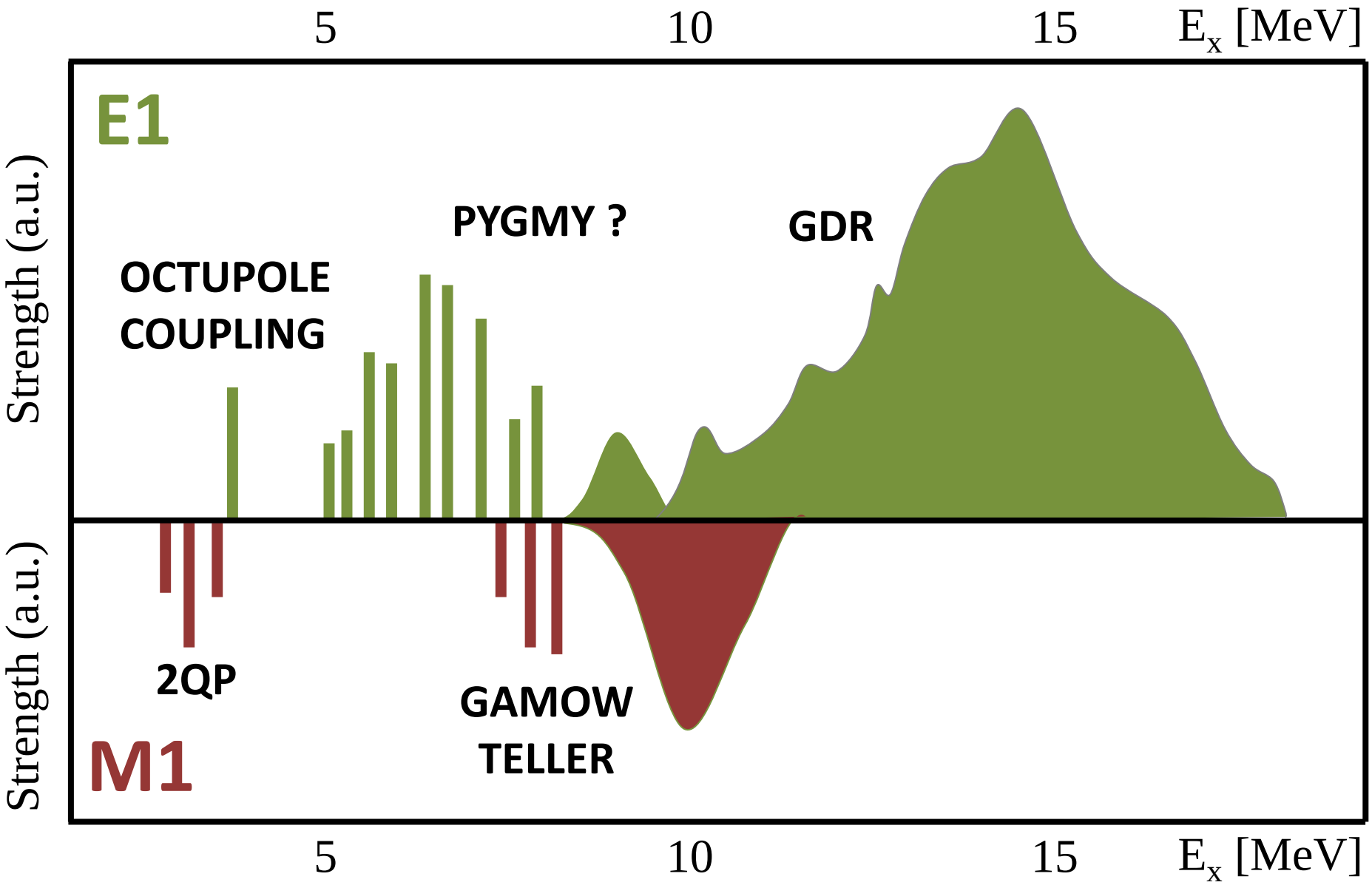
The Pygmy Dipole Resonance – past, presence, and future

- The **past**: From Giants to Pygmies
- The **presence**: Methods and experimental status
- The **future**: New experimental approaches

CGS 15 • Dresden, Germany • August 2014

Dipole response of atomic nuclei



History of the Giant Dipole Resonance (GDR)

1937:

Atomumwandlungen durch γ-Strahlen.

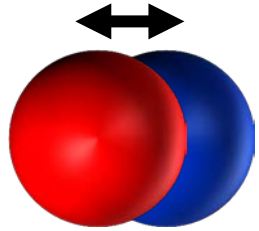
Von **W. Bothe** und **W. Gentner** in Heidelberg.

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

1944:

QUADRUPOLE AND DIPOLE γ-RADIATION OF NUCLEI

By **A. MIGDAL**



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

1947:

Photo-Fission in Heavy Elements*

G. C. BALDWIN AND G. S. KLAIBER

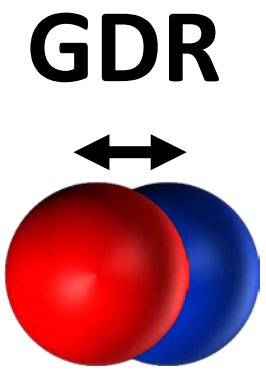
Research Laboratory, General Electric Company, Schenectady, New York

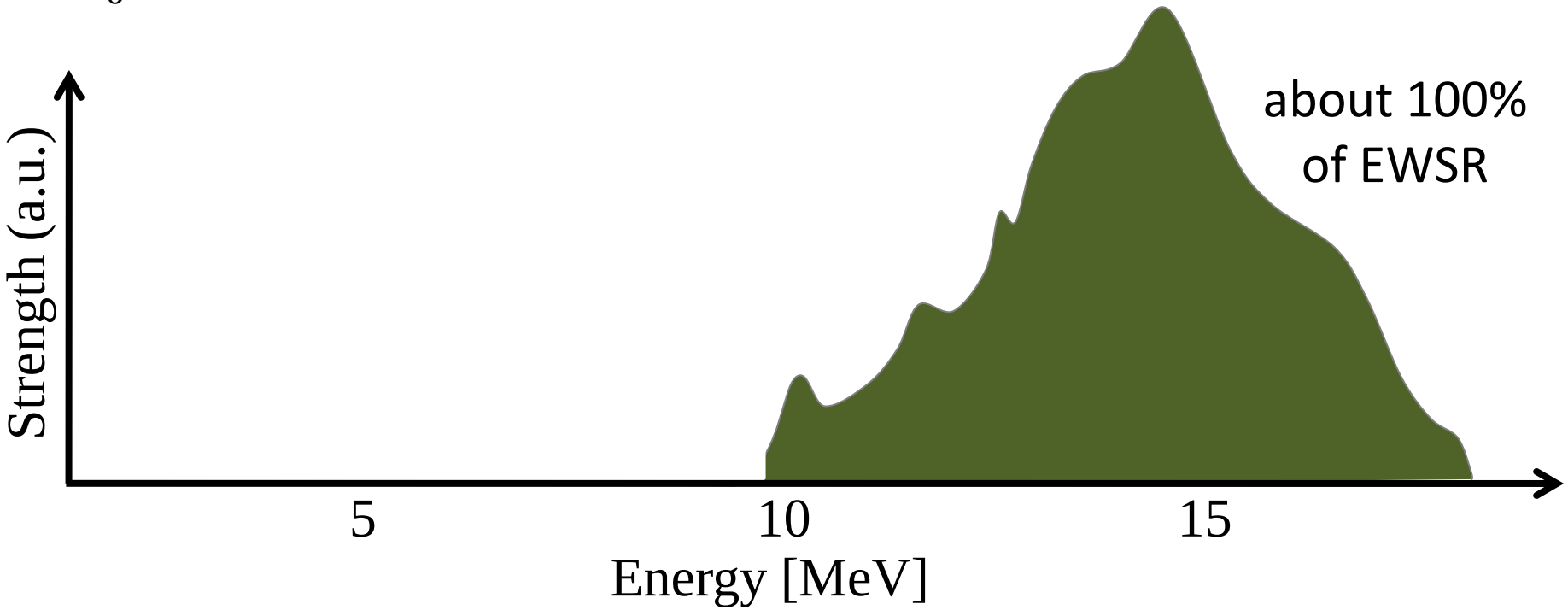
Phys. Rev. ***71*** *(1947) 3*

Giant Dipole Resonance (GDR)

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

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





History of the 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*

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

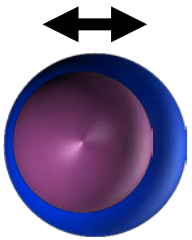
Can. J. Phys. ***47*** *(1969) 2850*

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)

1997:

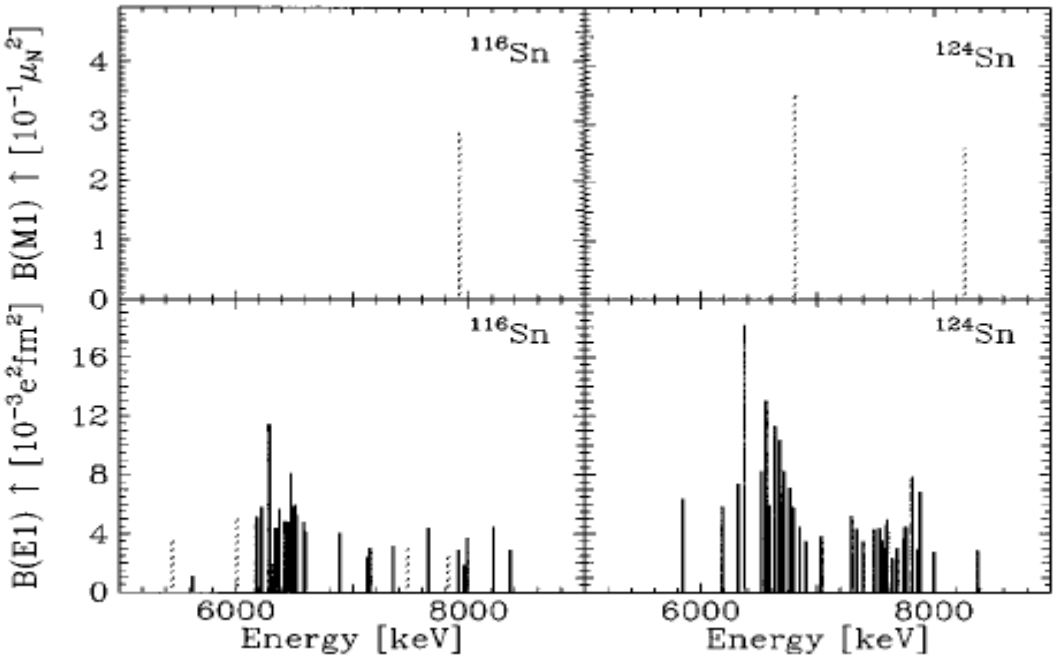
Dipole excitations to bound states in ^{116}Sn and ^{124}Sn

