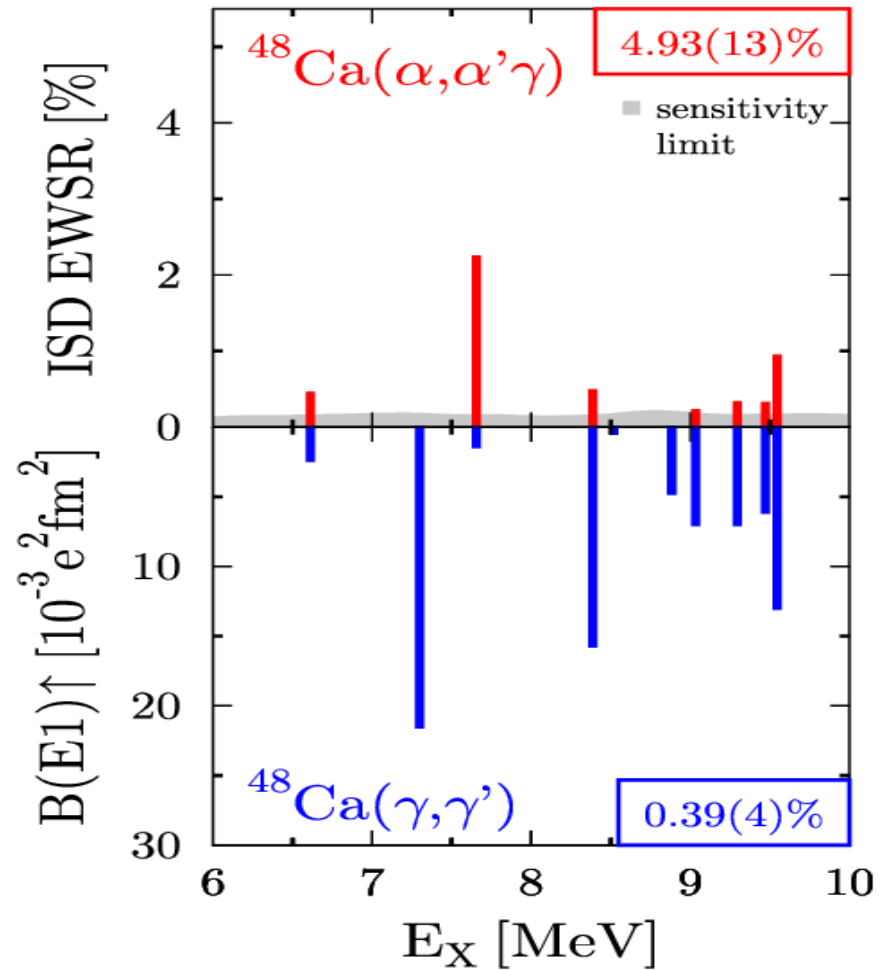
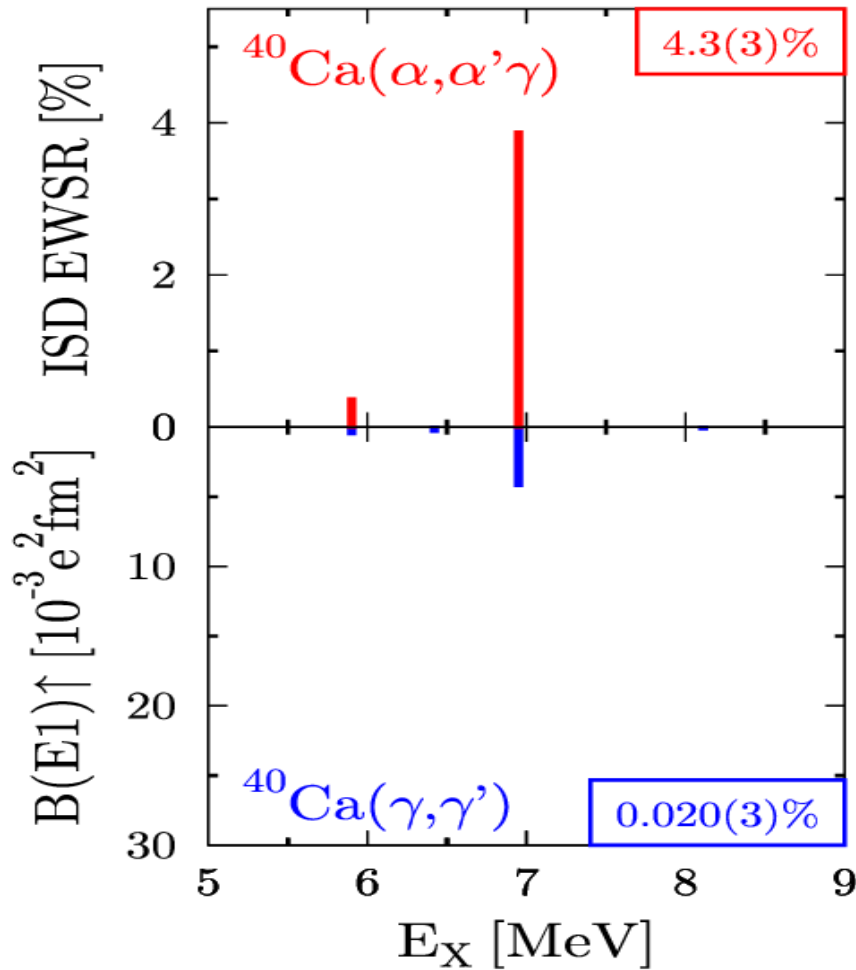
*L. Pellegri, A. Bracco, et al., EUNPC 2012*

