The Electric Dipole Response of Atomic Nuclei – from Giants to Pygmies

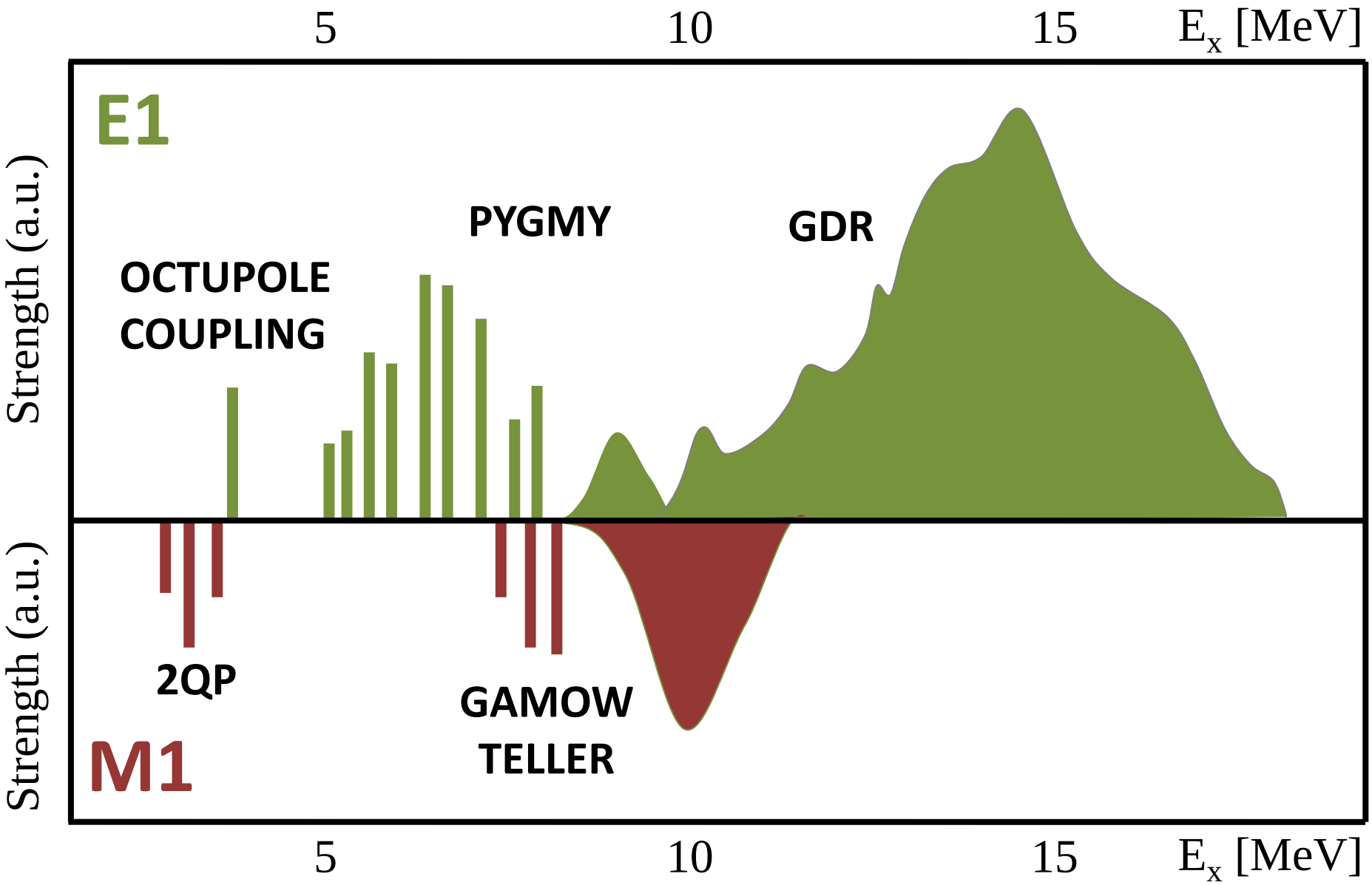
Andreas Zilges
Institut für Kernphysik
Universität zu Köln

The Electric Dipole Response of Atomic Nuclei – from Giants to Pygmies

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

Andreas Zilges
Institut für Kernphysik, Universität zu Köln

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*

75 years ago

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.**

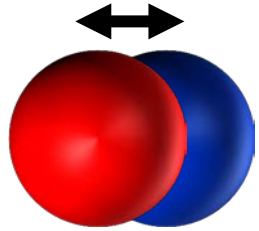
Von **W. Bothe** und **W. Gentner** in Heidelberg.

