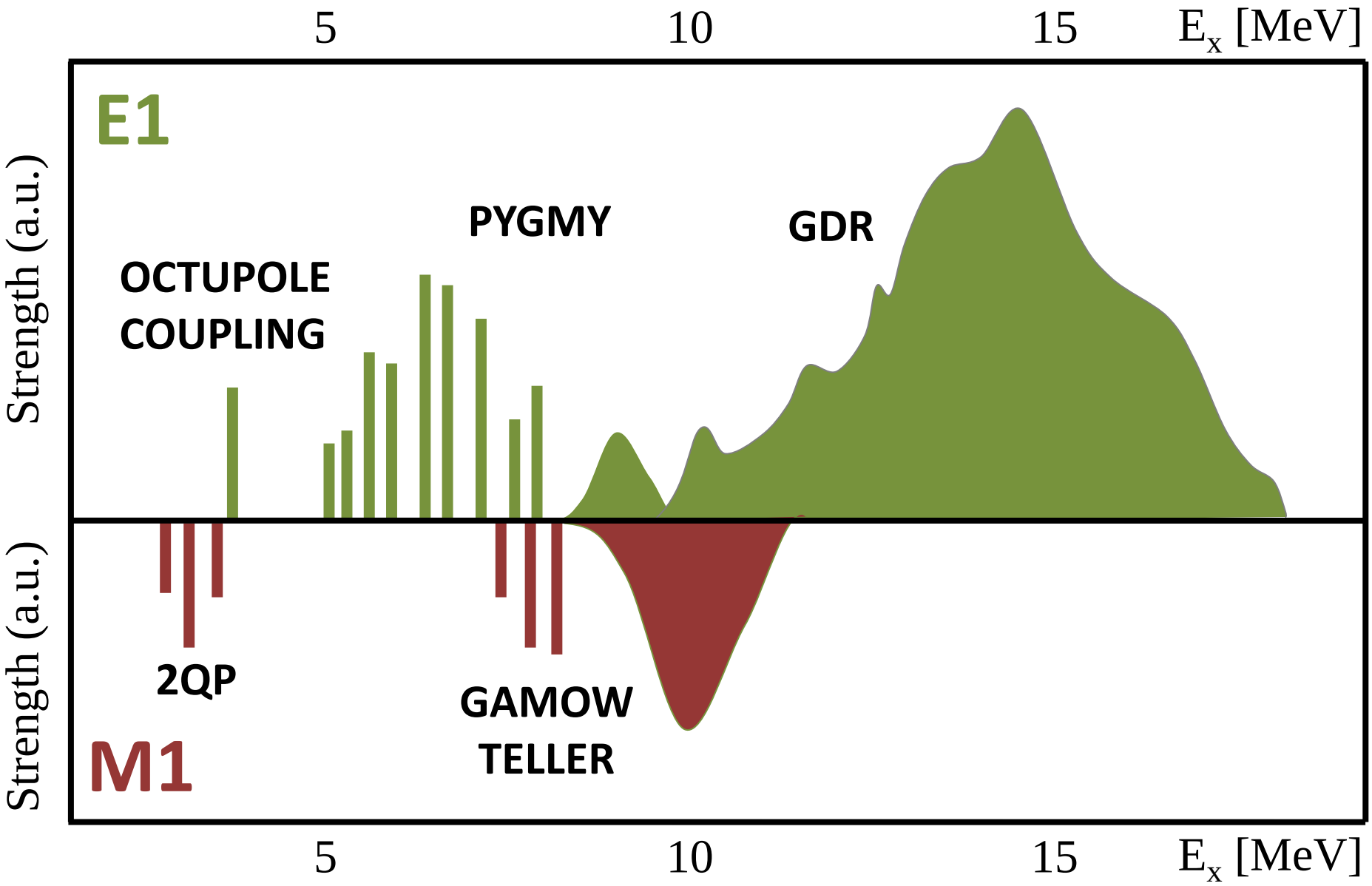
The Pygmy Dipole Resonance – status and new experimental developments

- 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 γ-Strahlen.

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

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

Giant Dipole Resonance (GDR)

1938:

Nuclear Photo-effects

THE beautiful experiments of Bothe and Gentner[1] on the ejection of neutrons from heavier nuclei by means of γ-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 γ-Strahlen.**

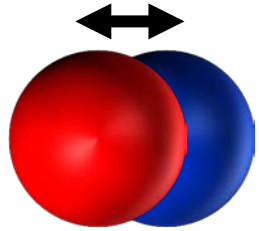
Von **W. Bothe** und **W. Gentner** in Heidelberg.

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

1944: **QUADRUPOLE AND DIPOLE γ-RADIATION OF NUCLEI**

By **A. MIGDAL**

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



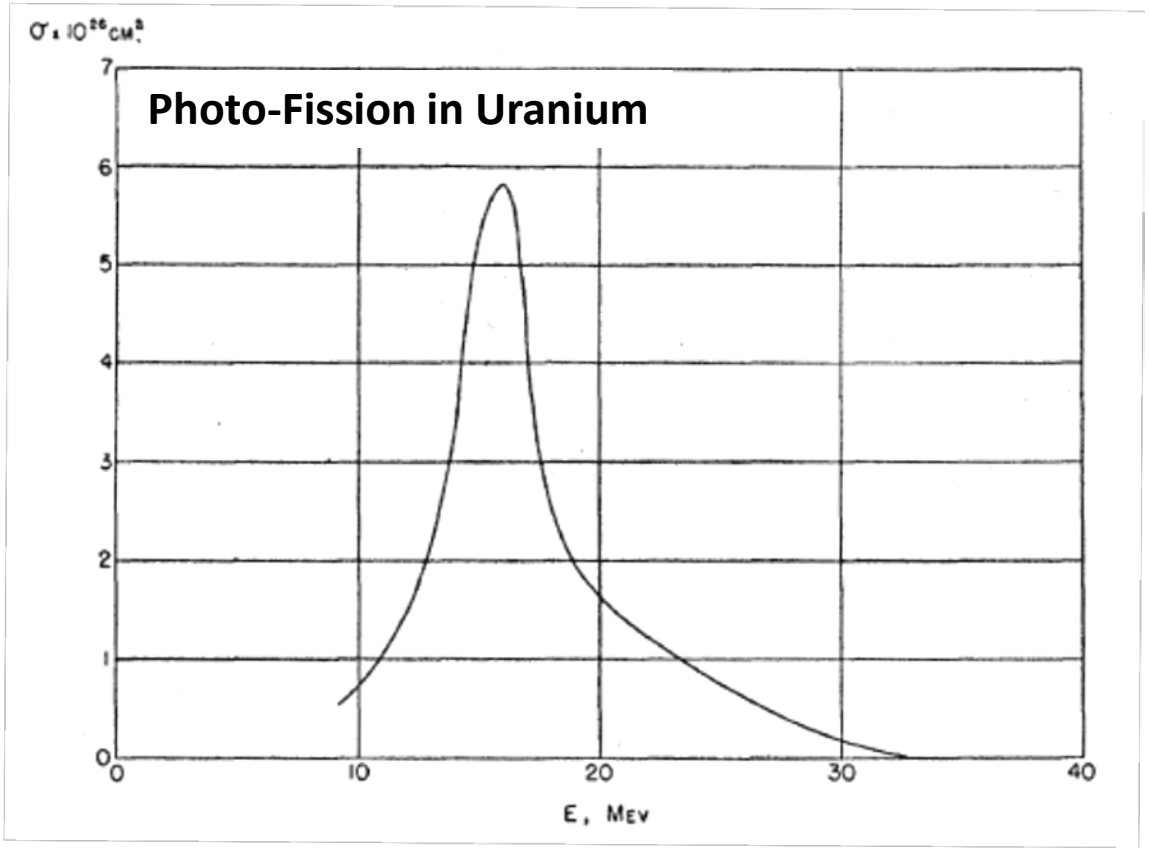
Giant Dipole Resonance (GDR)

1947:

Photo-Fission in Heavy Elements*

G. C. Baldwin and G. S. Klaiber
Research Laboratory, General Electric Company, Schenectady, New York

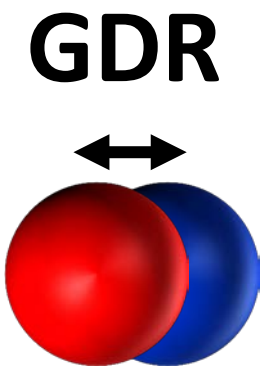
Phys. Rev. ***71*** *(1947) 3*

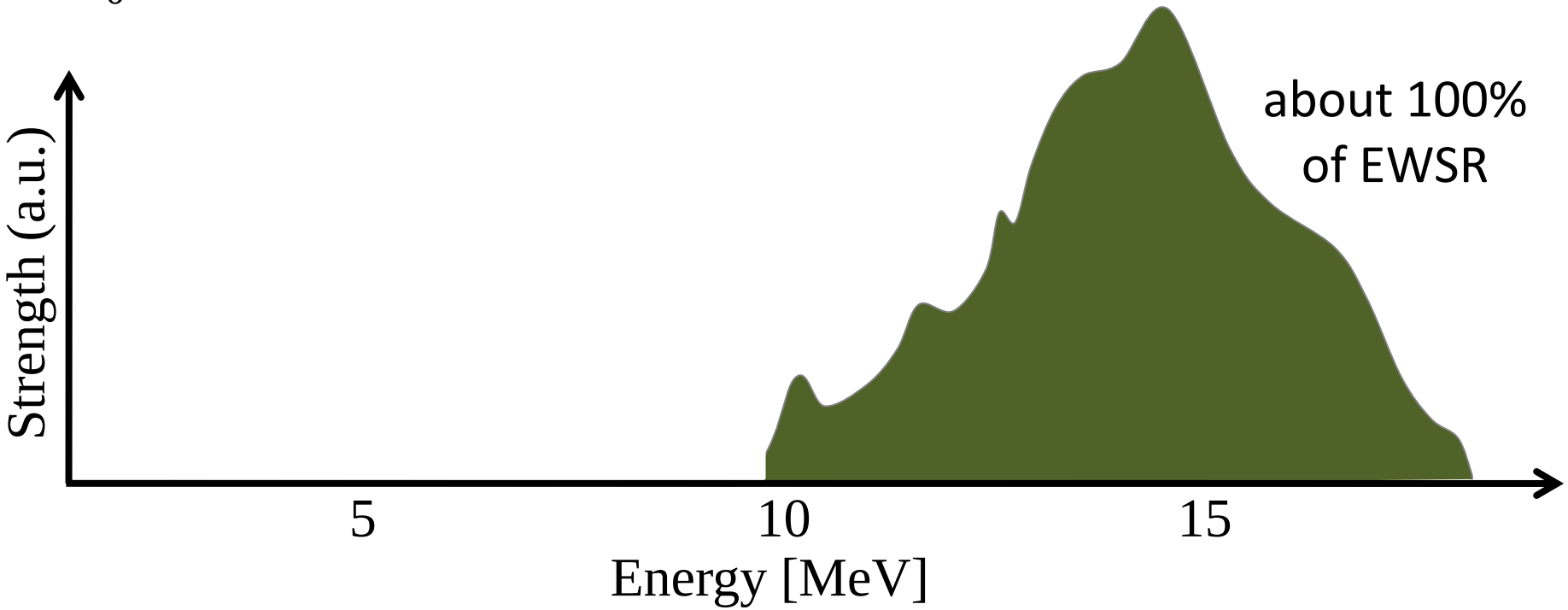


Giant Dipole Resonance (GDR)

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

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





Pygmy Dipole Resonance (PDR)

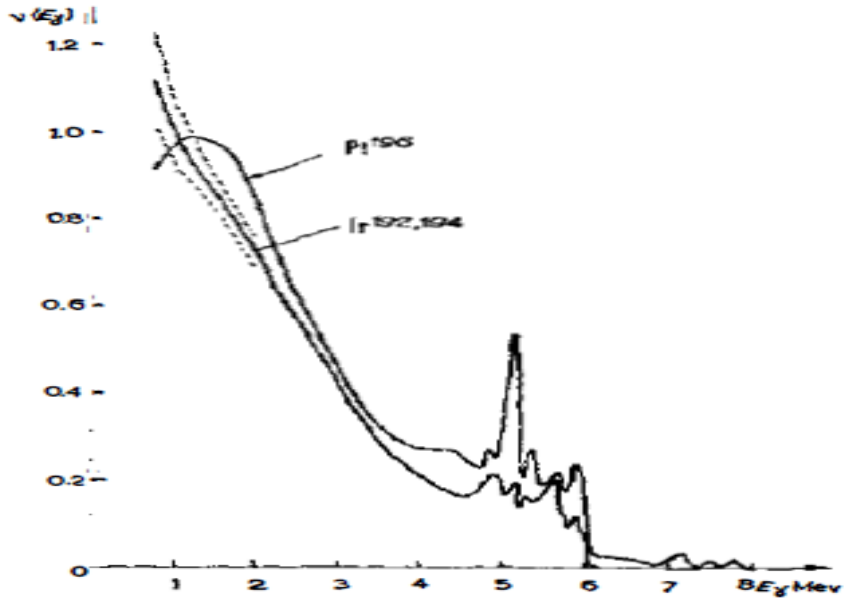
1961:

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*



Pygmy Dipole Resonance (PDR)

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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

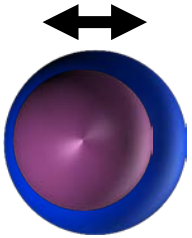
J. S. Brzosko, E. Gierlik, A. Soltan, Jr., and Z. Wilhelmi

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)

1997:

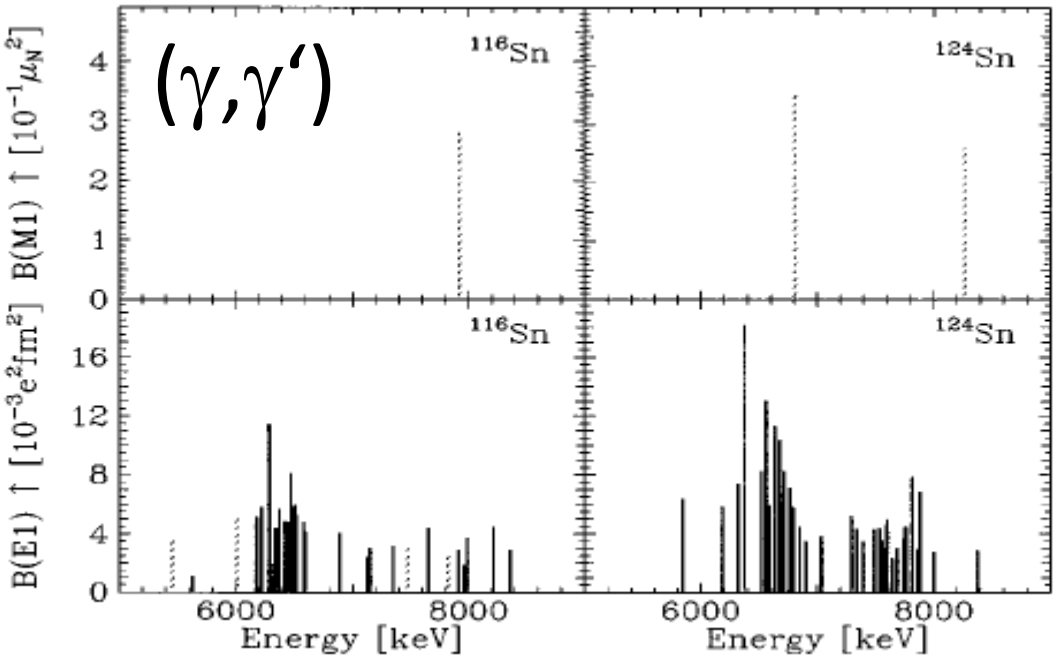
Dipole excitations to bound states in ^{116}Sn and ^{124}Sn

K. Govaert,* F. Bauwens, J. Bryssinck, D. De Frenne, E. Jacobs, and W. Mondelaers
Vakgroep Subatomaire en Stralingsfysica, University Gent, Proeftuinstraat 86, 9000 Gent, Belgium

L. Govor
Russian Research Center ''Kurchatov Institute,'' Moscow, Russia

V. Yu. Ponomarev
Bogoliubov Laboratory of Theoretical Physics, JINR, Dubna, Russia
(Received 22 December 1997)

*Phys. Rev. C **57** (1997) 2229*

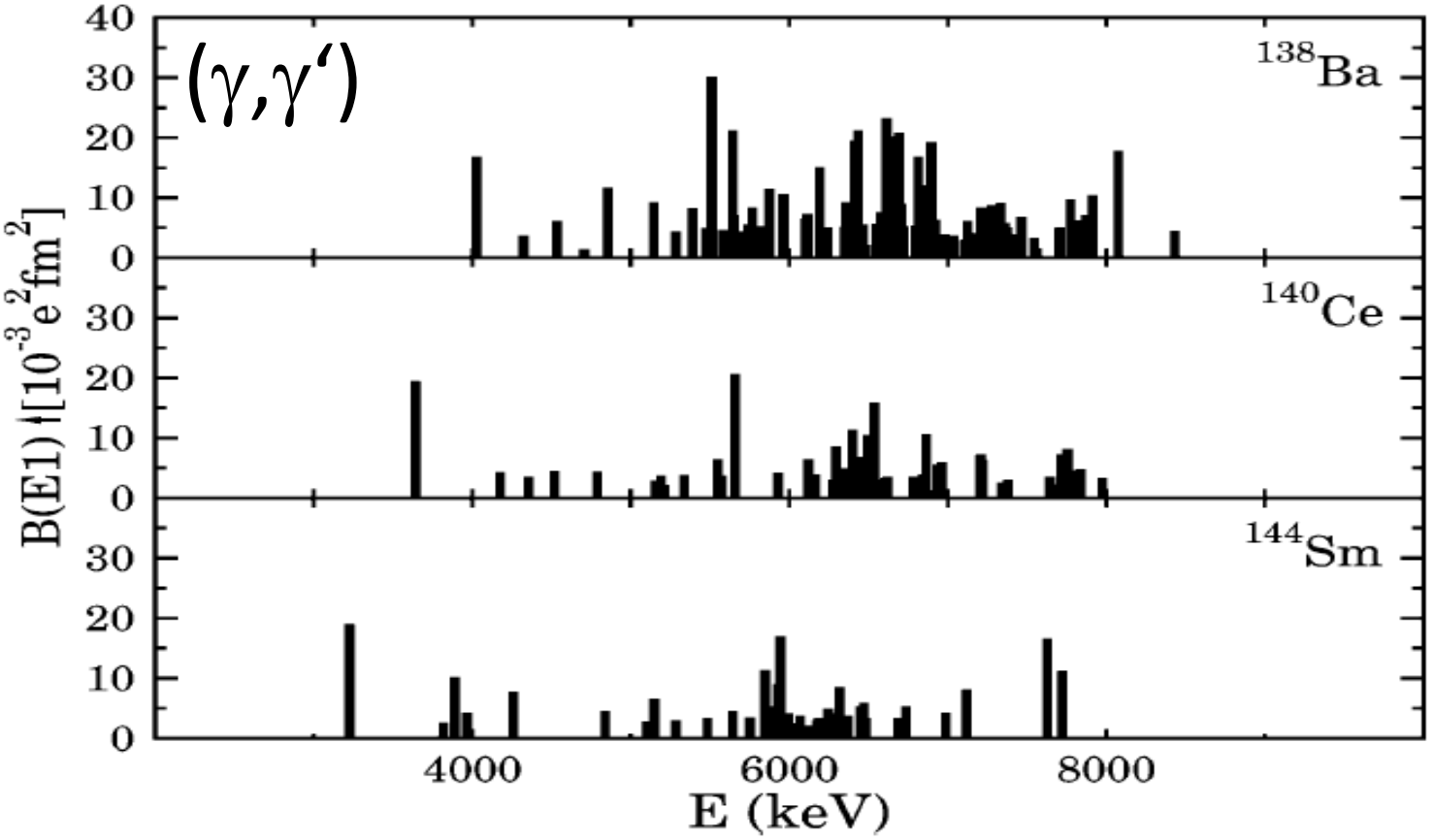


Pygmy Dipole Resonance (PDR)

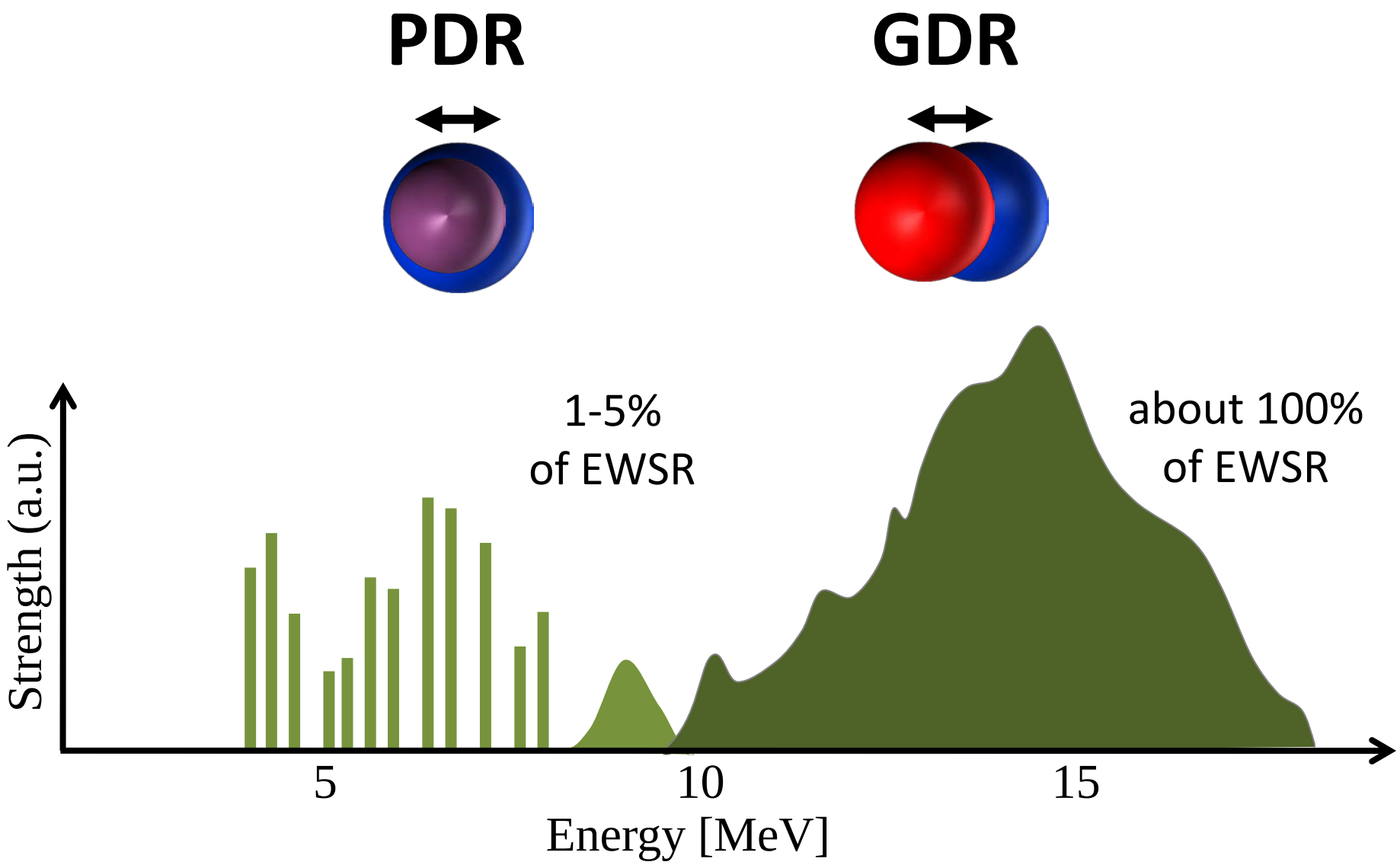
2002: Concentration of electric dipole strength below the neutron separation energy in $N = 82$ nuclei

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

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

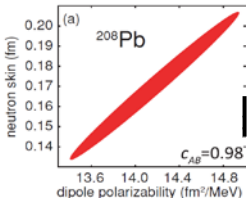


From giants to pygmies

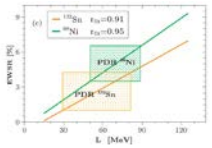


Relevance of low-lying E1 strength

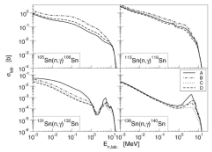
- PDR as a universal „collective“ excitation mode
- Connection to neutron skin, neutron star radius
- Slope of symmetry energy in EoS
- Impact on nucleosynthesis



*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*

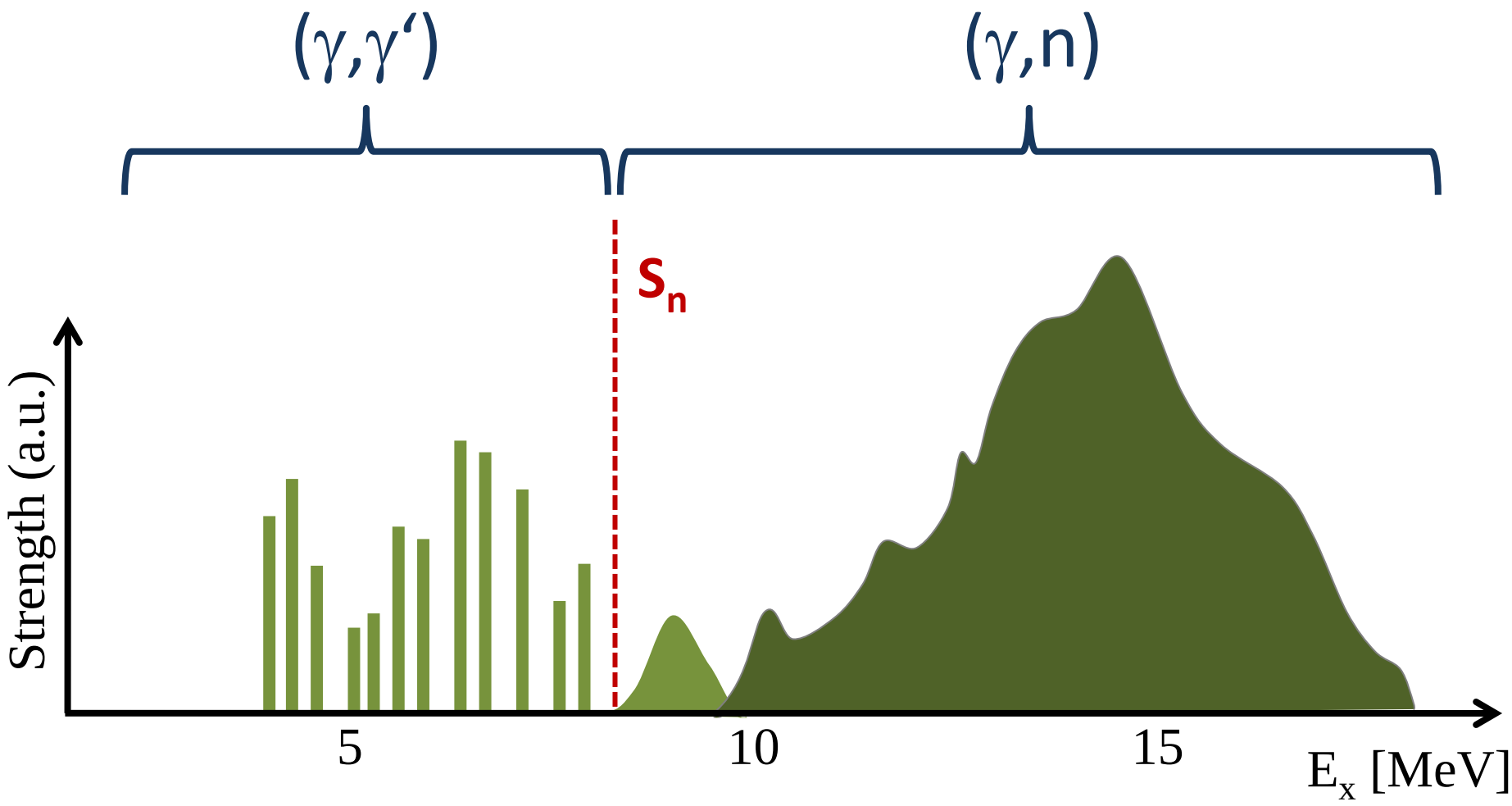


*A. Carbone et al. PRC **81** (2010) 041301(R)*
*B.A. Brown and A. Schwenk, PRC **89** (2014) 011307(R)*