→ talk by L. Pellegri

# Open questions

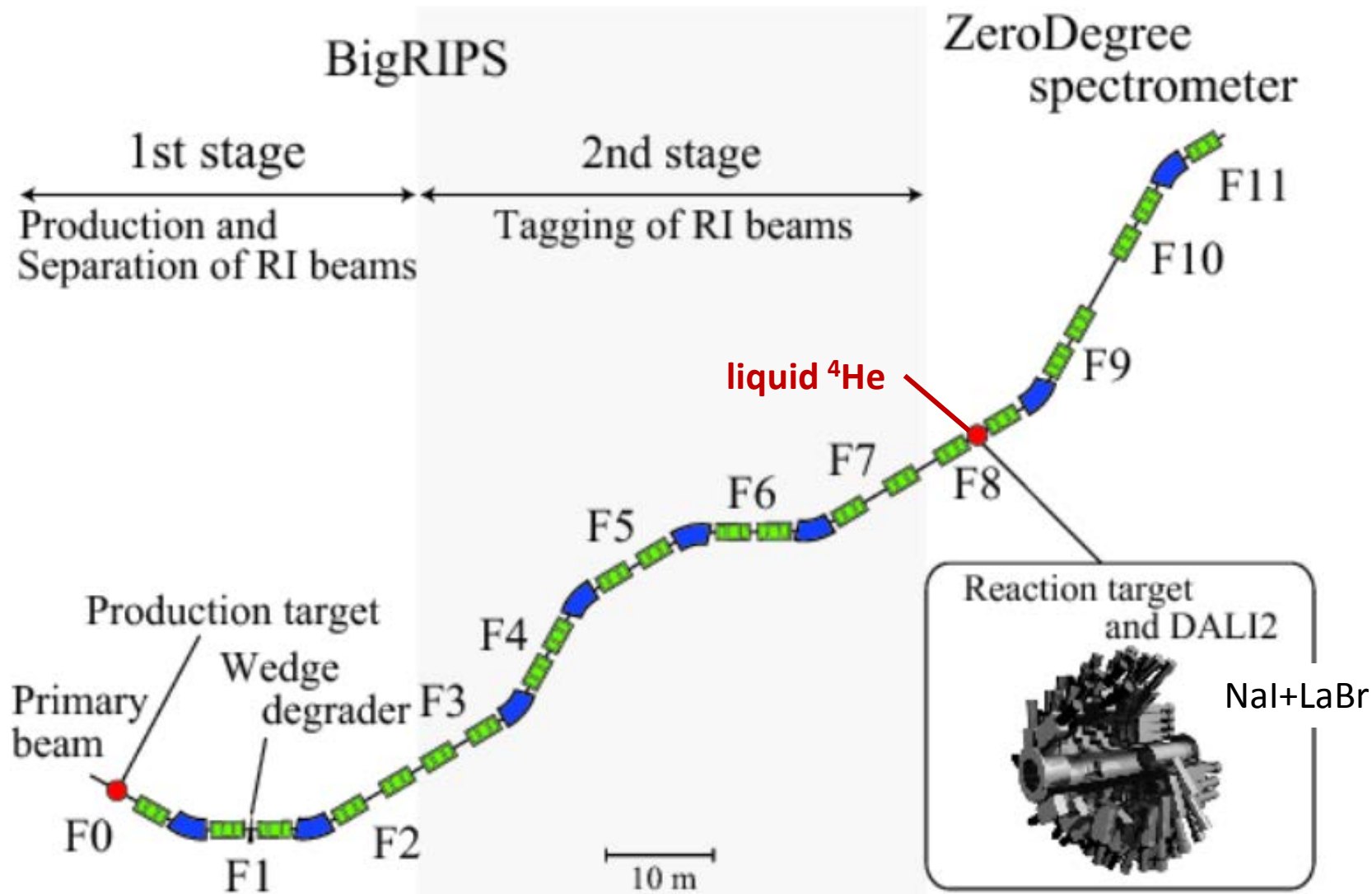
- **Systematics (mass, N/Z, exoticity)**
- **Decay pattern**
- **Comparison of electromagnetic and hadronic excitation**
- **Single-particle structure**