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*

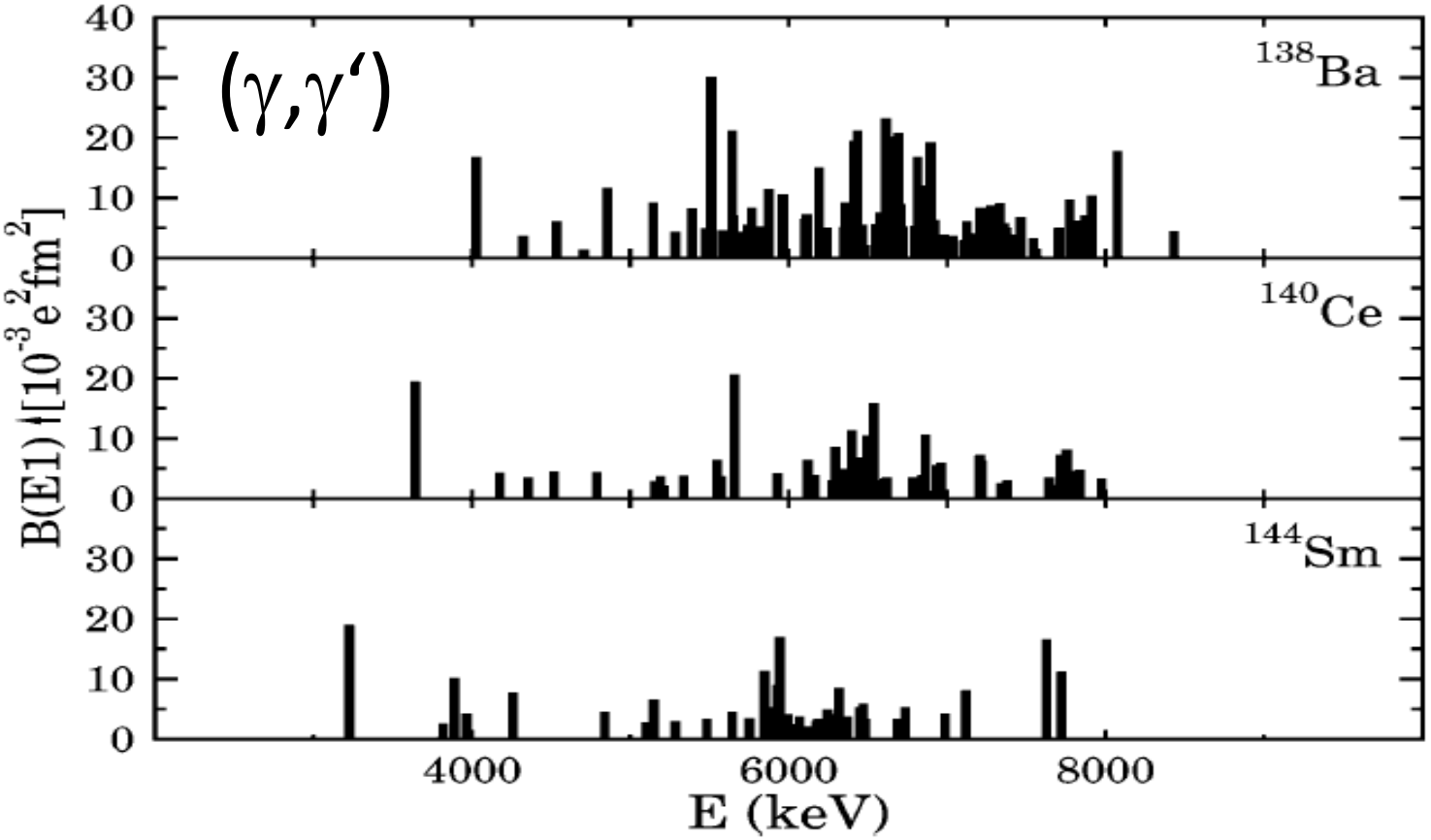


Pygmy Dipole Resonance (PDR)

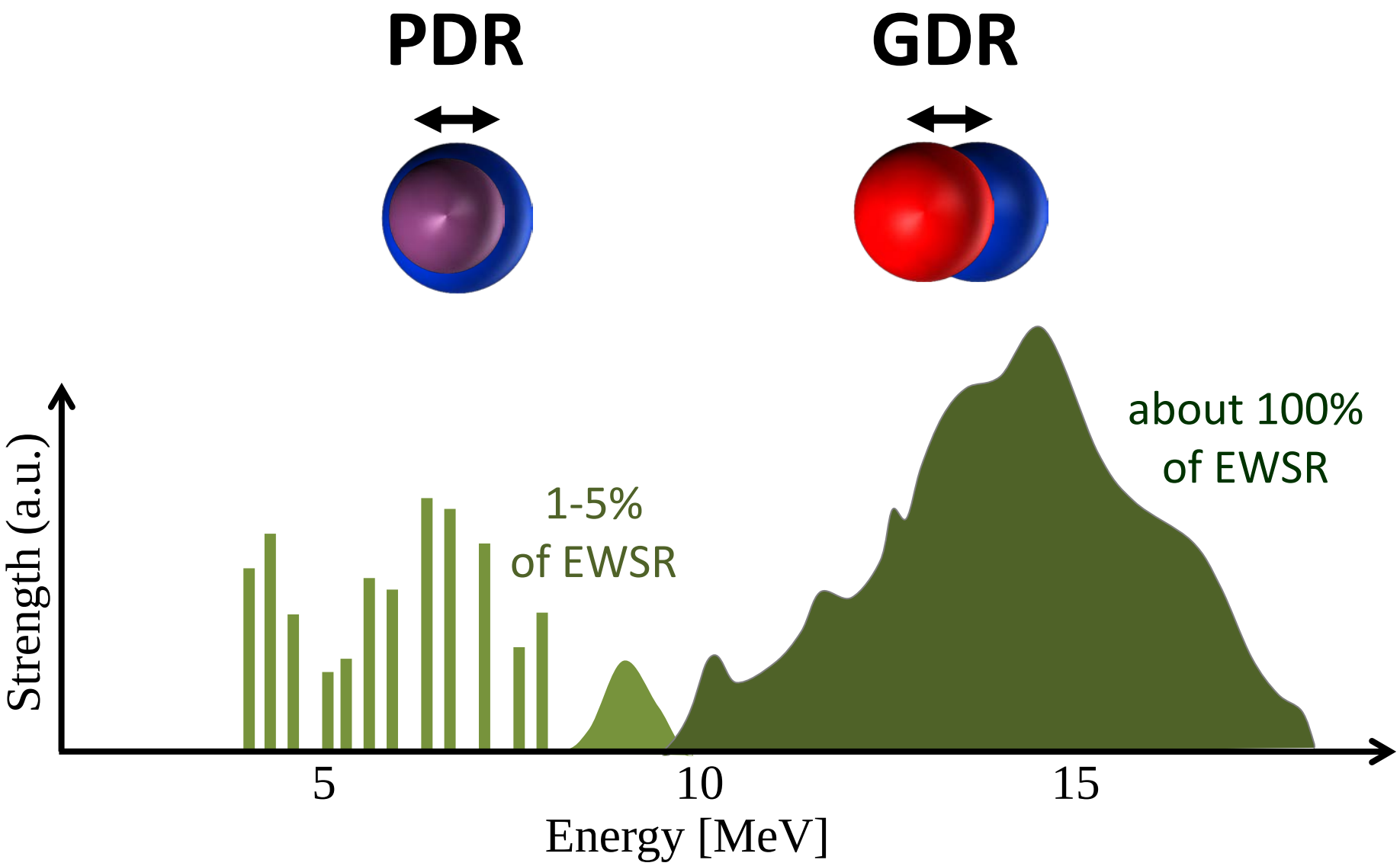
2002: Concentration of electric dipole strength below the neutron separation energy in $N = 82$ nuclei

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

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

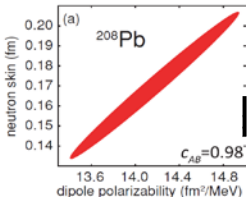


From giants to pygmies

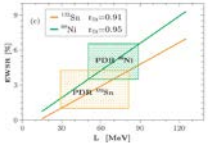


Relevance of low-lying E1 strength

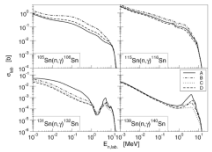
- PDR as a universal „collective“ excitation mode
- Connection to neutron skin, neutron star radius
- Slope of symmetry energy in EoS
- Impact on nucleosynthesis
- 12 talks and 4 posters at CGS15…



*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*

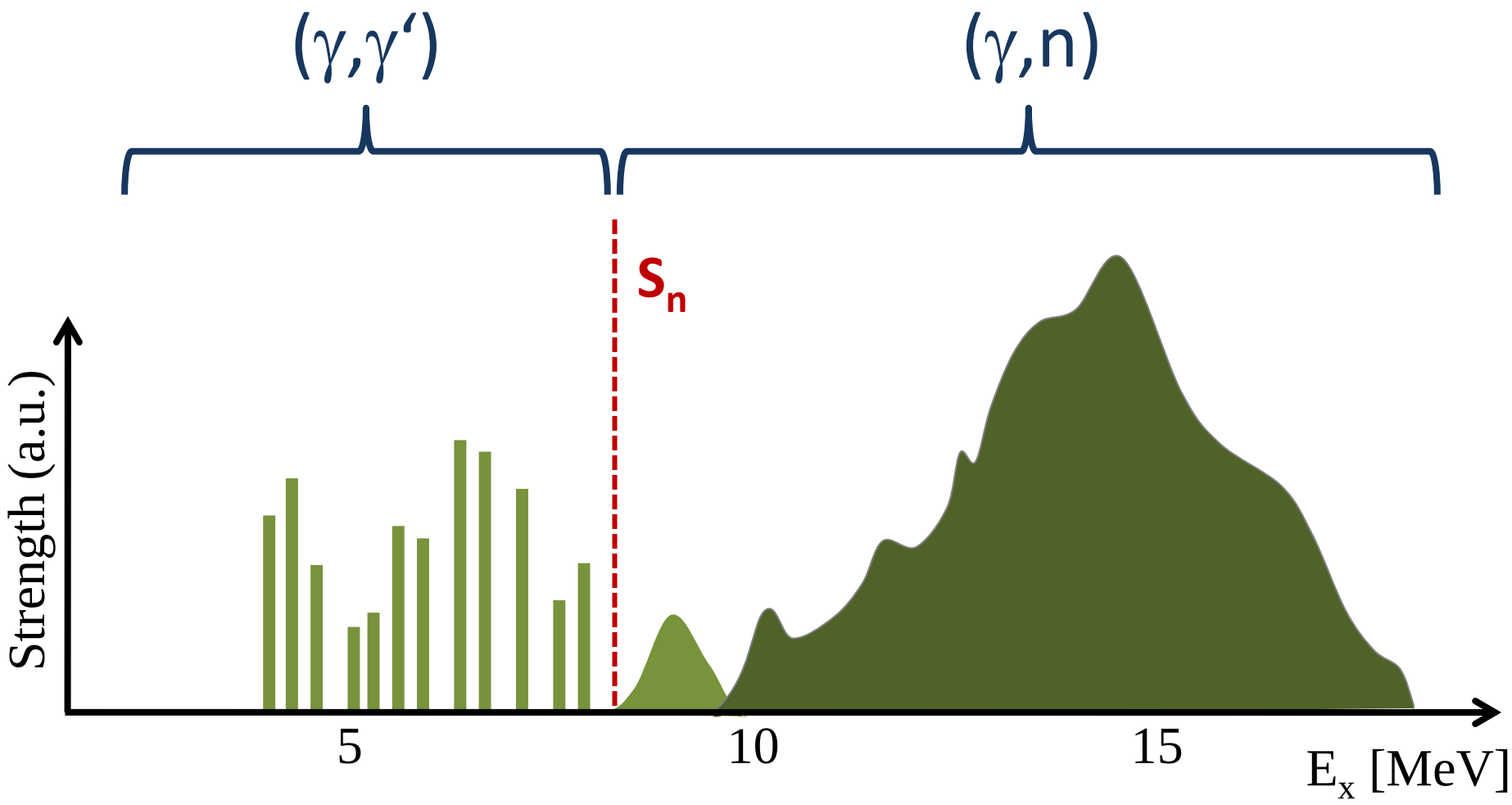


*A. Carbone et al. PRC **81** (2010) 041301(R)*
*B.A. Brown and A. Schwenk, PRC **89** (2014) 011307(R)*



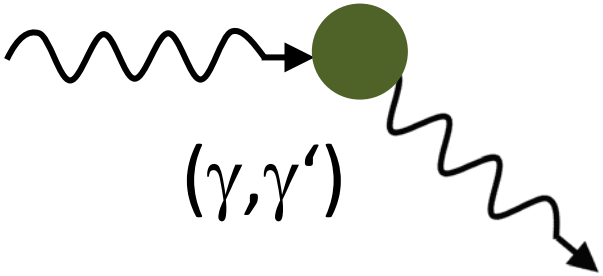
*S. Goriely, PLB **436** (1998) 10*
*E. Litvinova et al., NPA **823** (2009) 26*