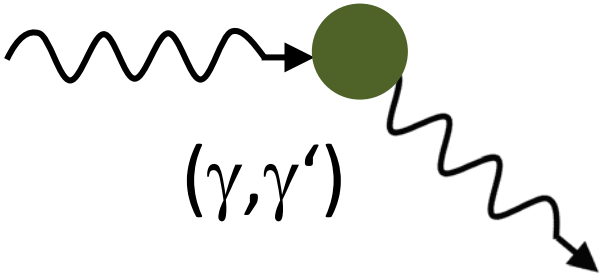
*S. Goriely, PLB **436** (1998) 10*
*E. Litvinova et al., NPA **823** (2009) 26*

Study of the E1 strength distribution via electromagnetic interaction

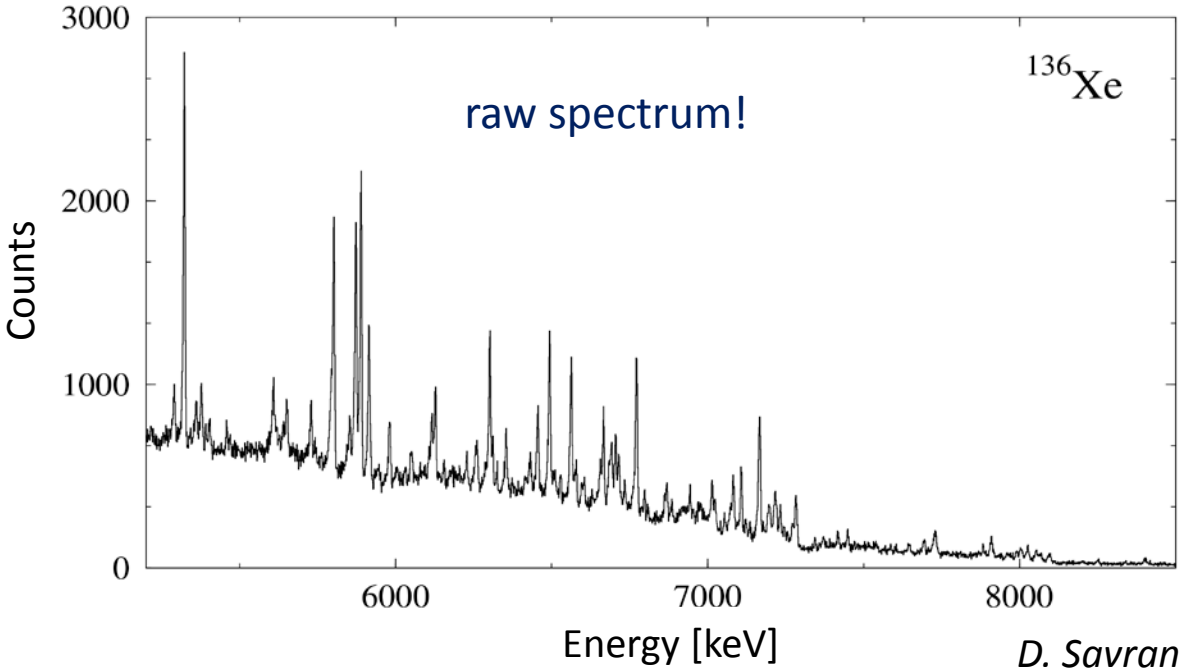


The photons can be real or virtual!

Scattering of real photons (γ,γ')



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



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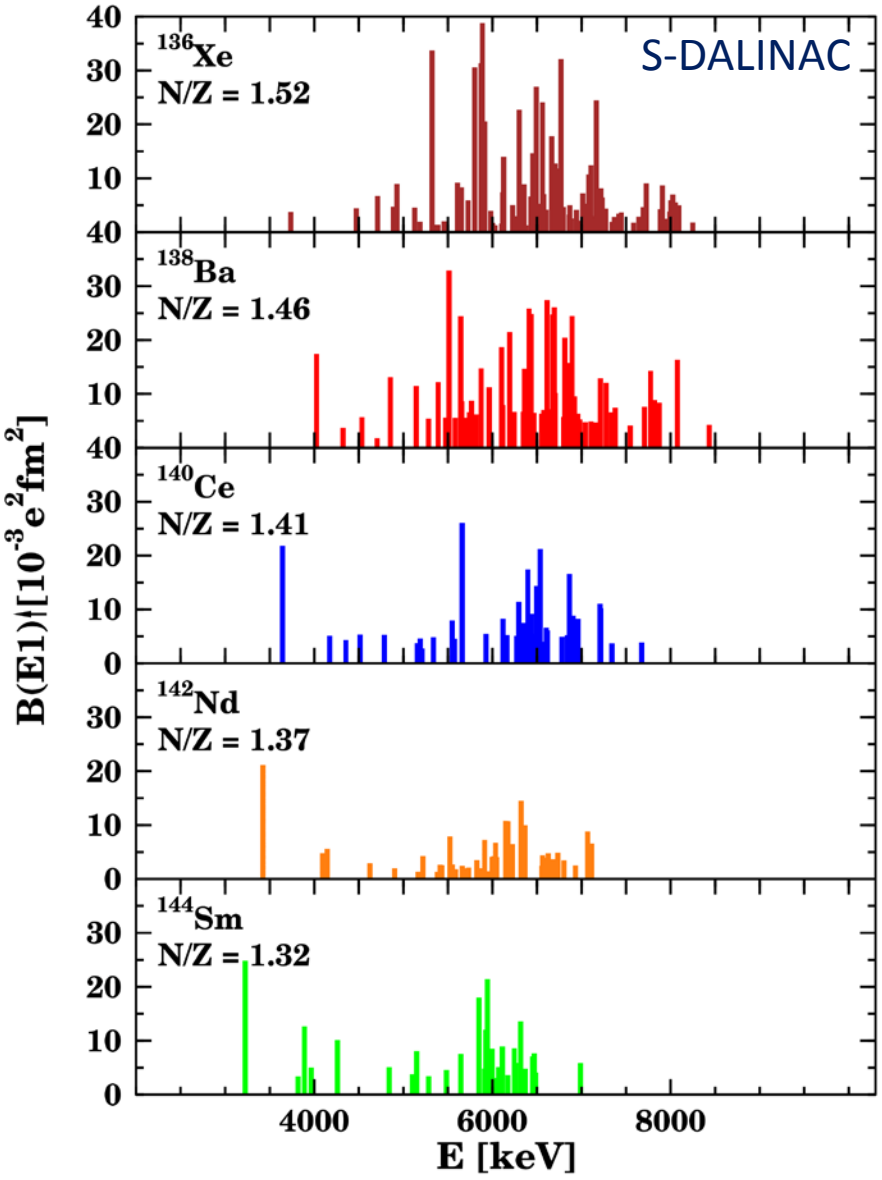
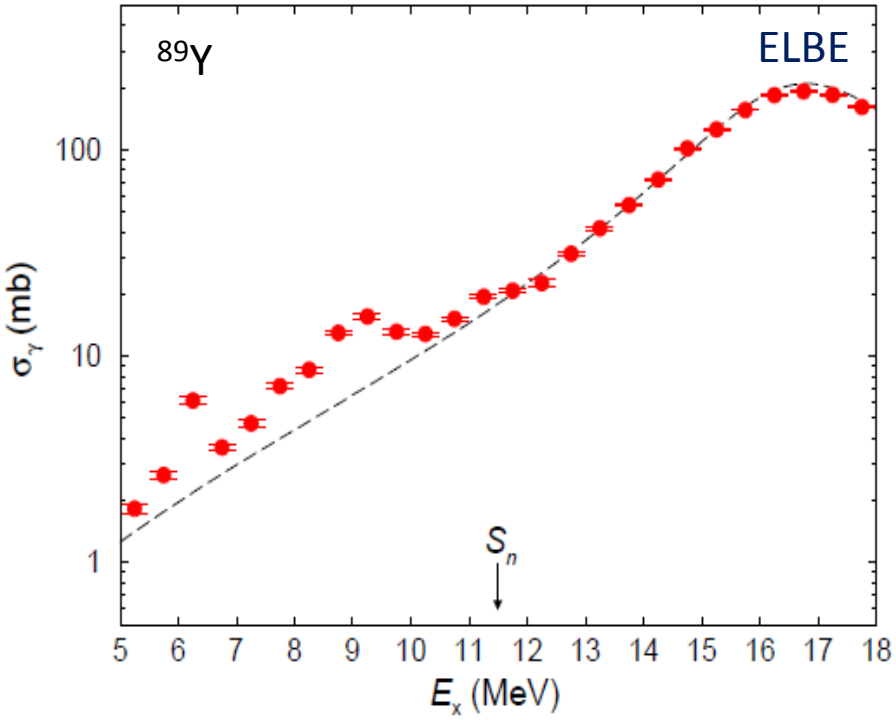
ELI@Bukarest
Akdeniz University

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

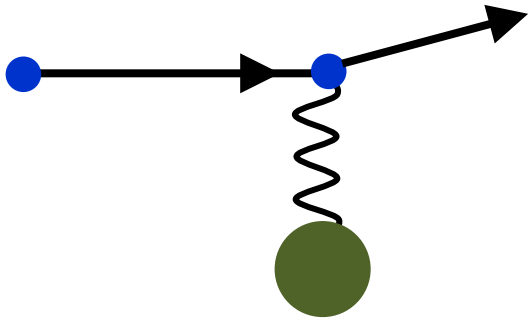
E1 distribution in stable nuclei: (γ,γ')



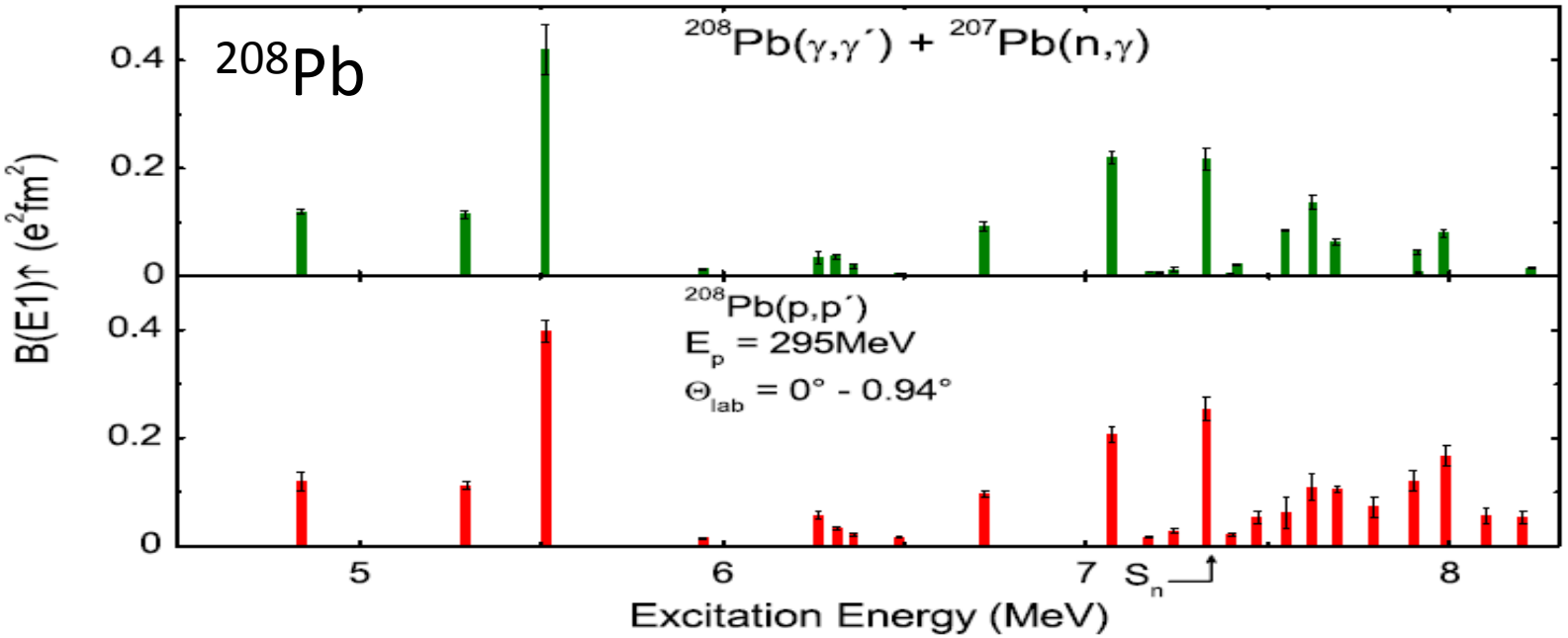


*N. Benouaret et al., PRC **79** (2009) 014303*
*D. Savran et al., PRC **84** (2011) 024326*
*S. Volz et al., NPA **779** (2006) 1*
*A. Zilges et al., PLB **542** (2002) 43*

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



- E_x = 0 – 25 MeV
- energy resolution ΔE=25 keV
- less selective, complex disentanglement
- only stable nuclei can be studied