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

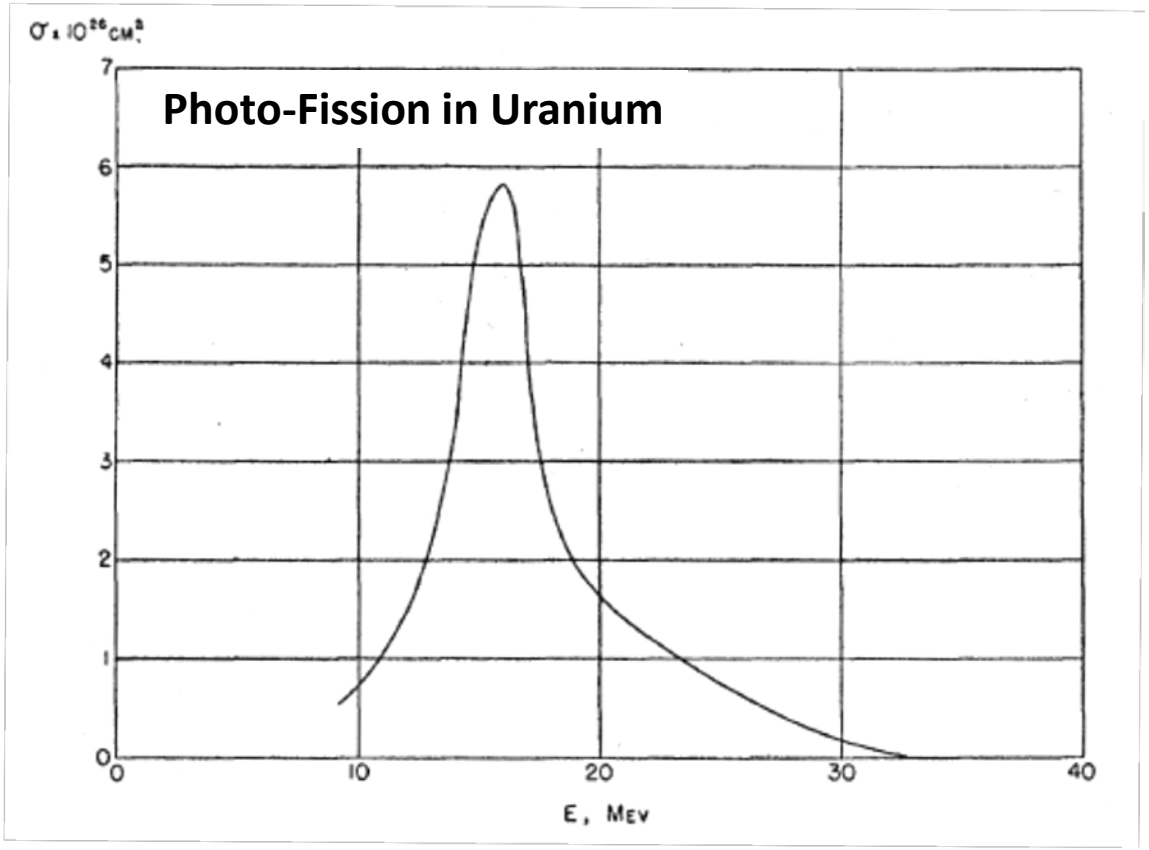
1944: **QUADRUPOLE AND DIPOLE γ-RADIATION OF NUCLEI**

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)

1937:

Atomumwandlungen durch γ-Strahlen.

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

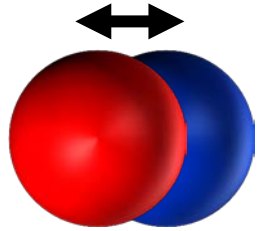
Z. Phys. ***106*** *(1937) 236*

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

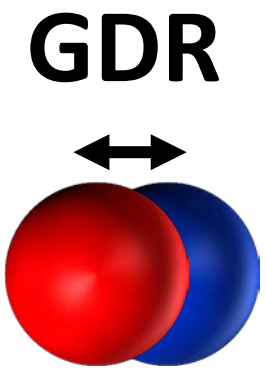
Research Laboratory, General Electric Company, Schenectady, New York