Study of the E1 strength distribution via electromagnetic interaction

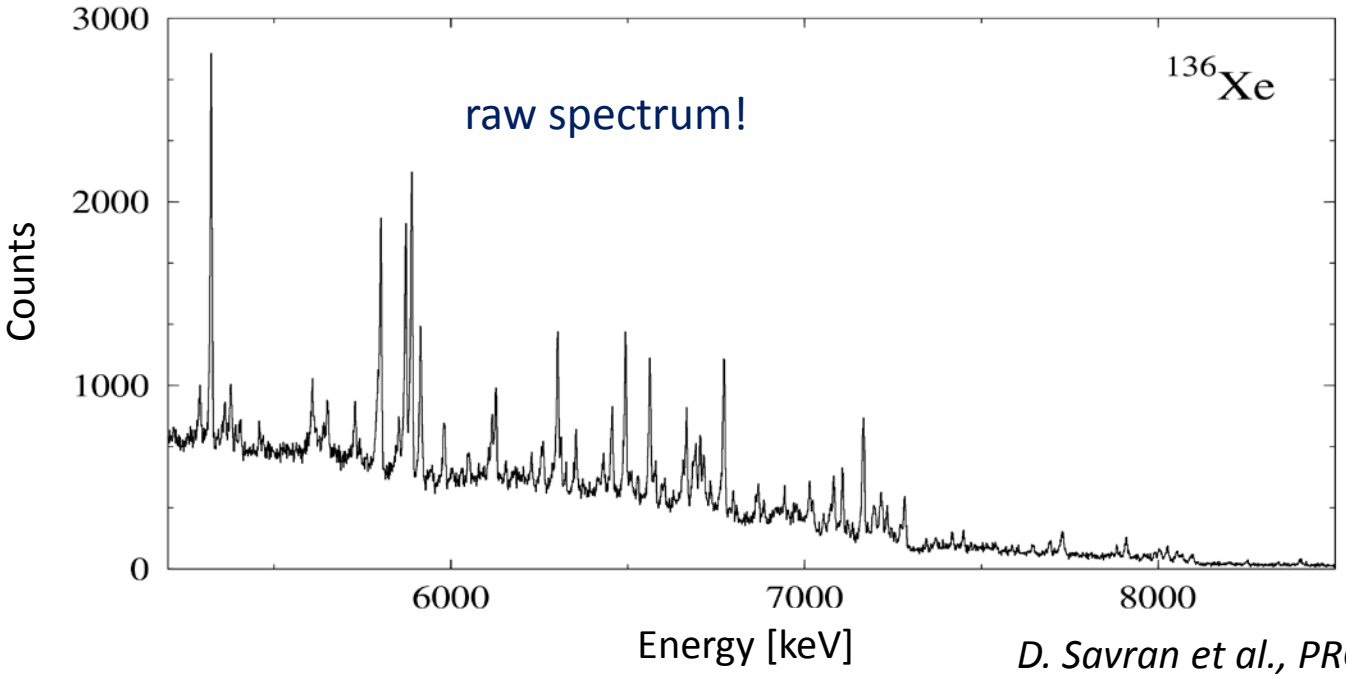


The photons can be real or virtual!

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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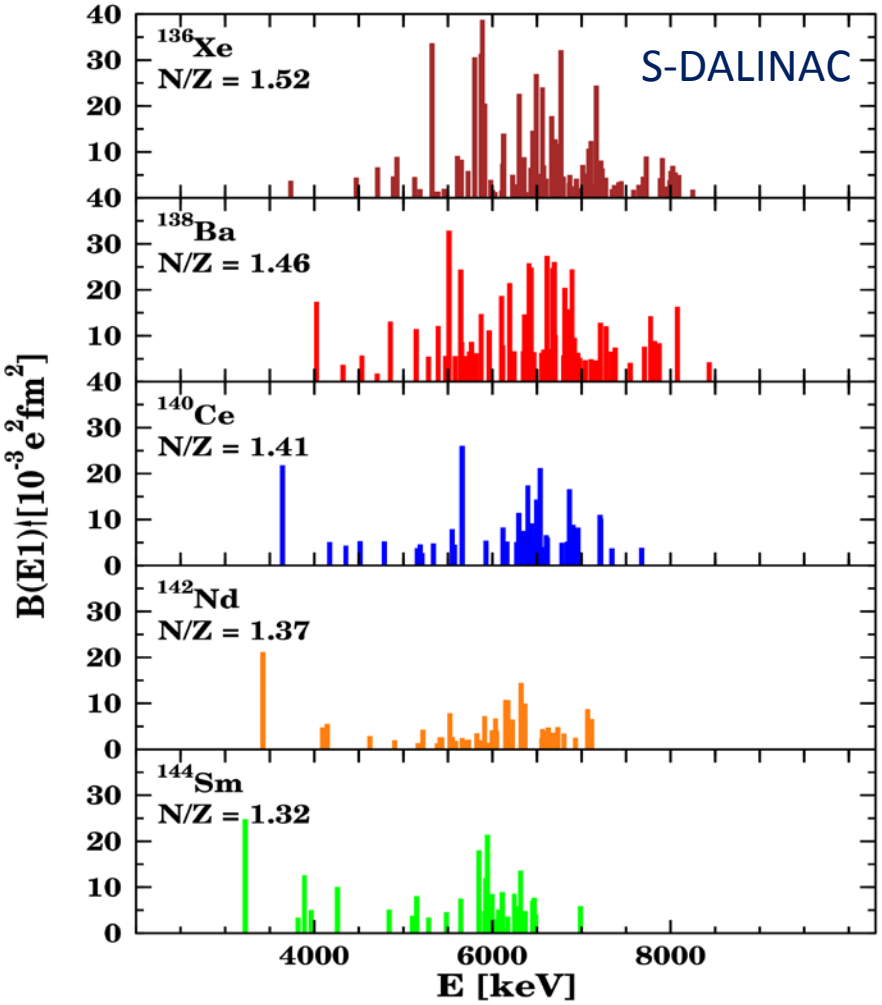
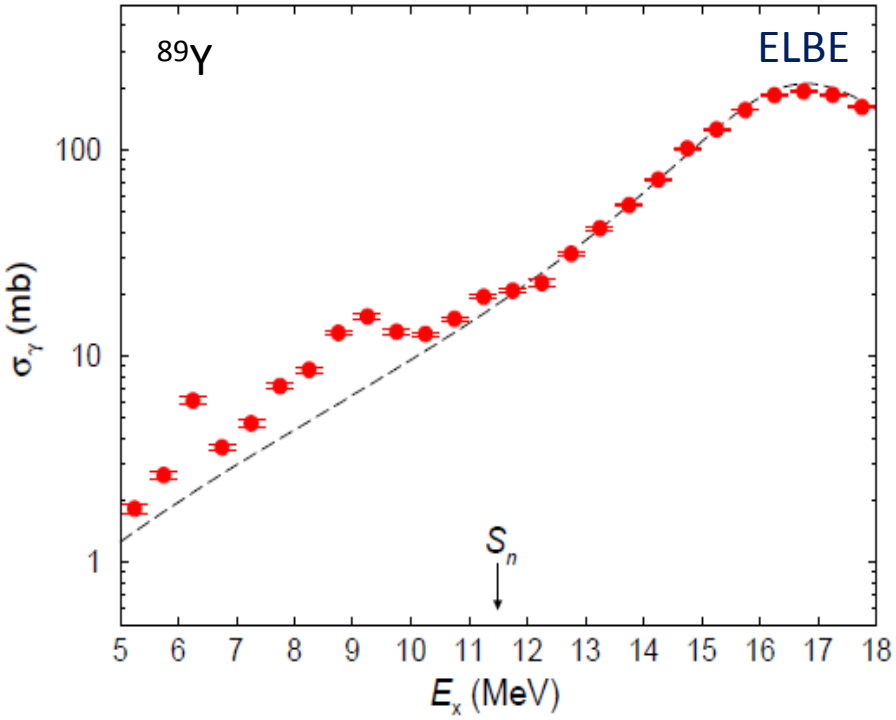
ELI@Bukarest

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

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

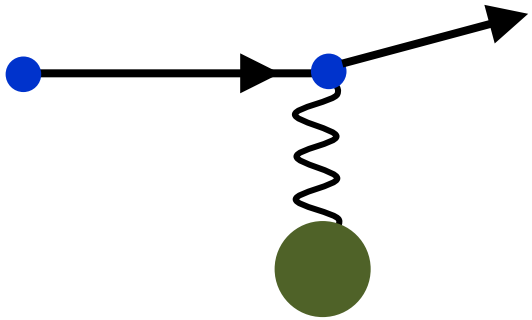




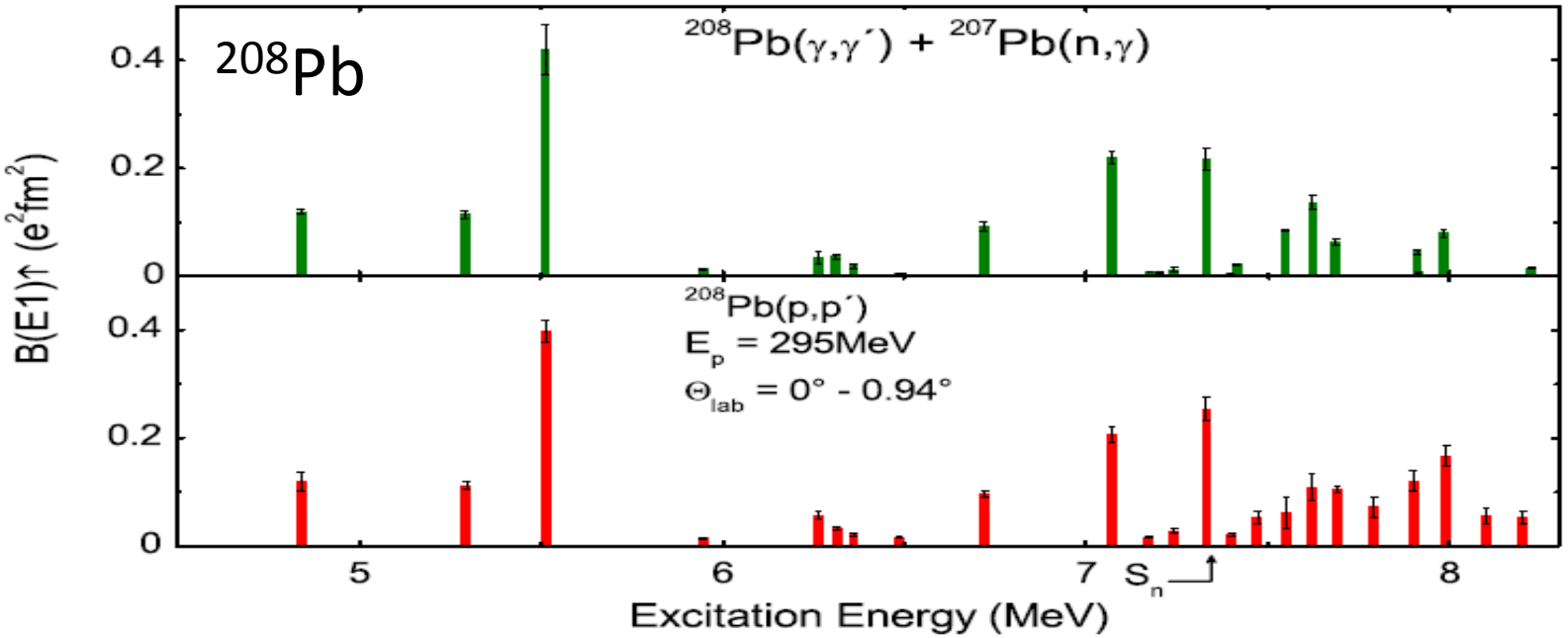
*A. Zilges et al., PLB **542** (2002) 43*
*S. Volz et al., NPA **779** (2006) 1*
*N. Benouaret et al., PRC **79** (2009) 014303*
*D. Savran et al., PRC **84** (2011) 024326*