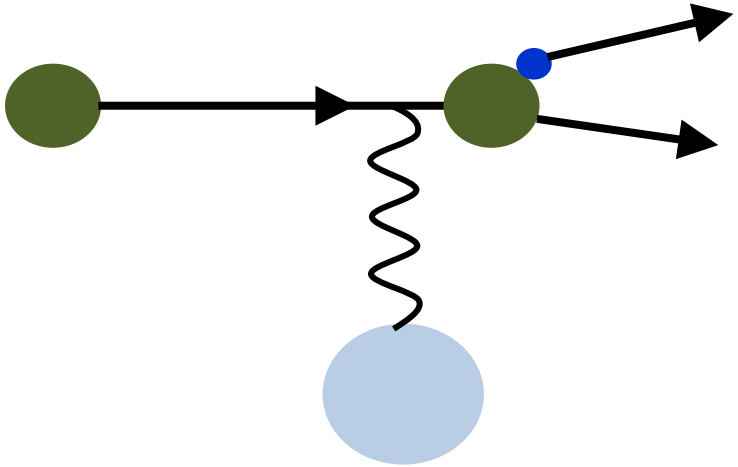


GRAND RAIDEN @RCNP

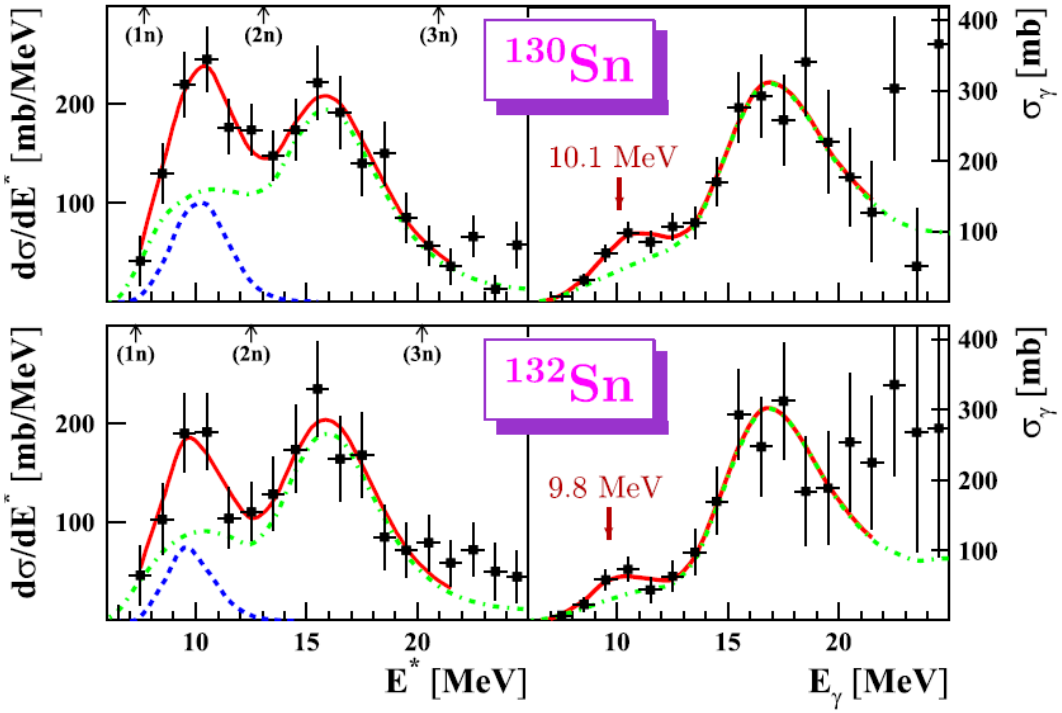
*A. Tamii et al., PRL **107** (2011) 062502*

→ talk by Peter von Neumann-Cosel

Coulomb interaction in inverse kinematics



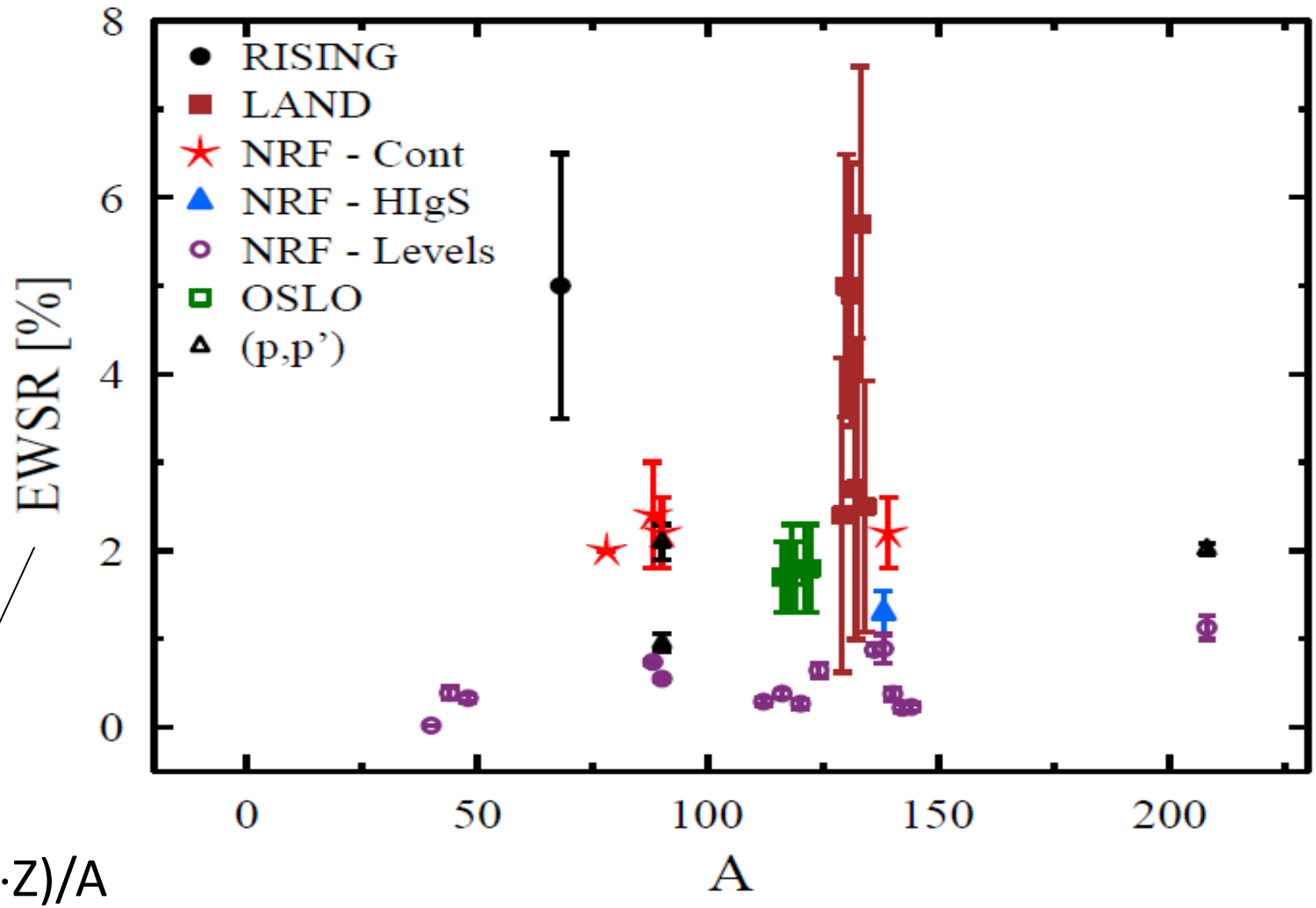
- E_{cm} = few 100 MeV/A
- radioactive nuclei can be studied
- energy resolution ΔE=500 keV
- complex data evaluation



LAND@FRS@GSI
RISING/HECTOR@FRS@GSI
NeuLAND@R3B@FAIR
…

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

Summed B(E1) strength of Pygmy Dipole Resonance

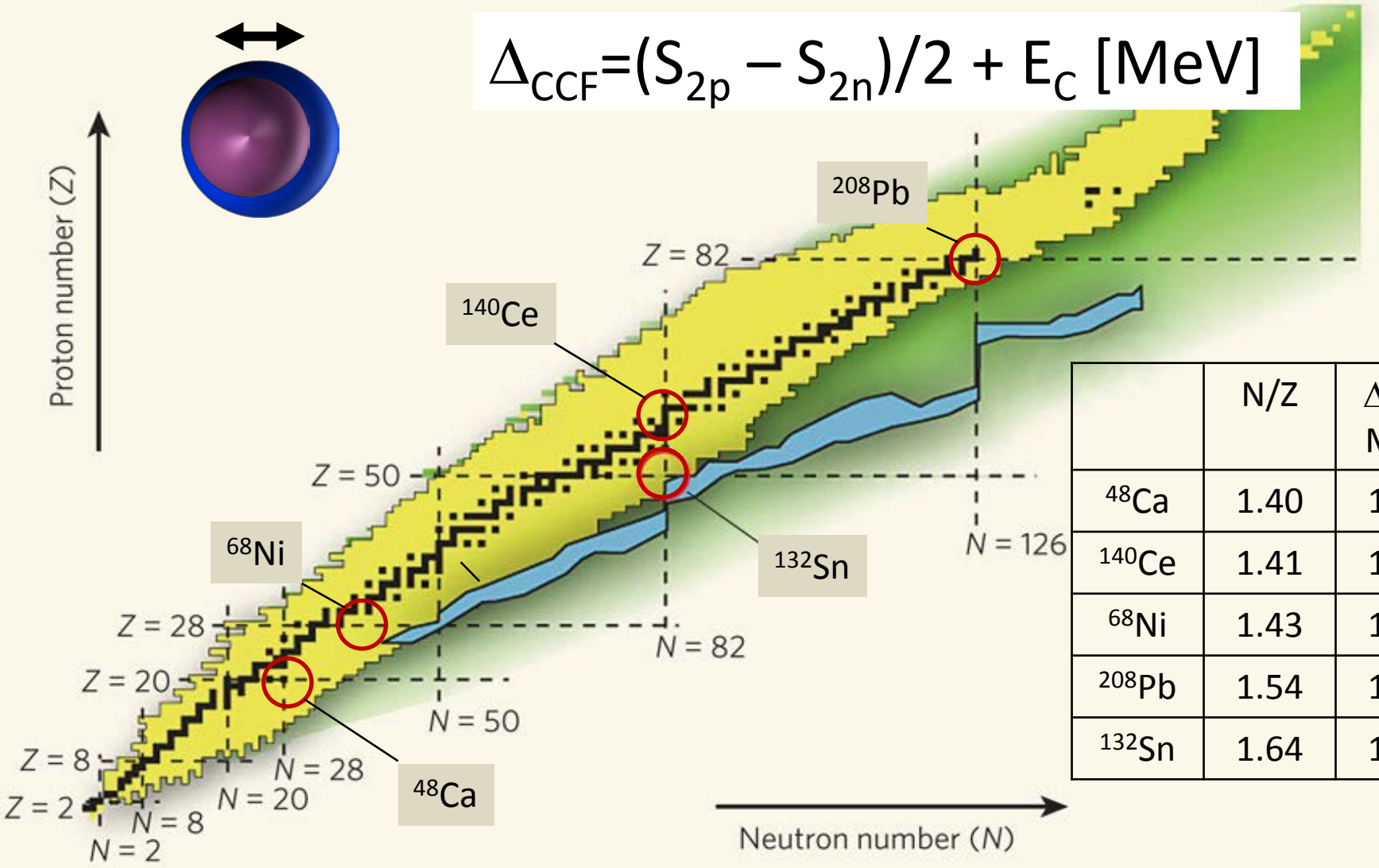


$\propto (N \cdot Z)/A$

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

Parametrization of „exoticity“

$$\Delta_{CCF}=(S_{2p} - S_{2n})/2 + E_C \text{ [MeV]}$$

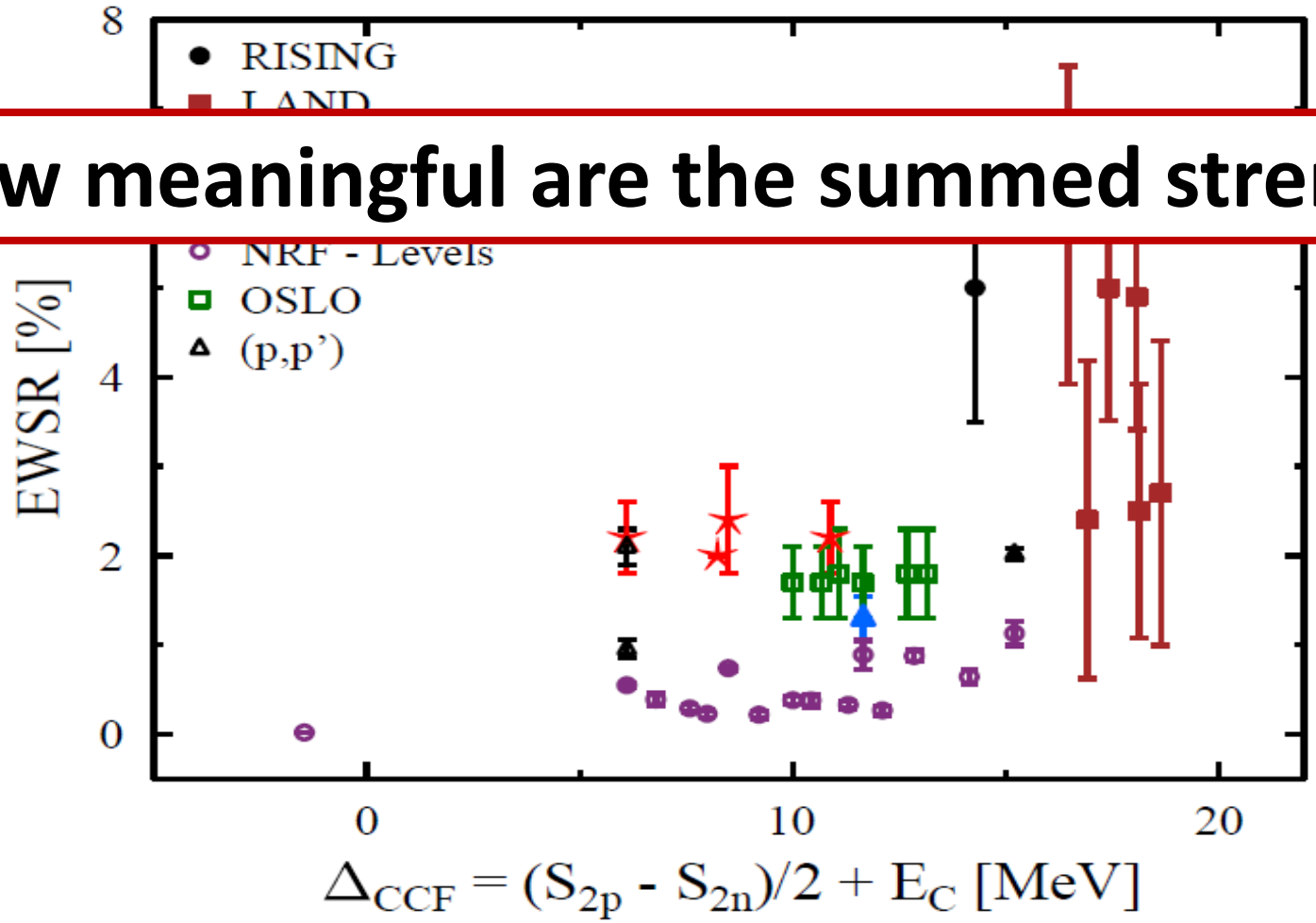


	N/Z	Δ_{CCF}/ MeV
^{48}Ca	1.40	11.3
^{140}Ce	1.41	10.4
^{68}Ni	1.43	14.3
^{208}Pb	1.54	15.2
^{132}Sn	1.64	18.6

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

Summed B(E1) strength vs. Coulomb corrected Fermy energy

How meaningful are the summed strengths?