# E1 strength in light nuclei: $^{40}\text{Ca}$ and $^{48}\text{Ca}$



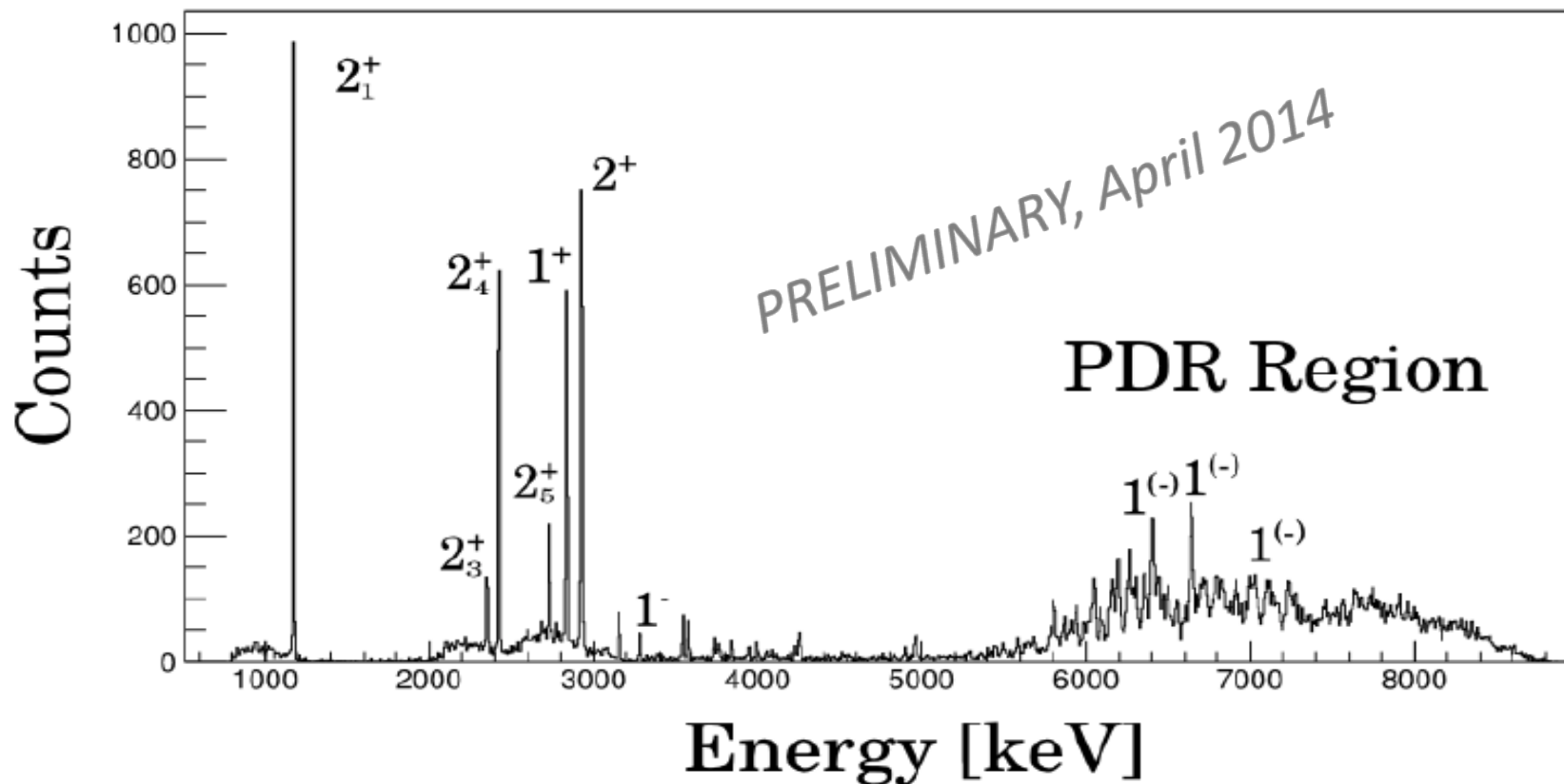


# Isospin structure of the PDR in exotic nuclei: ( $\alpha, \alpha'$ ) in inverse kinematics at BigRIPS@RIKEN



# Single-particle structure of the PDR

$^{119}\text{Sn}(d,p\gamma)^{120}\text{Sn}$  measured at SONIC@HORUS, Cologne



*S.G. Pickstone, A. Hennig, M. Spieker, V. Derya, M. Weinert, J. Wilhelm*

A black and white photograph showing a close-up of a large, textured dinosaur foot. The foot is positioned in the upper half of the frame, with its toes pointing downwards. In the lower half of the frame, a small, dark mouse is visible, standing on a flat surface. The mouse is positioned to the right of the dinosaur's foot, looking towards it. The background is a plain, light-colored surface.

**GDR**

PDR



drawing: Henrike Wilson

# The Pygmy Dipole Resonance – status and new developments



V. Derya, J. Endres, A. Hennig, J. Mayer, L. Netterdon,  
S. Pascu, S.G. Pickstone, P. Scholz, M. Spieker, M. Weinert,  
J. Wilhelmy, and A. Z.

*Institut für Kernphysik, University of Cologne*



M.N. Harakeh and H.J. Wörtche  
*KVI Groningen, The Netherlands*



D. Savran

*Extreme Matter Institute EMMI, Darmstadt*

supported by **DFG** (ZI 510/4-2, SFB 634, INST 216/544-1, and BCGS)



(RII3-CT-2004-506065)