→ talks by Anton Tonchev, Volker Werner, Ralph Massarczyk, Dmytro Symochko

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

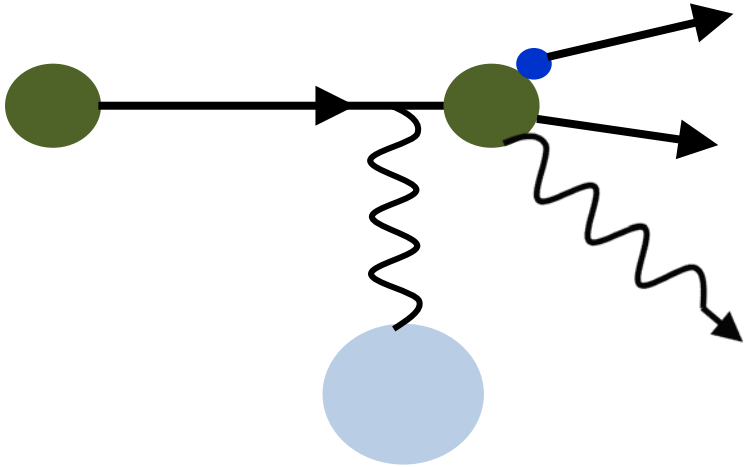


GRAND RAIDEN @RCNP

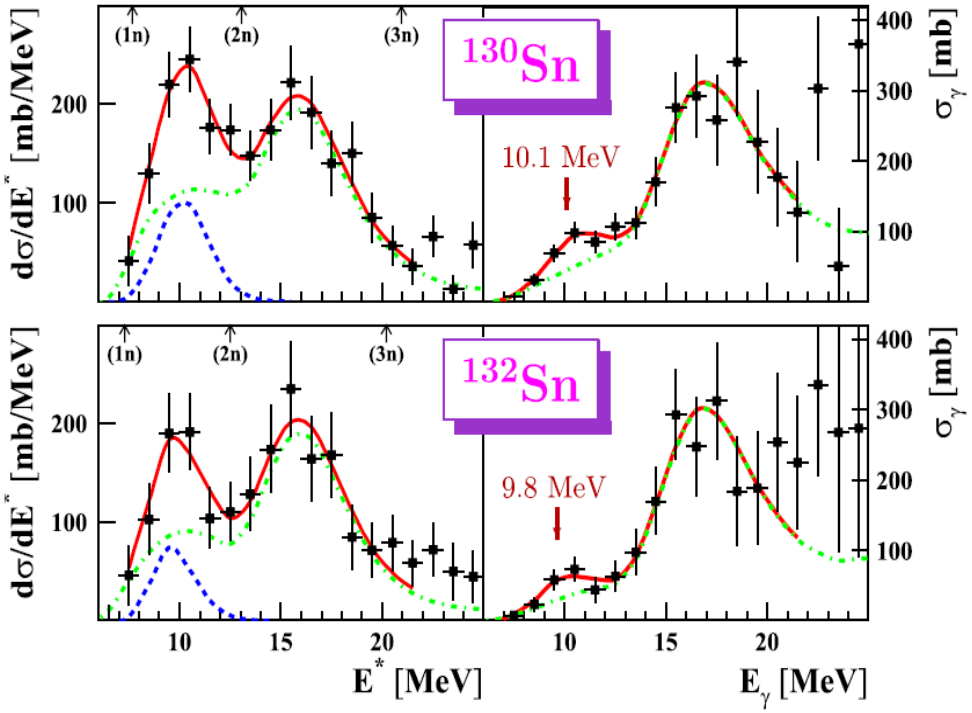
*A. Tamii et al., PRL **107** (2011) 062502*

→ 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



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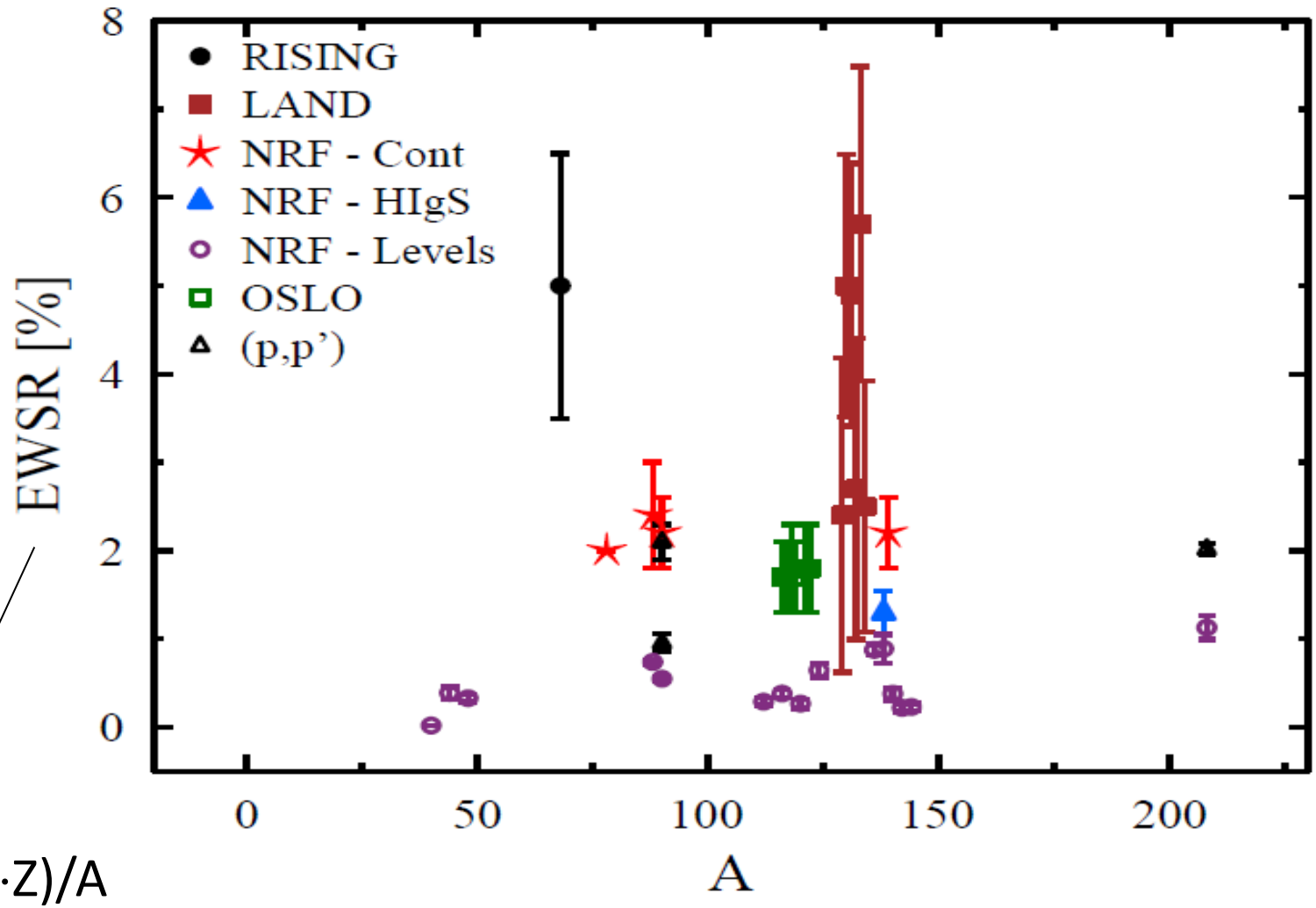
NeuLAND@R3B@FAIR
…

*P. Adrich et al., PRL **95** (2005) 132501*
*A. Klimkiewicz et al., PRC **76** (2007) 051603 (R)*
*O. Wieland et al., PRL **102** (2009) 092502*