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

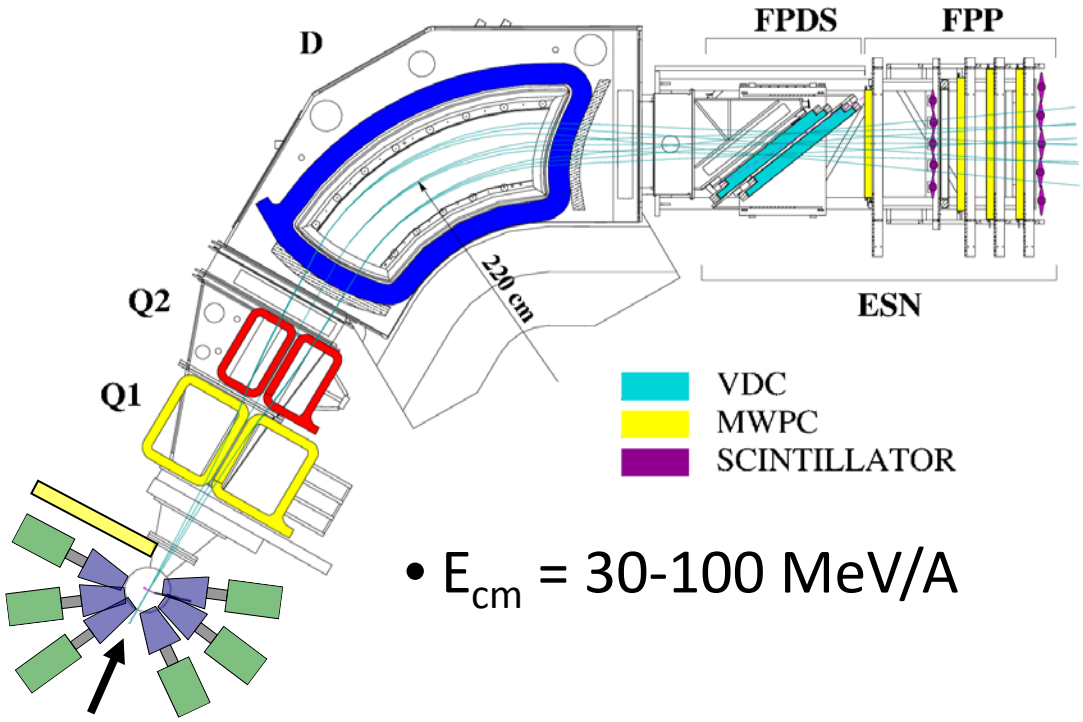
Testing the structure: (γ,γ′) vs. (α,α′)

	(γ,γ′) or Coulex	(α,α′) @ 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, …
ΔE	3-500 keV	50-200 keV

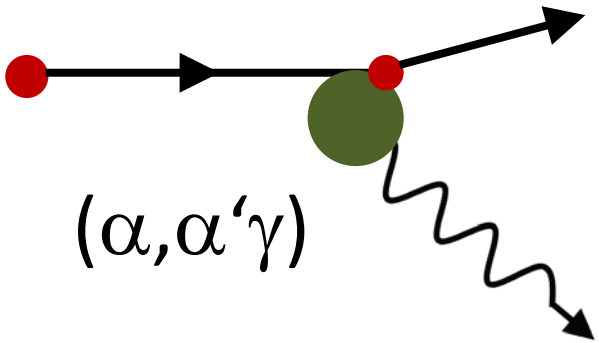
A coincident detection of the γ decay enhances the selectivity (and possibly the energy resolution) → **(α,α′γ)**

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

(α,α'γ) and (p,p'γ) experiments



α beam

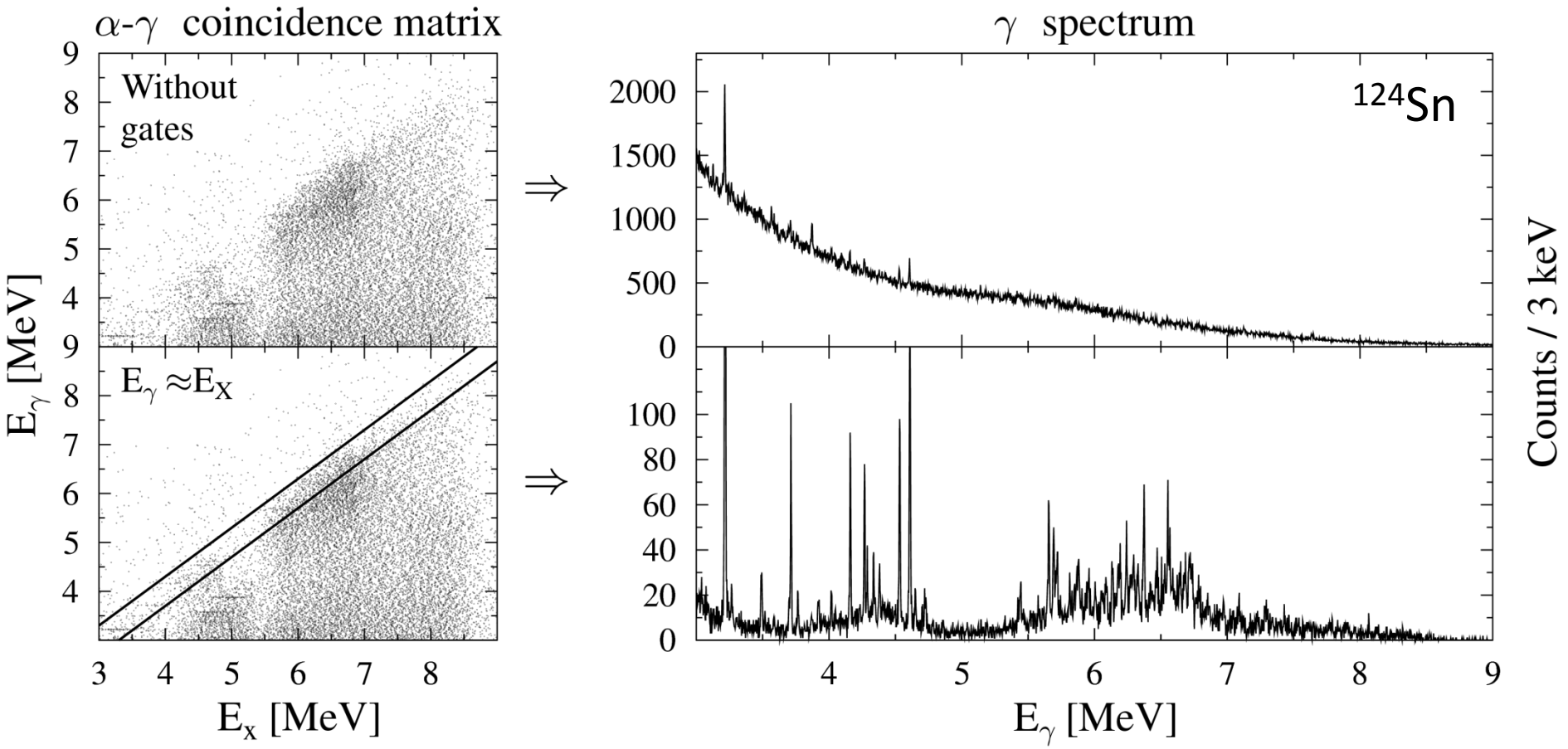


- E_{cm} = 30-100 MeV/A

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

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

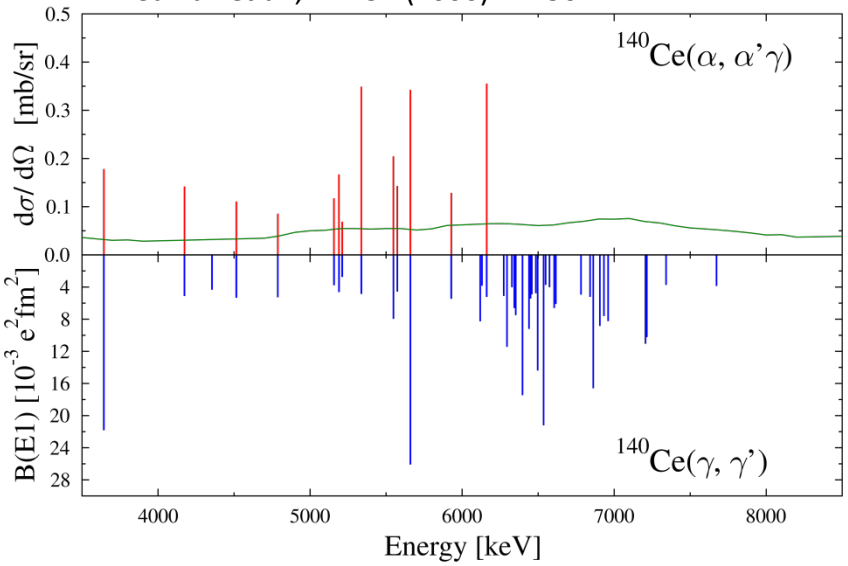
Structure of the PDR: (α,α'γ) experiments



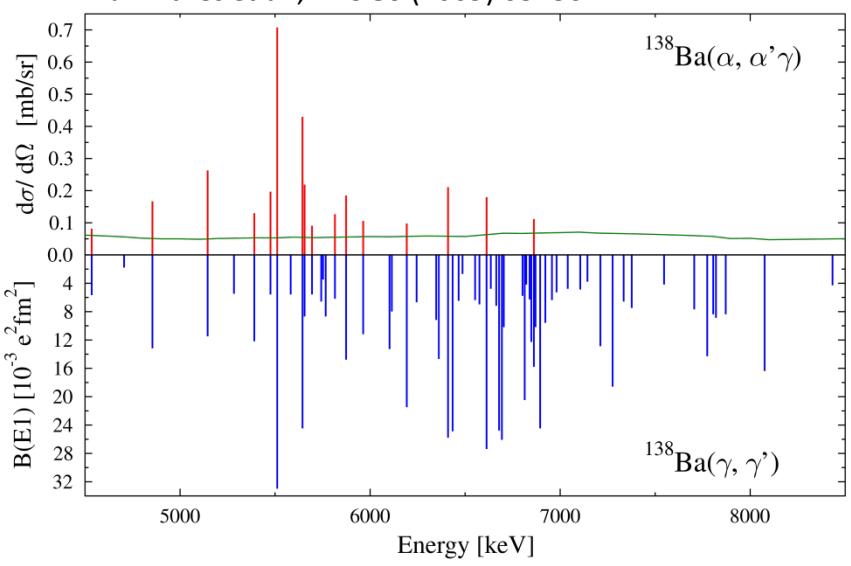
*Janis Endres et al., PRL **105** (2010) 112503*
*Janis Endres et al., PRC **85** (2012) 064331*

Splitting of strength: Experimental results

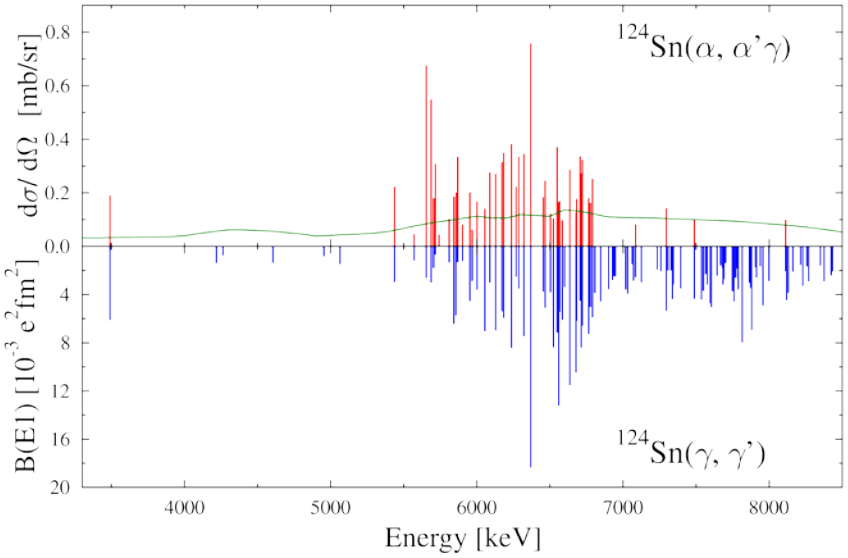
D. Savran *et al.*, PRL **97** (2006) 172502