Summed B(E1) strength of Pygmy Dipole Resonance

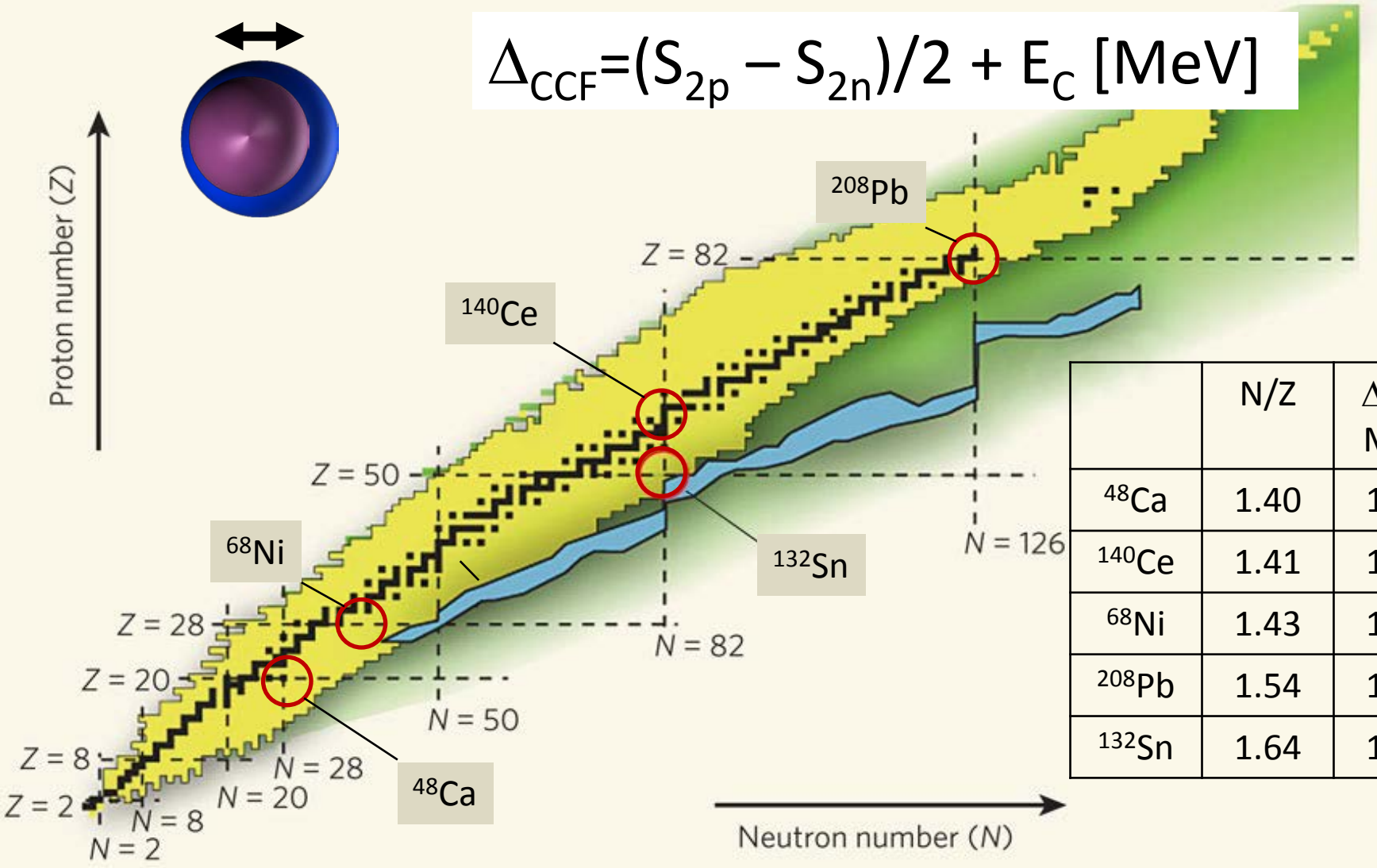


$\propto (N \cdot Z)/A$

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

Parametrization of „exoticity“

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

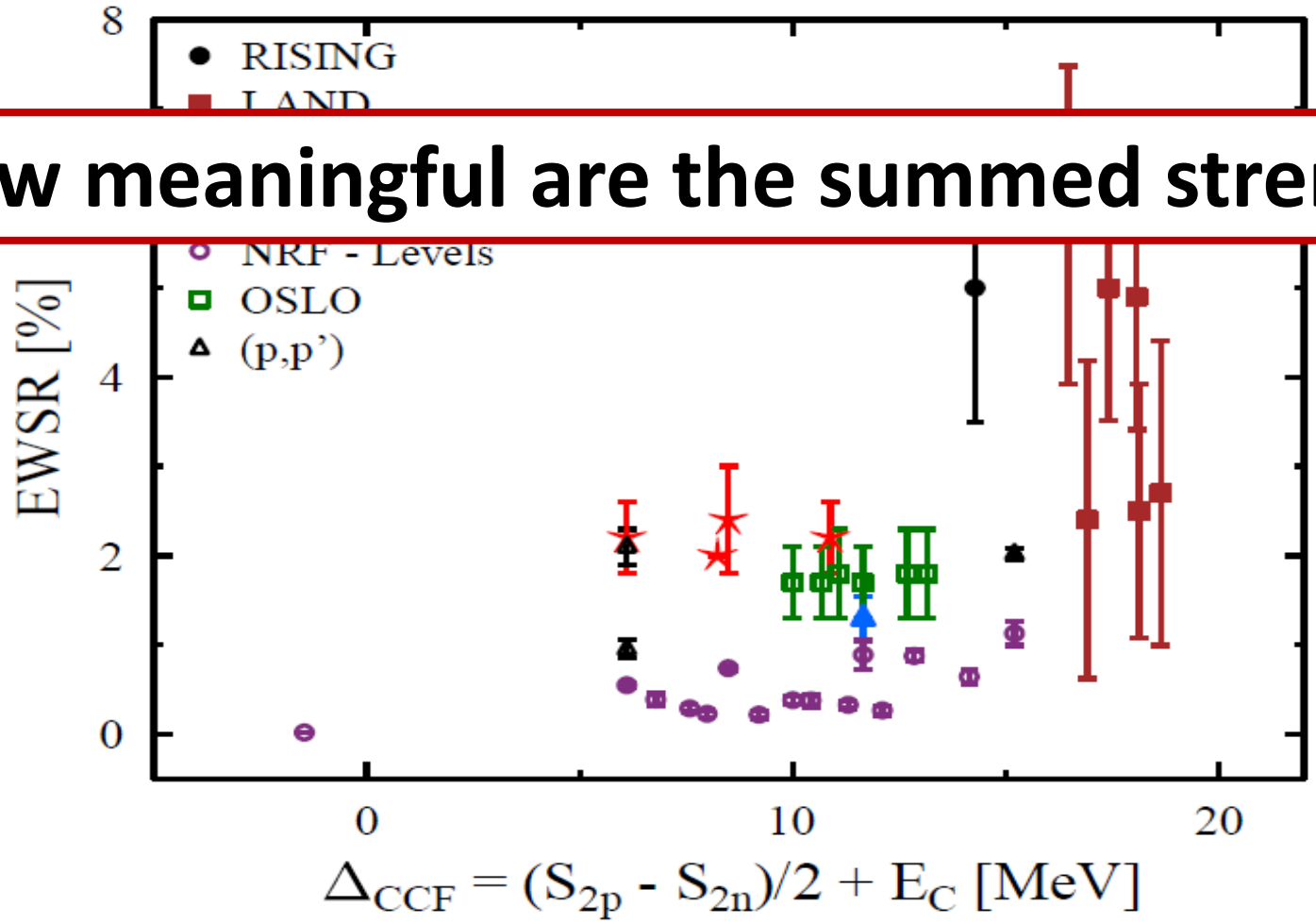


	N/Z	Δ_{CCF}/ MeV
^{48}Ca	1.40	11.3
^{140}Ce	1.41	10.4
^{68}Ni	1.43	14.3
^{208}Pb	1.54	15.2
^{132}Sn	1.64	18.6

*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*

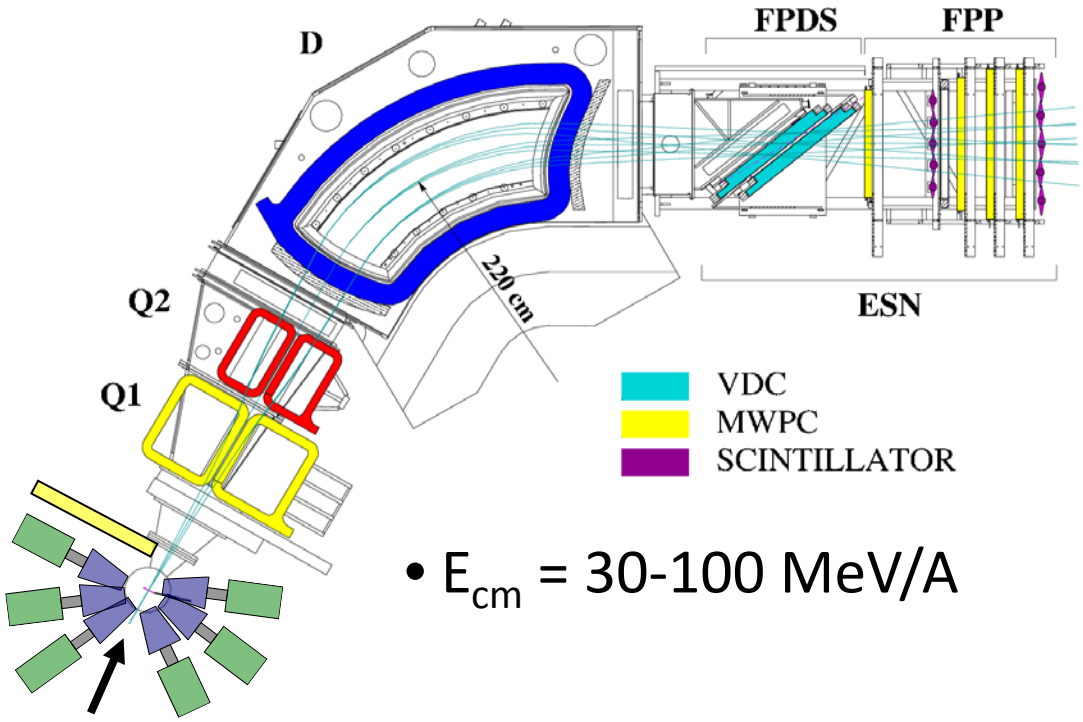
Testing the structure: (γ,γ′) vs. (α,α′)

	(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

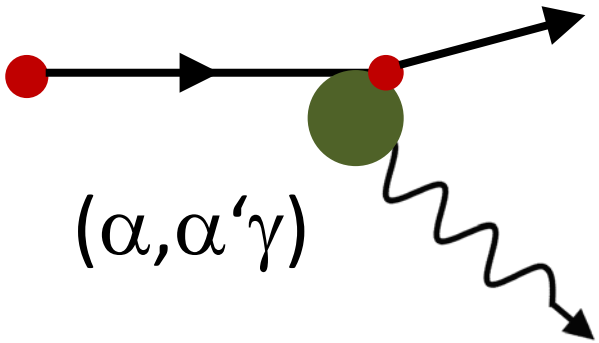
A coincident detection of the γ decay enhances the selectivity (and possibly the energy resolution) → **(α,α′γ)**

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

(α,α'γ) and (p,p'γ) experiments



α beam



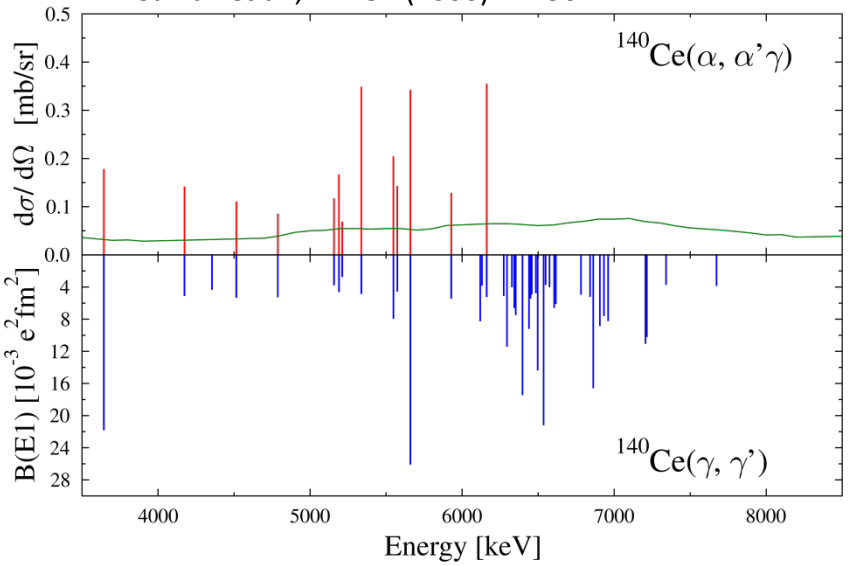
- E_{cm} = 30-100 MeV/A

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

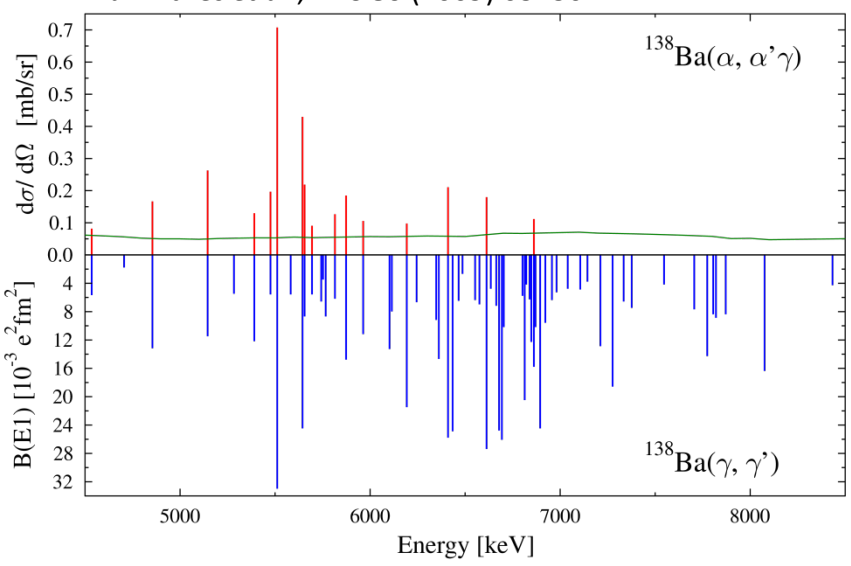
- BBS@KVI (deceased 15/11/12)
- K600 @ iThemba LABS
- CAGRA campaign @ RCNP
- BigRIPS@RIKEN (inverse kinematics)

Splitting of strength: Experimental results

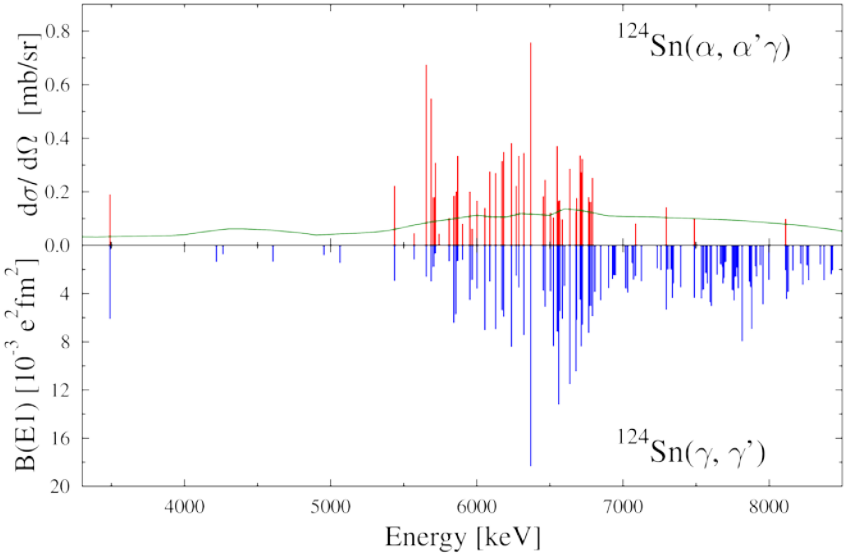
D. Savran *et al.*, PRL **97** (2006) 172502



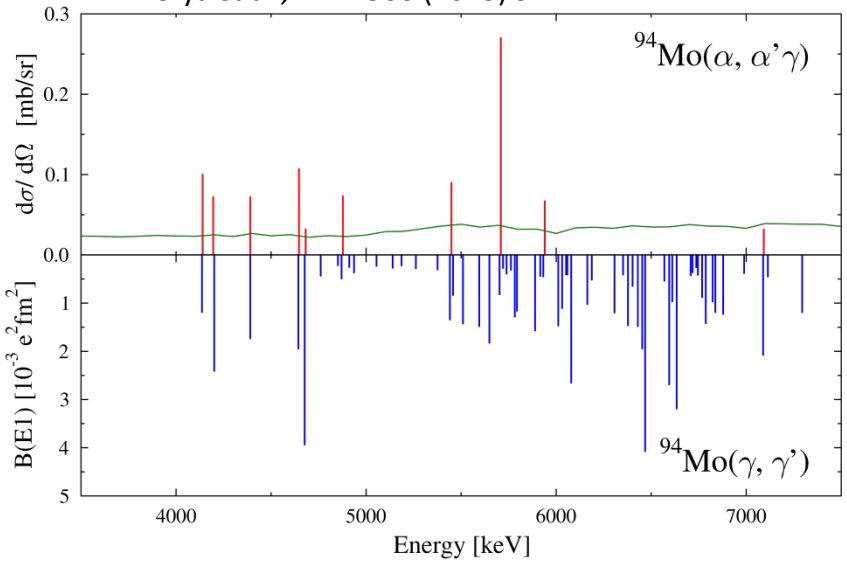
J. Endres *et al.*, PRC **80** (2009) 034302