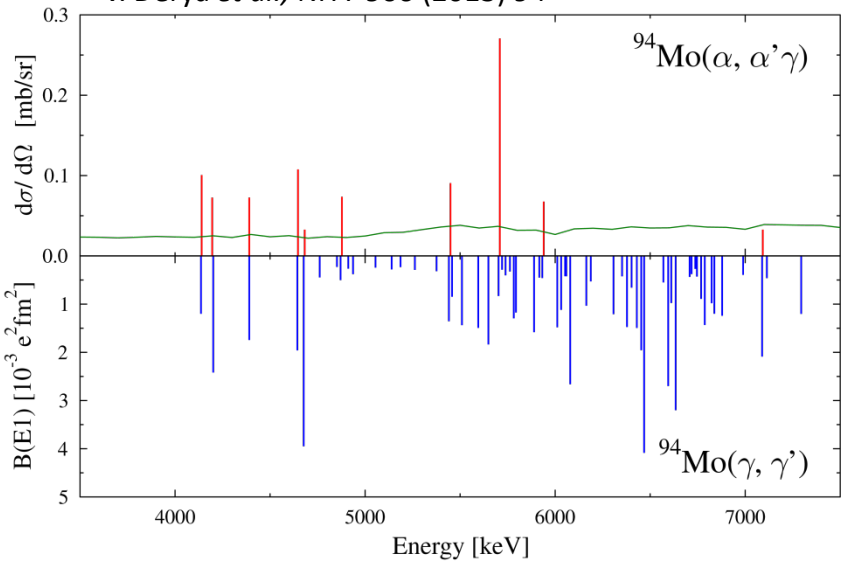
J. Endres *et al.*, PRC **80** (2009) 034302



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

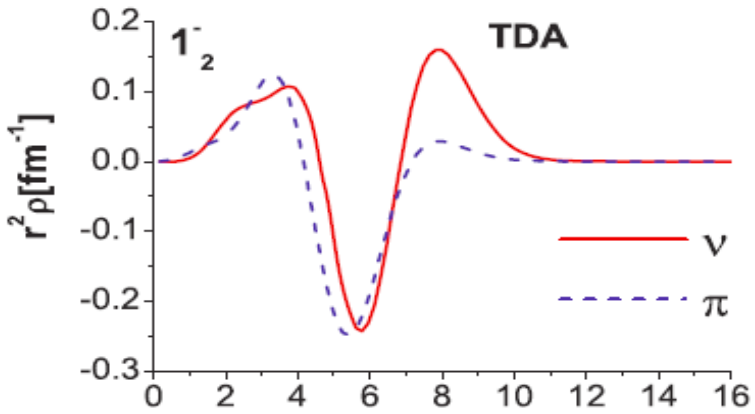


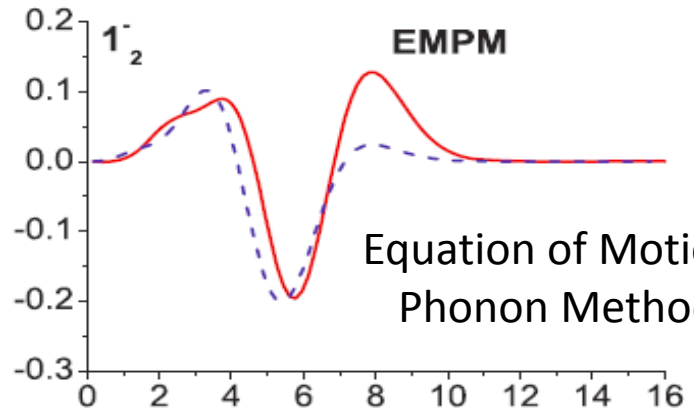
V. Derya *et al.*, NPA **906** (2013) 94



Transition densities for 1^- states in ^{208}Pb

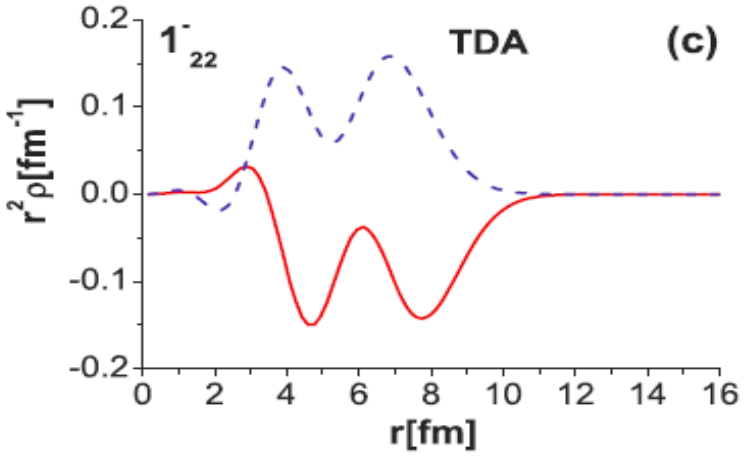
PDR region

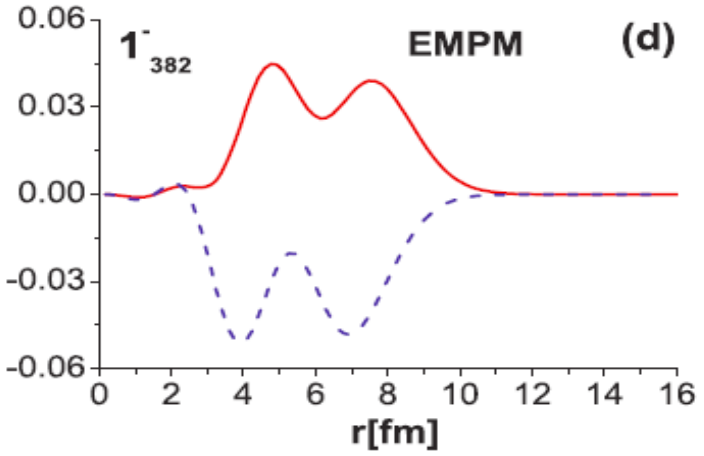




Equation of Motion Phonon Method

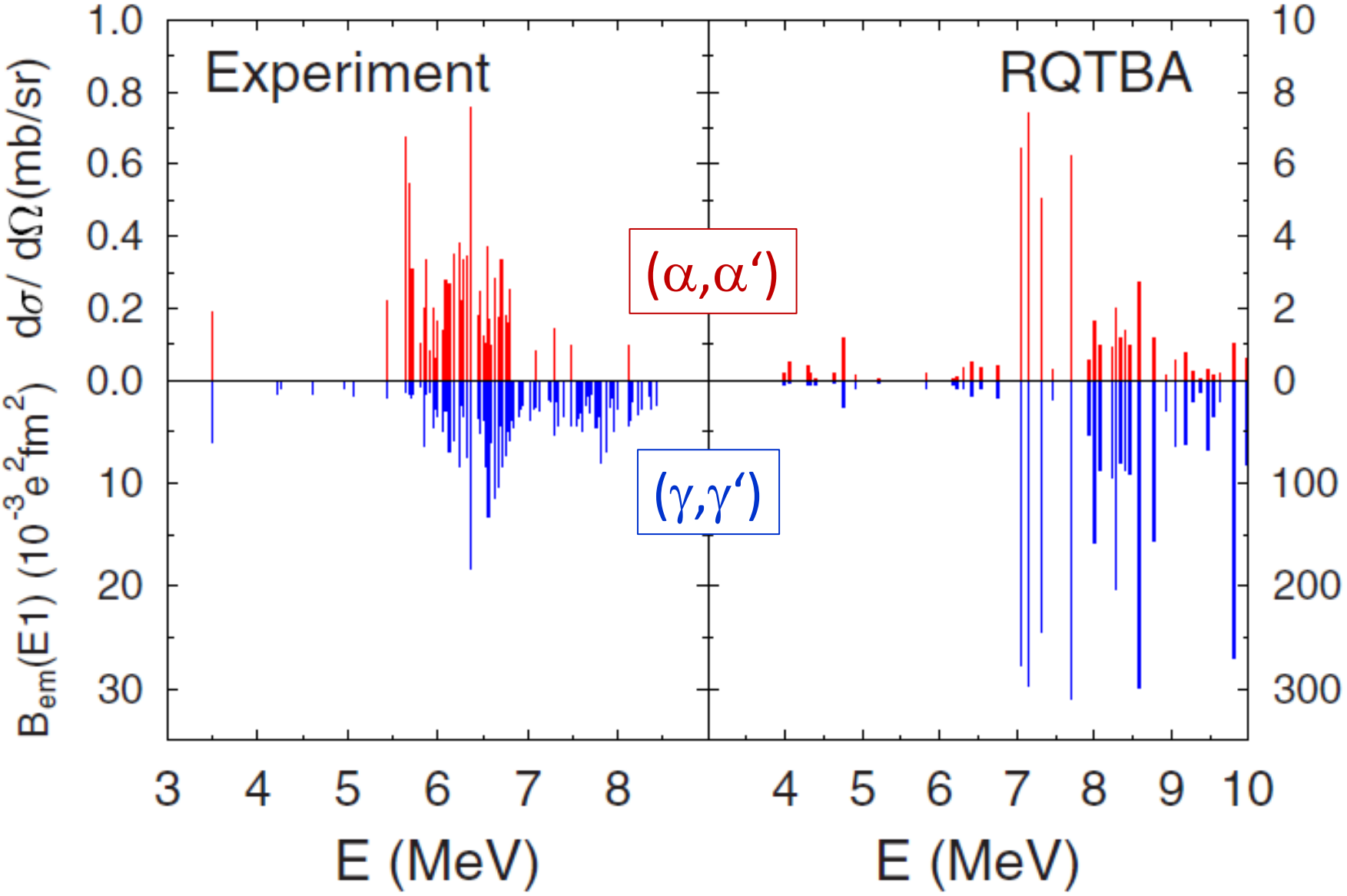
GDR region





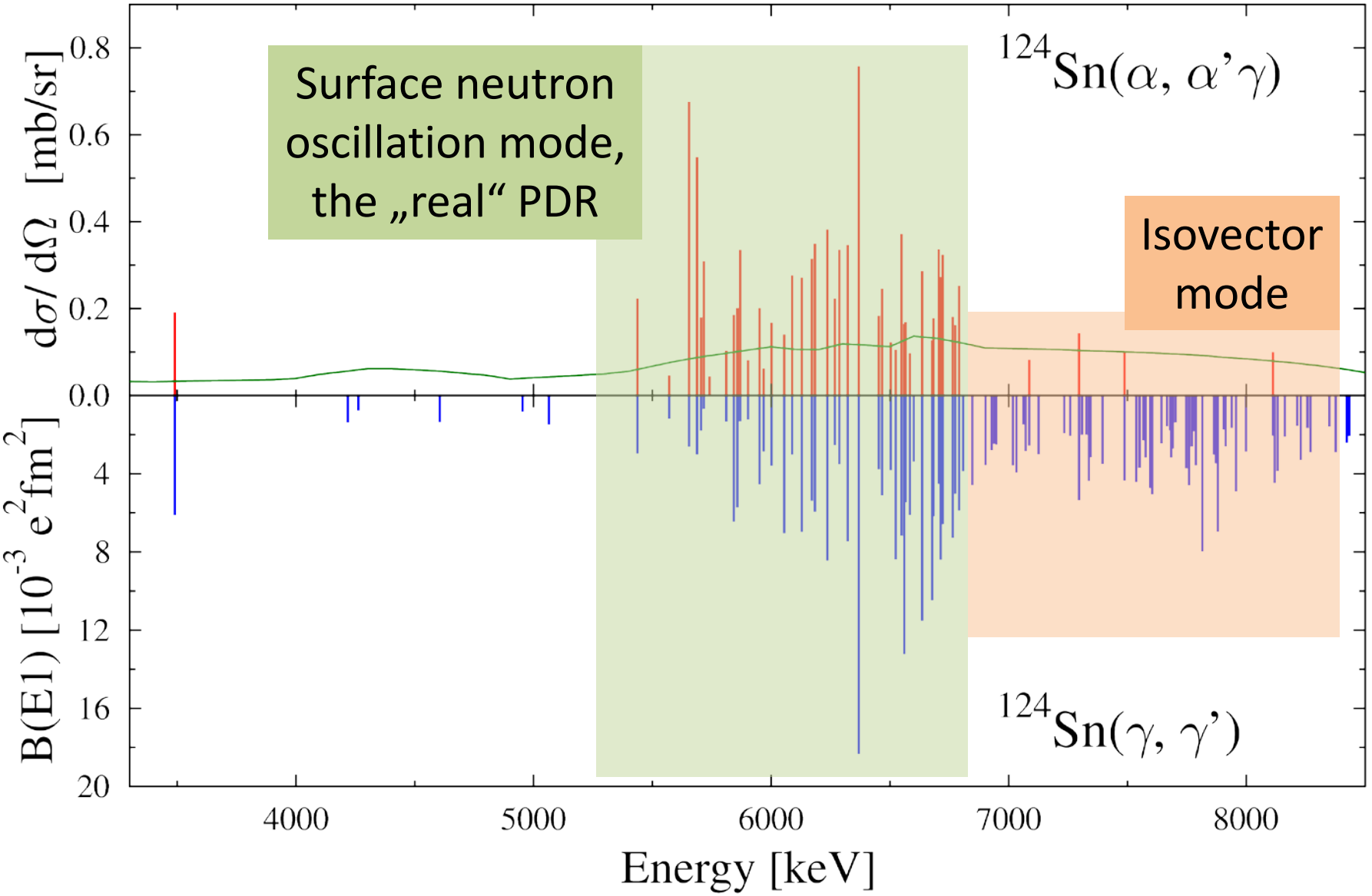
*D. Bianco et al. PRC **86** (2012) 044327*

Splitting of E1 strength in ^{124}Sn



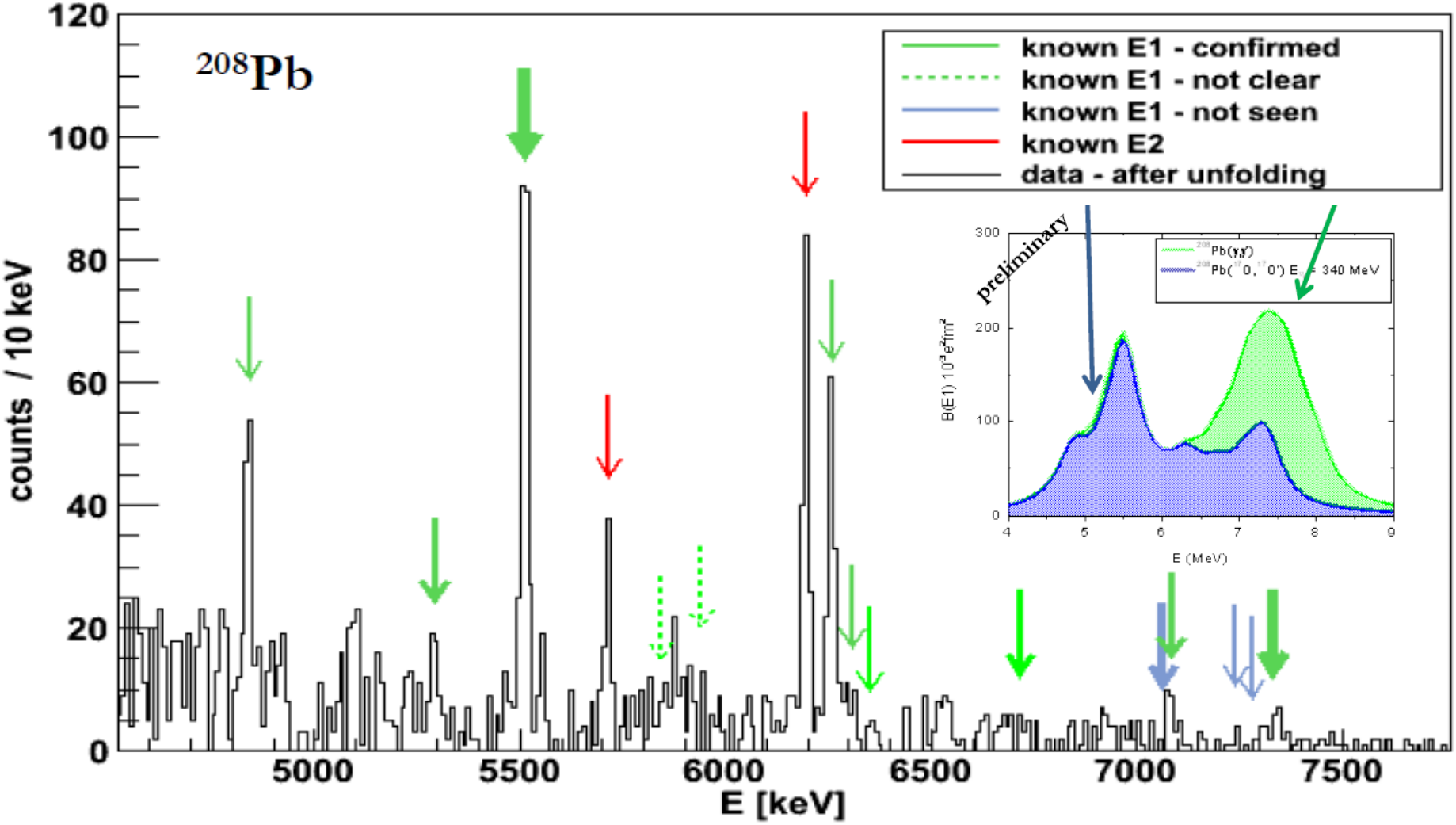
*E.G. Lanza, A. Vitturi et al., PRC **89** (2014) 041601 (R)*

Splitting of the PDR: Interpretation from RQTBA



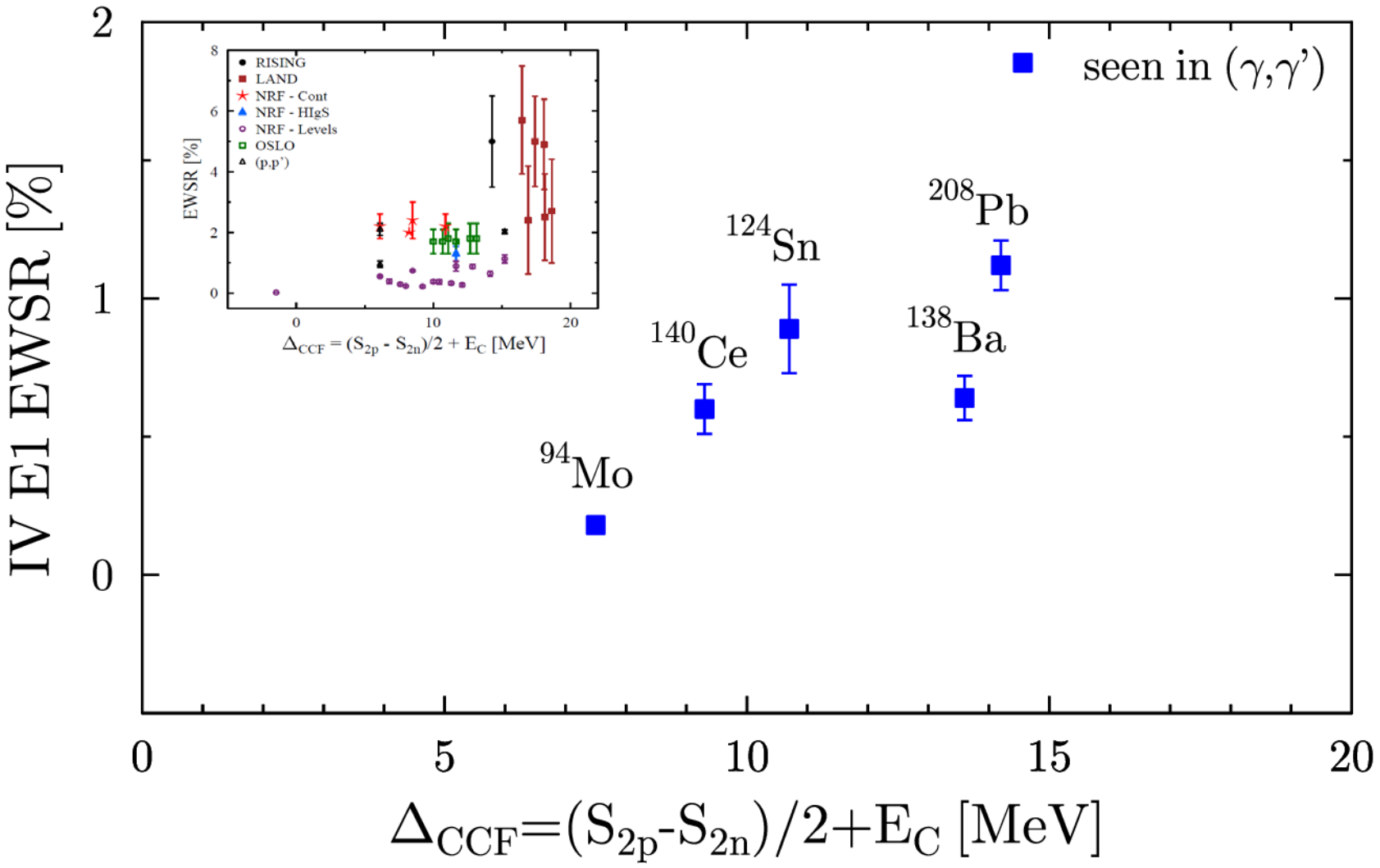
*Janis Endres et al., PRL **105** (2010) 112503*
*Janis Endres et al., PRC **85** (2012) 064331*

Result confirmed in (^{17}O, ^{17}O') on ^{208}Pb by Milano group

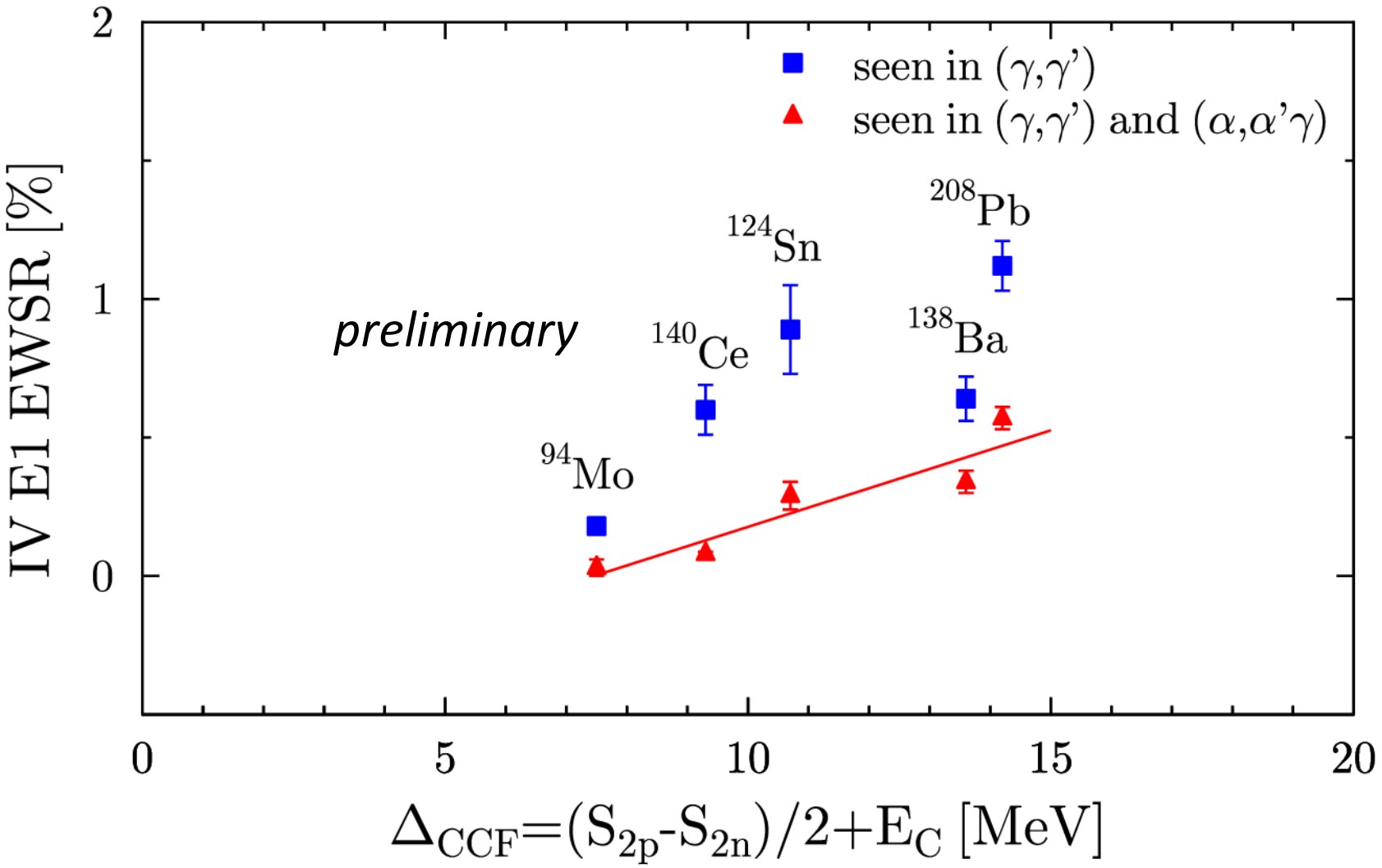


*F.C.L. Crespi, A. Bracco et al., PRL **113** (2014) 012501*

Summed E1 strength derived from EM excitation



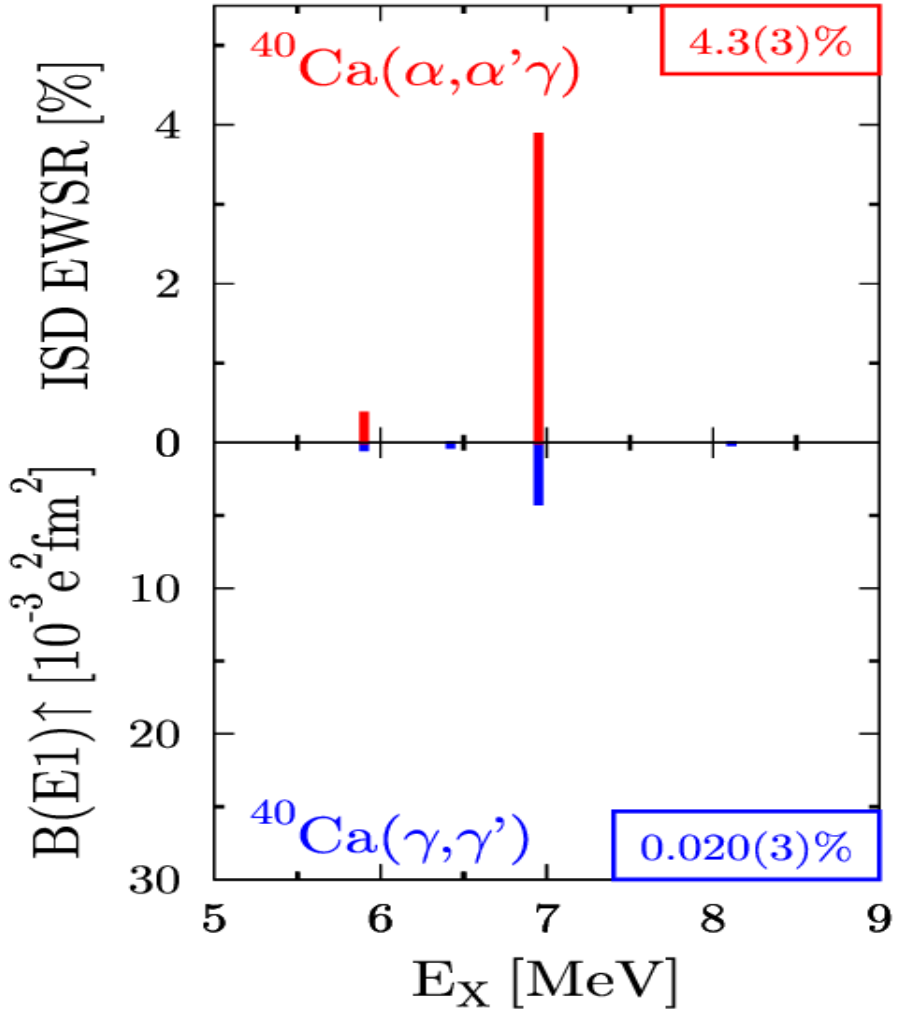
Summed E1 strength derived from (α,α‘)