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

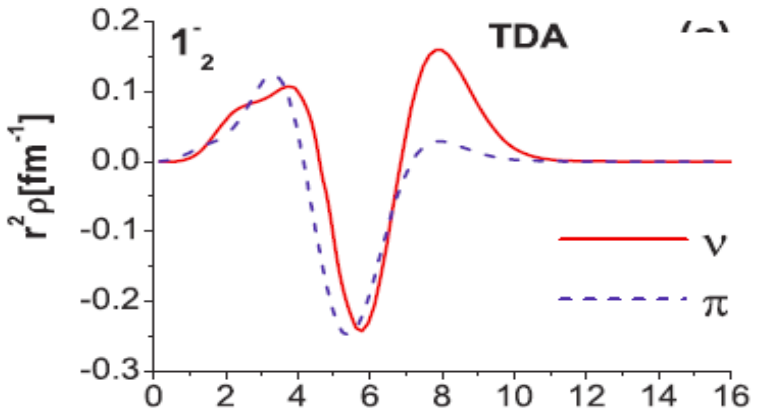


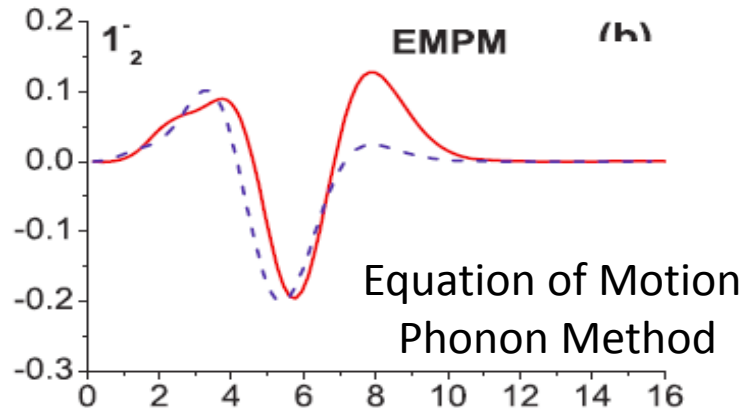
V. Derya *et al.*, NPA **906** (2013) 94



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

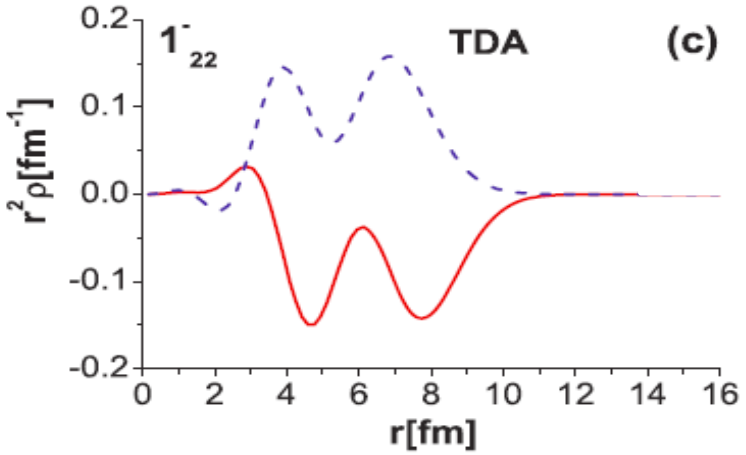
PDR region

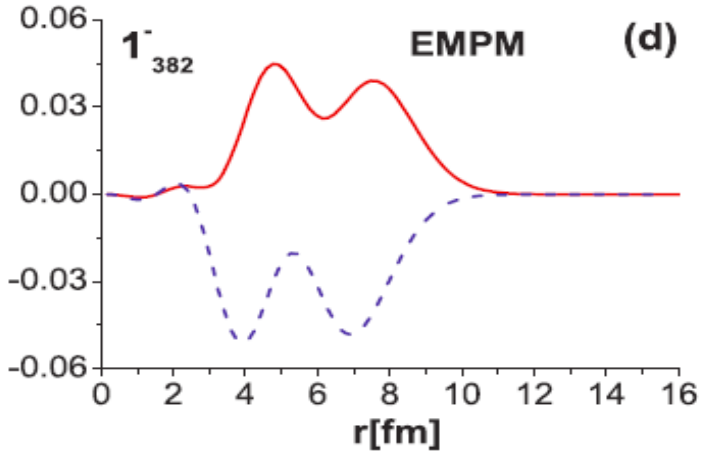




Equation of Motion Phonon Method

GDR region

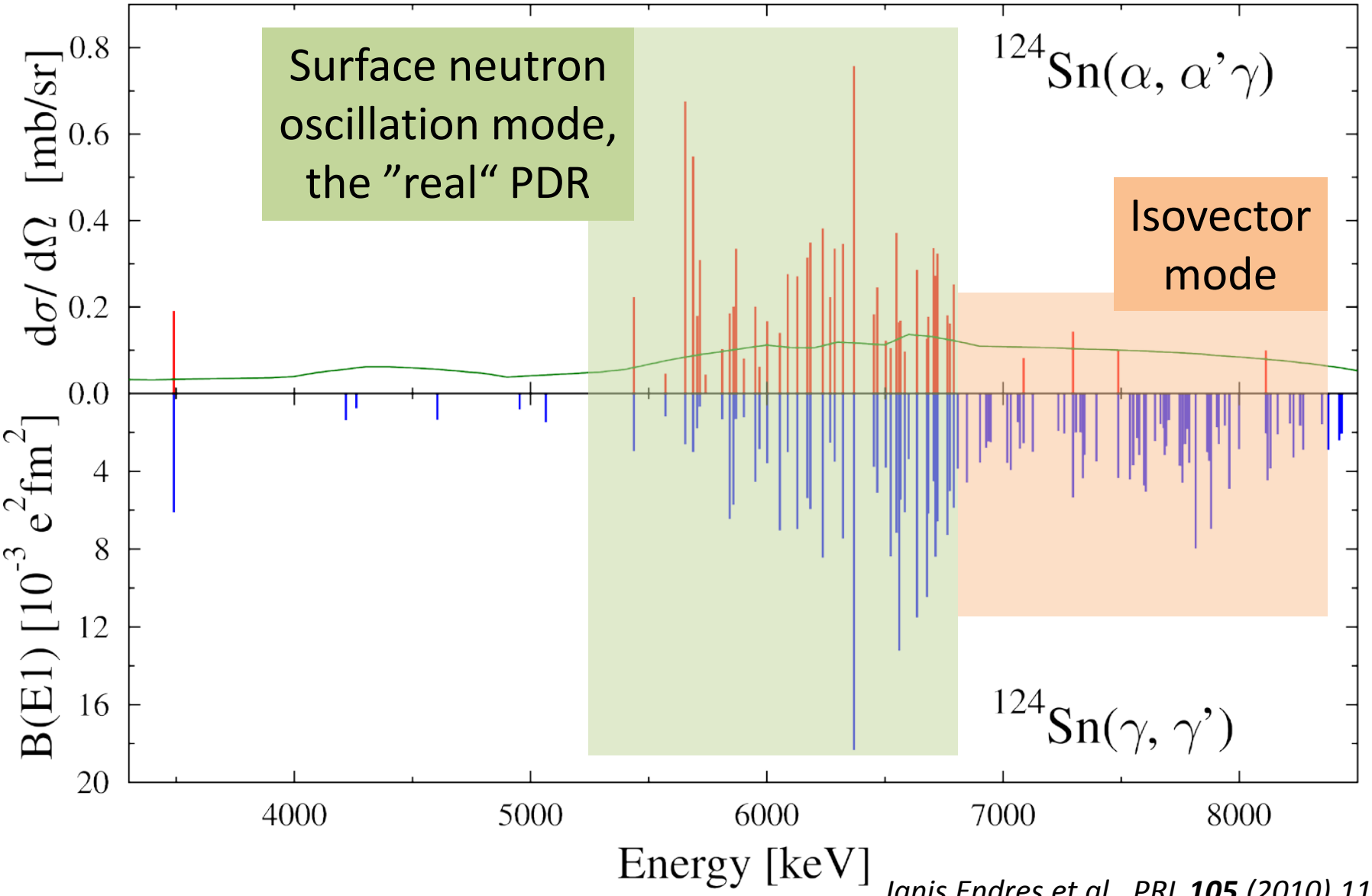




*D. Bianco et al., PRC **86** (2012) 044327*
*similar results in RQTBA: E.G. Lanza et al., PRC **89** (2014) 041601*

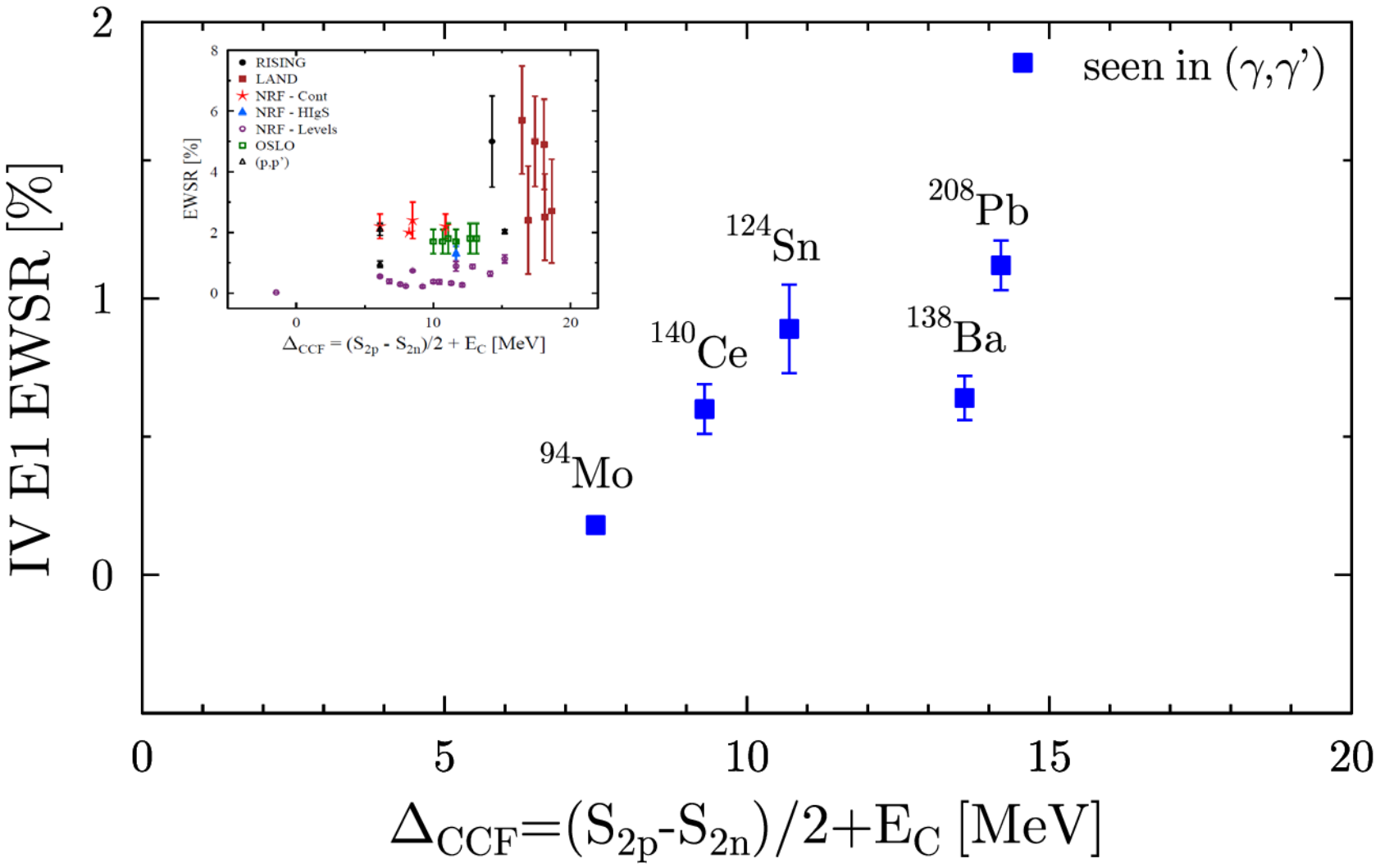
→ Contributions by Nicola Lo Iudice, Valentin Nesterenko, Nadia Tsoneva, Hitoshi Nakada, and Sergei Kamerdzhiev

Splitting of the PDR: Interpretation from RQTBA

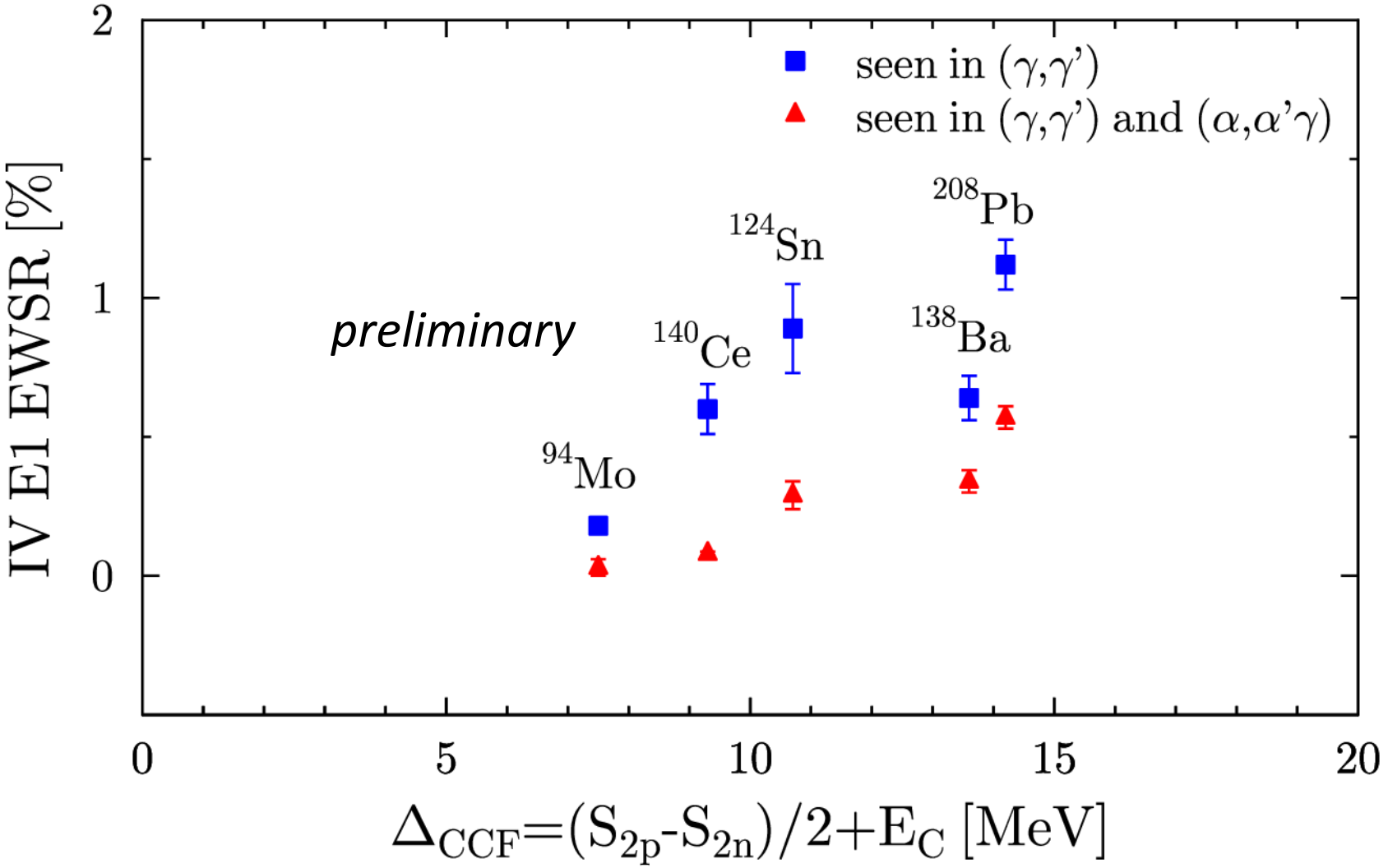


*Janis Endres et al., PRL **105** (2010) 112503*
*Janis Endres et al., PRC **85** (2012) 064331*

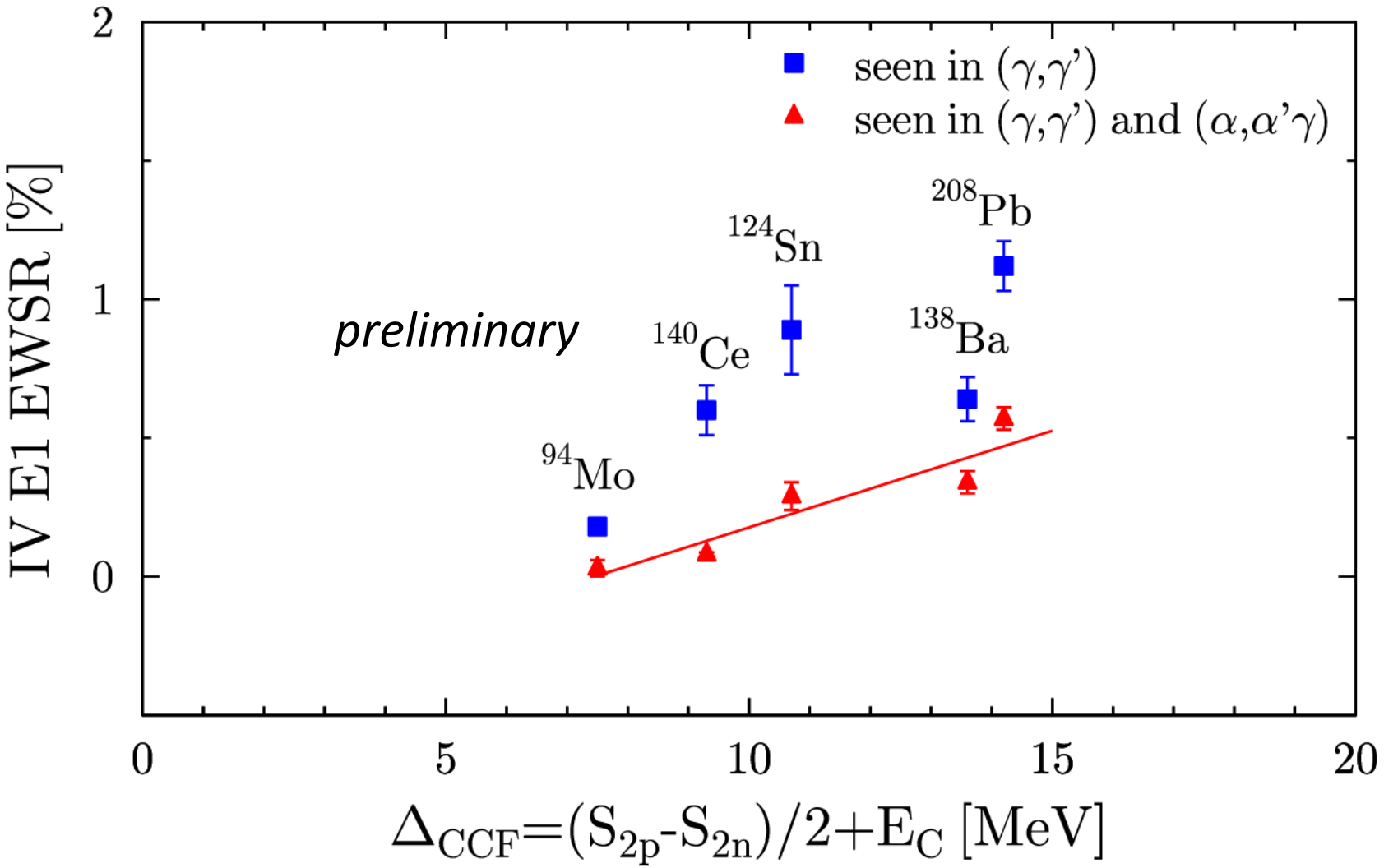
Summed E1 strength derived from EM excitation



Summed E1 strength derived from (α,α‘)



Summed E1 strength derived from (α,α‘)