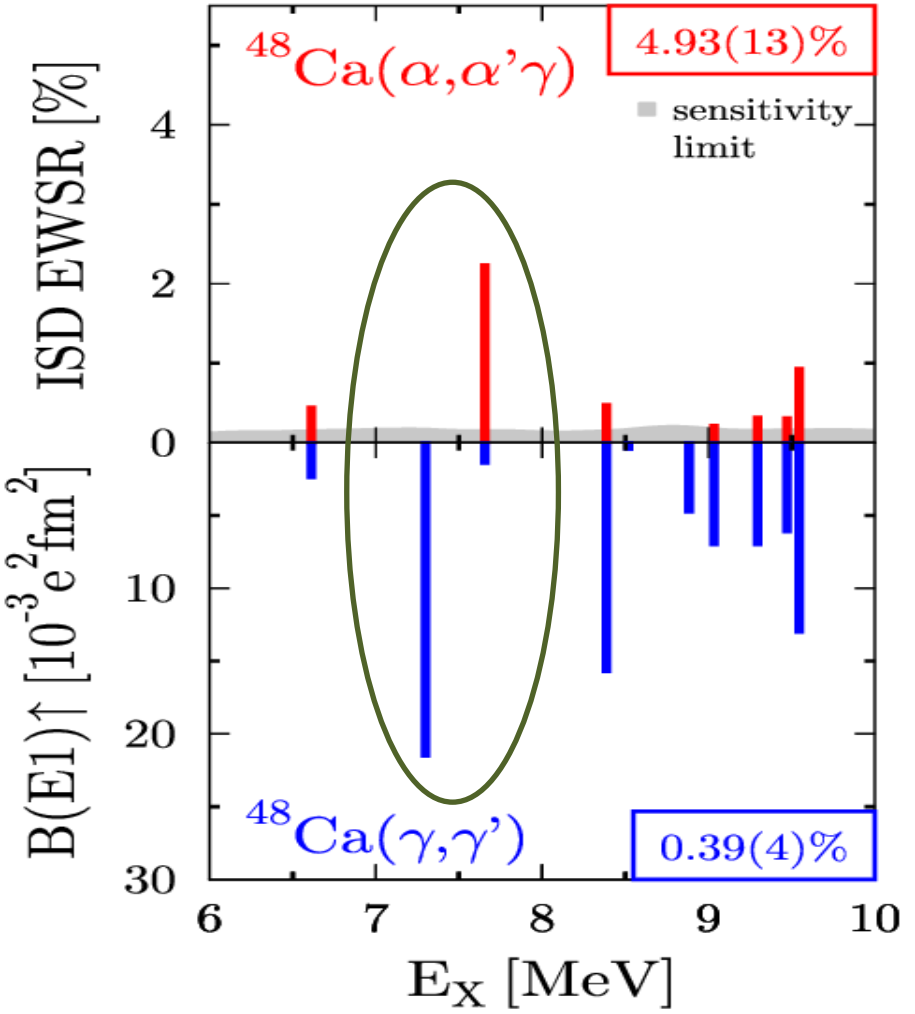


From presence to future: Open questions

- **Systematics (light vs. heavy nuclei, deformation, exoticity)**

E1 strength in light nuclei: ^{40}Ca and ^{48}Ca



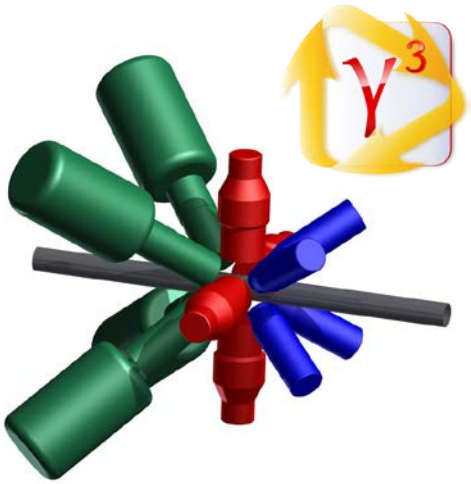


*V. Derya et al., PLB **730** (2014) 288*

From presence to future: Open questions

- Systematics (light vs. heavy nuclei, deformation, exoticity)
- **Decay pattern**

Decay pattern: γ^3 setup at HIGS



Combination of:
LaBr detectors (high efficiency) and
HPGe detectors (excellent energy resolution)

*B. Löher, V. Derya et al., NIM A **723** (2013) 136*

→ talk Deniz Savran

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Universität zu Köln

TECHNISCHE UNIVERSITÄT DARMSTADT

EMMI

Yale University

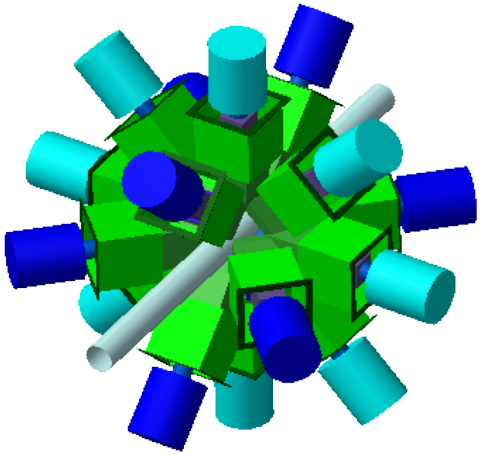
From presence to future: Open questions

- Systematics (light vs. heavy nuclei, deformation, exoticity)
- Decay pattern
- **Isospin structure: Comparison of electromagnetic and hadronic excitation**

Isospin structure of the PDR in stable nuclei: The CAGRA campaign @RCNP

$(\alpha,\alpha'\gamma)$ @ E_α= 140 MeV and $(p,p'\gamma)$ @ E_p= 80 MeV
combining Grand Raiden spectrometer and
16 Compton suppressed HPGe Clover detectors

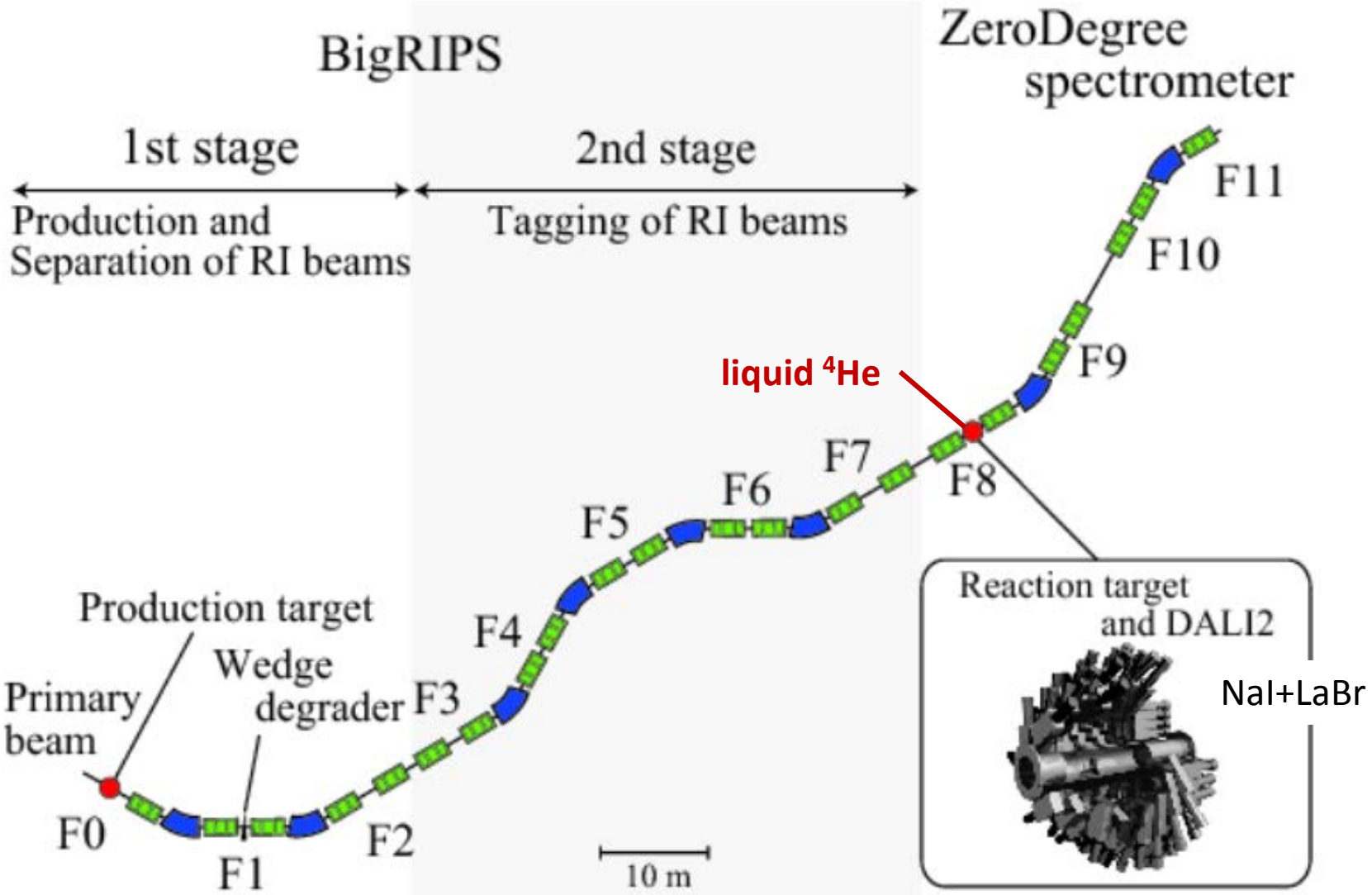
CAGRA



GRAND RAIDEN

Collaboration: Osaka – Cologne - Darmstadt - Milano

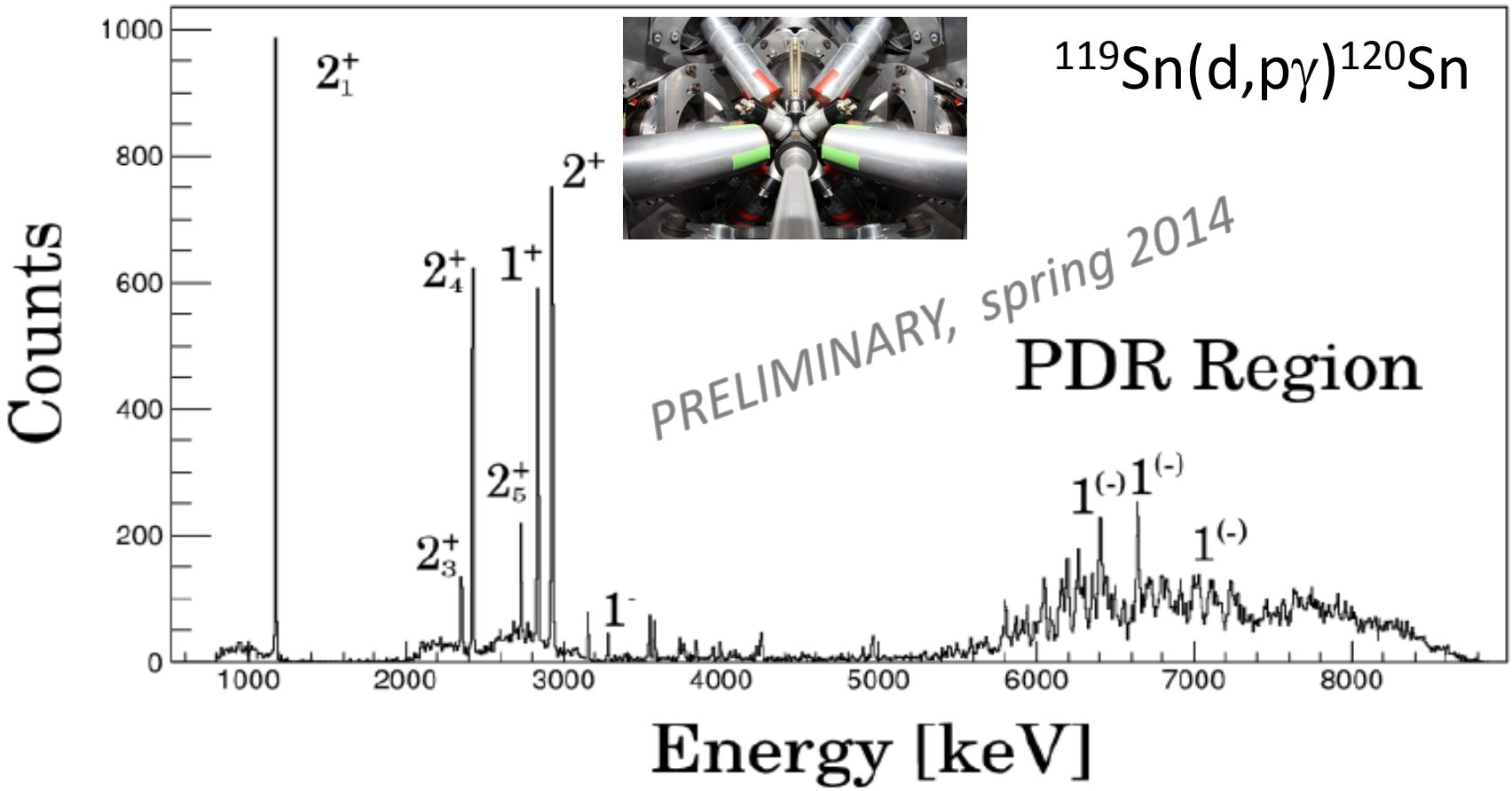
Isospin structure of the PDR in exotic nuclei: (α,α') in inverse kinematics at BigRIPS@RIKEN



From presence to future: Open questions

- Systematics (light vs. heavy nuclei, deformation, exoticity)
- Decay pattern
- Isospin structure: Comparison of electromagnetic and hadronic excitation
- **Single-particle structure**

Single-particle structure of the PDR: SONIC@HORUS, Cologne



S.G. Pickstone, A. Hennig, M. Spieker, V. Derya, M. Weinert, J. Wilhelmy, AZ

The Pygmy Dipole Resonance – status and new experimental 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.

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