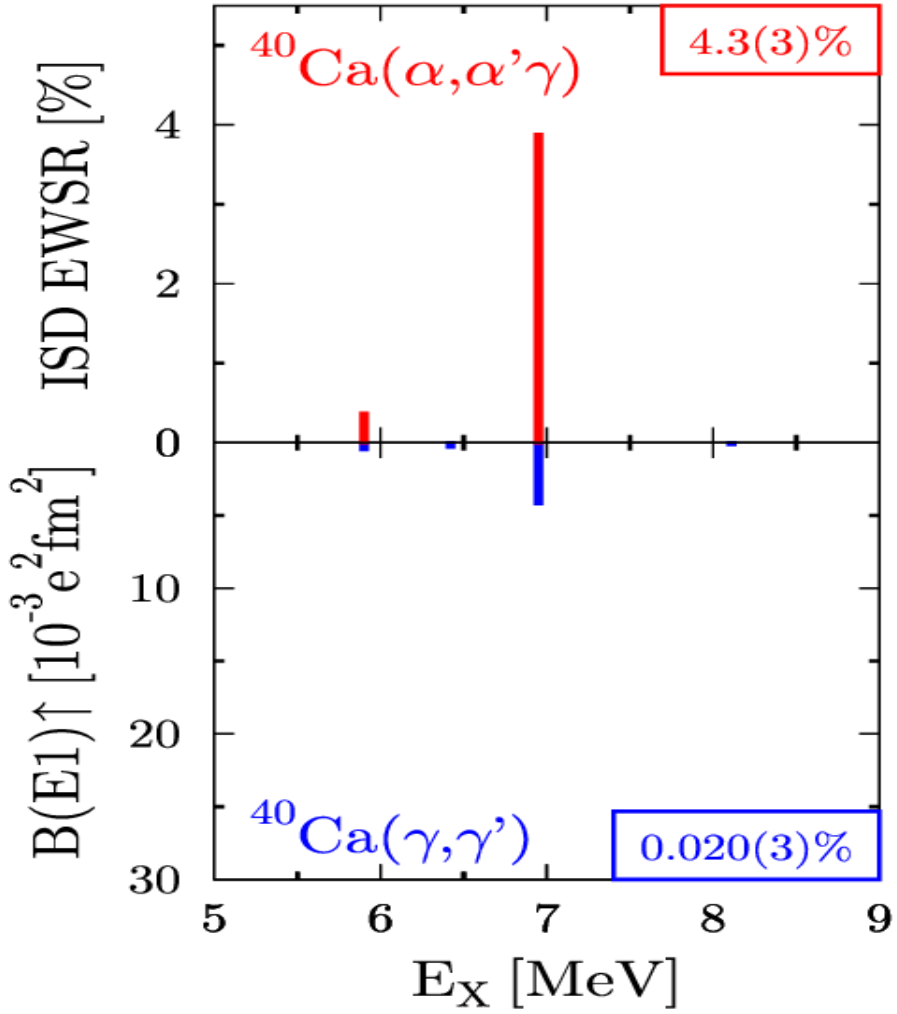


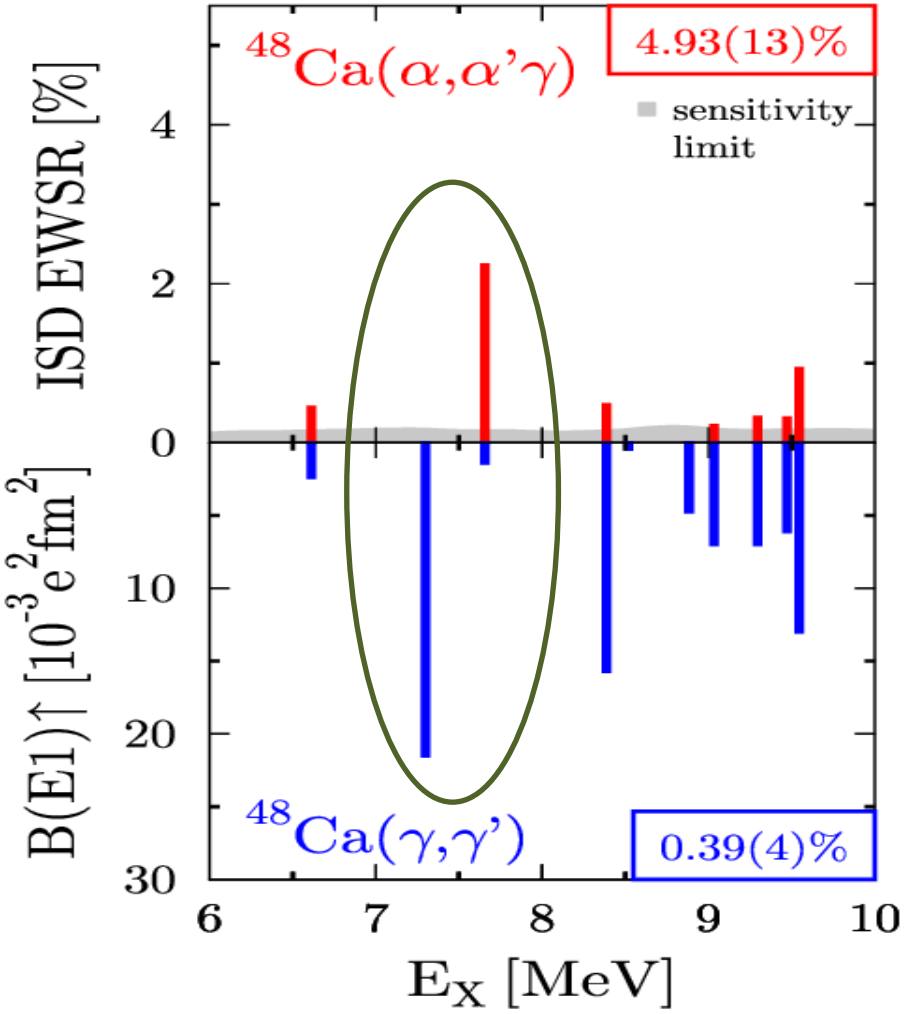
→ talk by Vera Derya

From presence to future: Open questions

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

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

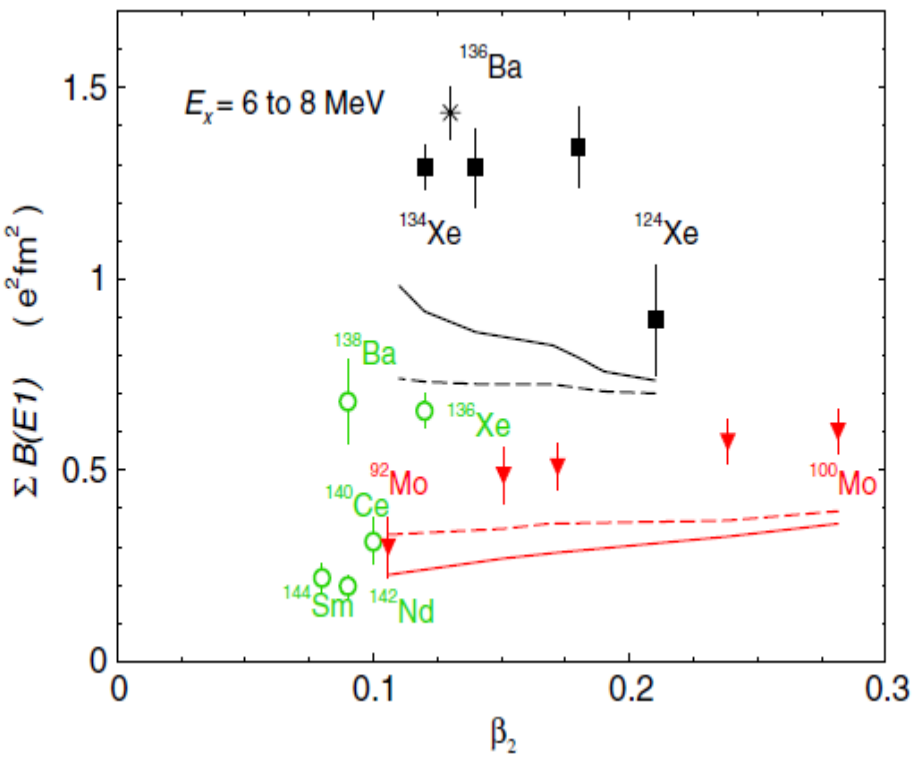


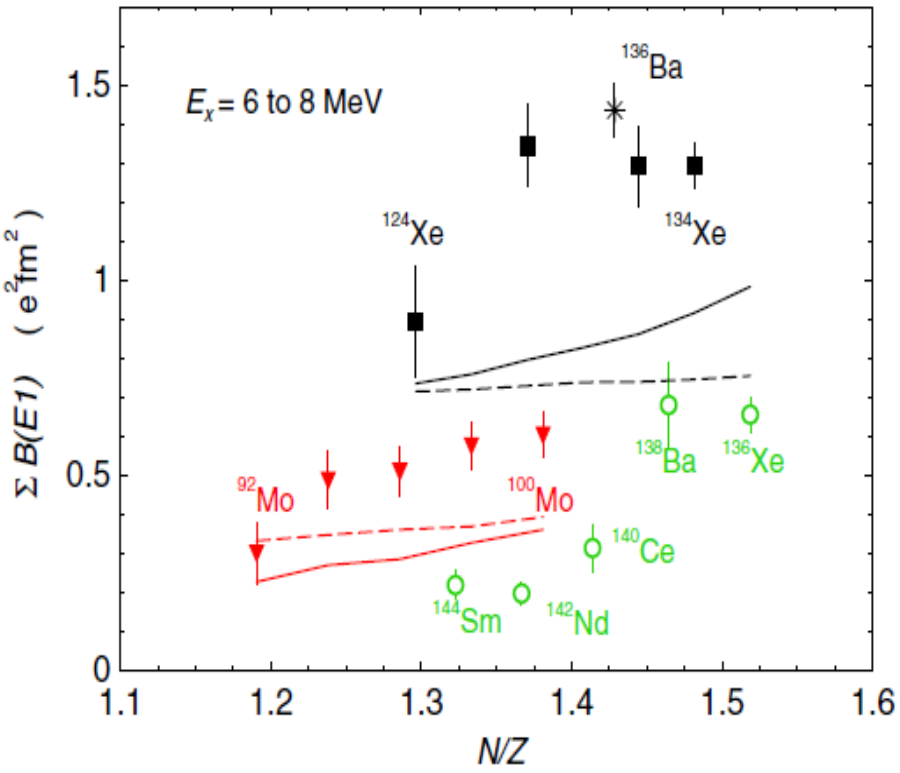


*V. Derya et al., PLB **730** (2014) 288*

→ talk by Vera Derya

E1 strength vs. deformation and N/Z





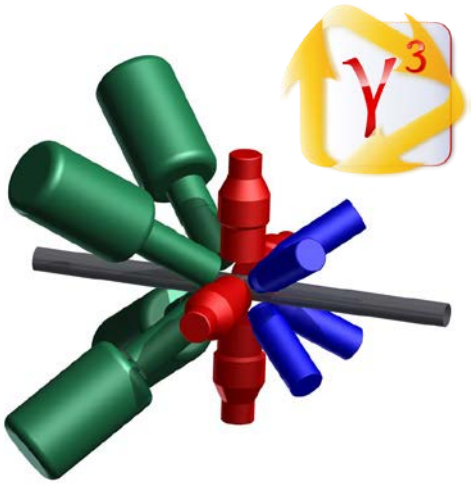
*R. Massarczyk , R. Schwengner et al., PRL **112** (2014) 072501*

→ talk by Ralph Massarczyk

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*

→ talks by Anton Tonchev and Volker Werner
→ poster by Johann Isaak

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EMMI
Yale University

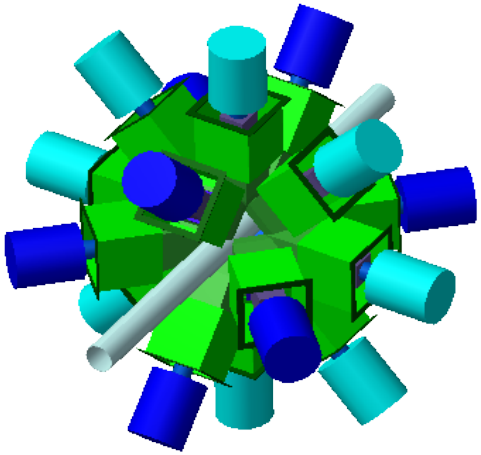
From presence to future: Open questions

- 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

From presence to future: Open questions

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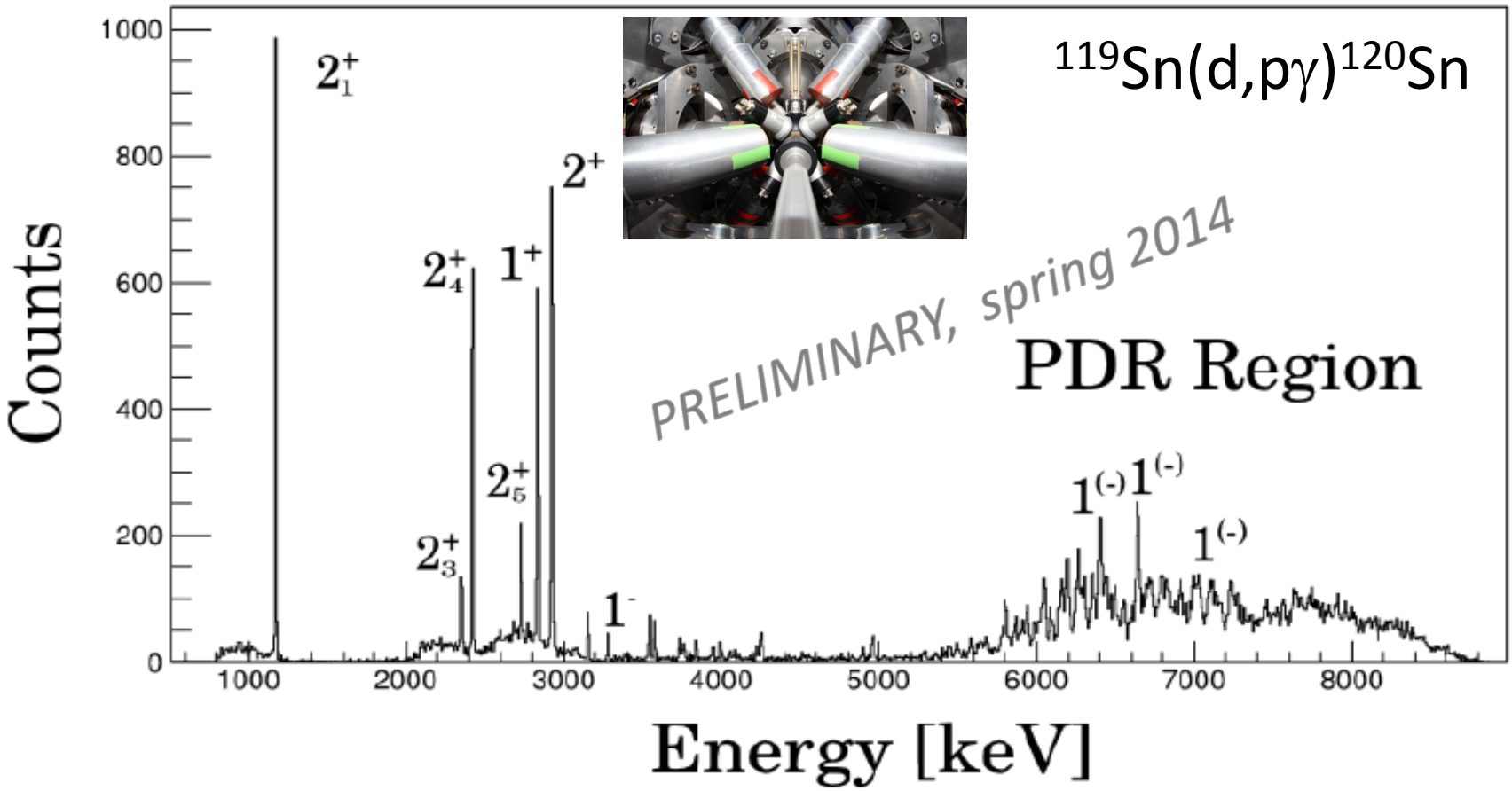
- Isospin structure: Comparison of electromagnetic and hadronic excitation
- **Single-particle structure**

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



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

→ poster by Simon Pickstone

The Pygmy Dipole Resonance – status and new developments

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