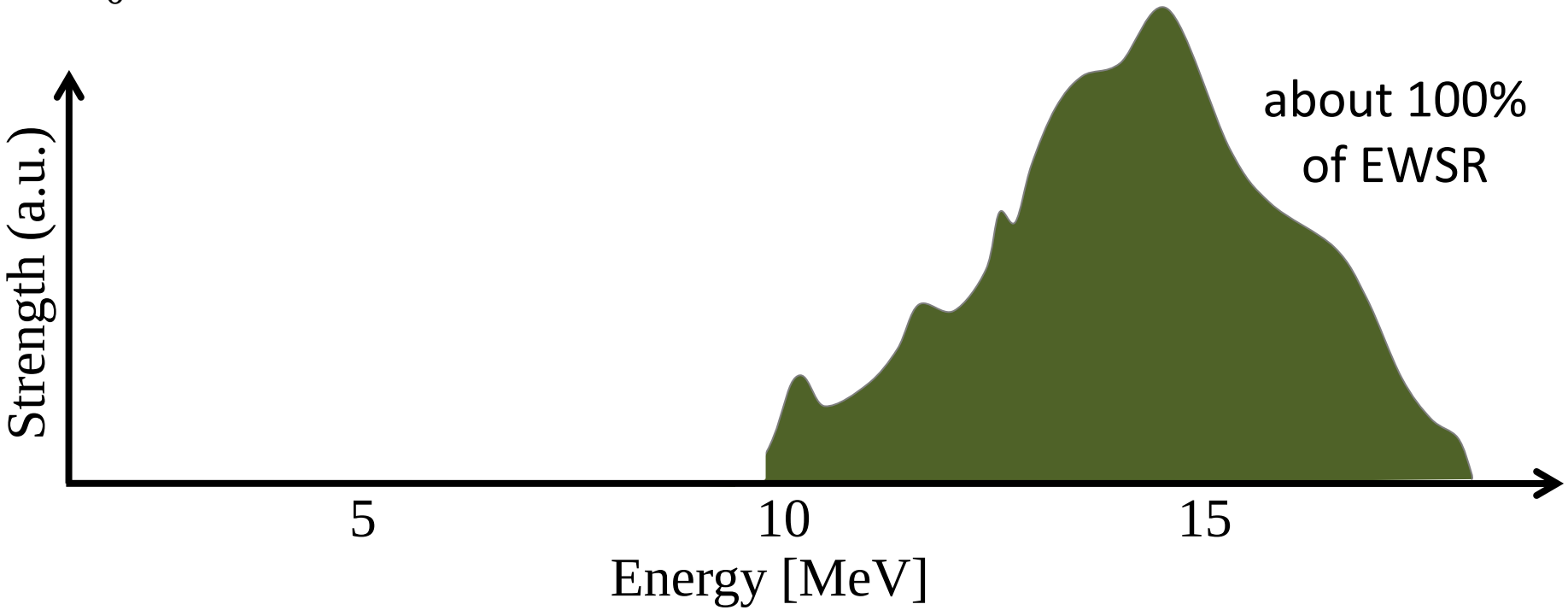
Phys. Rev. ***71*** *(1947) 3*

Giant Dipole Resonance (GDR)

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

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





Pygmy Dipole Resonance (PDR)

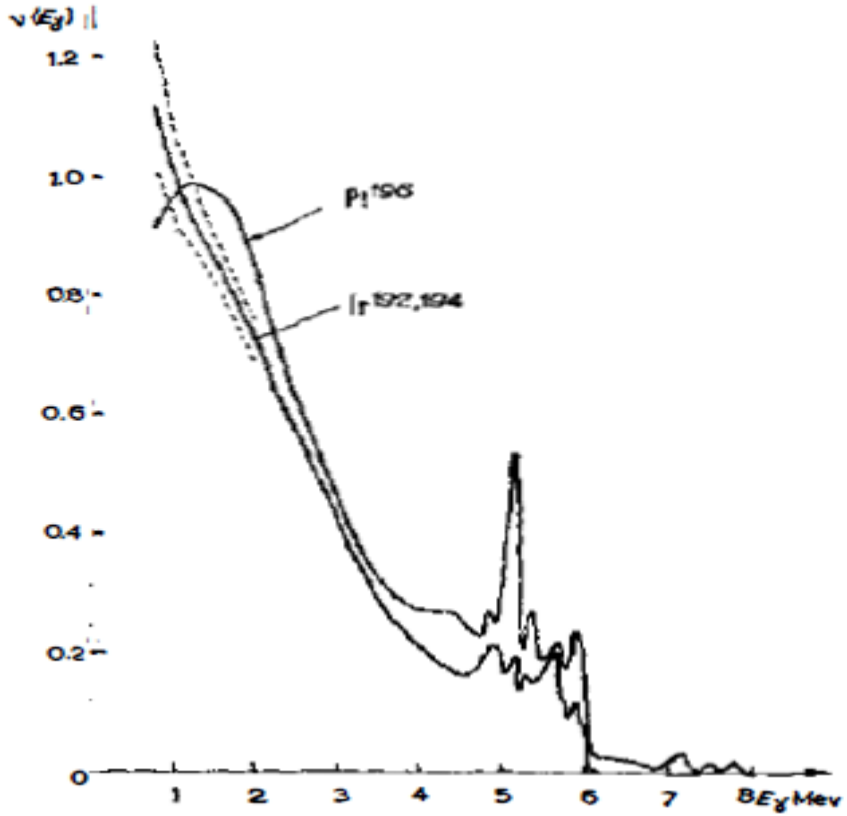
1961:

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)

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

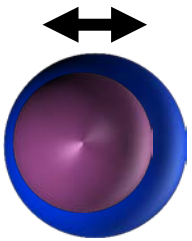
J. S. Brzosko, E. Gierlik, A. Soltan, Jr., and Z. Wilhelmi

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*



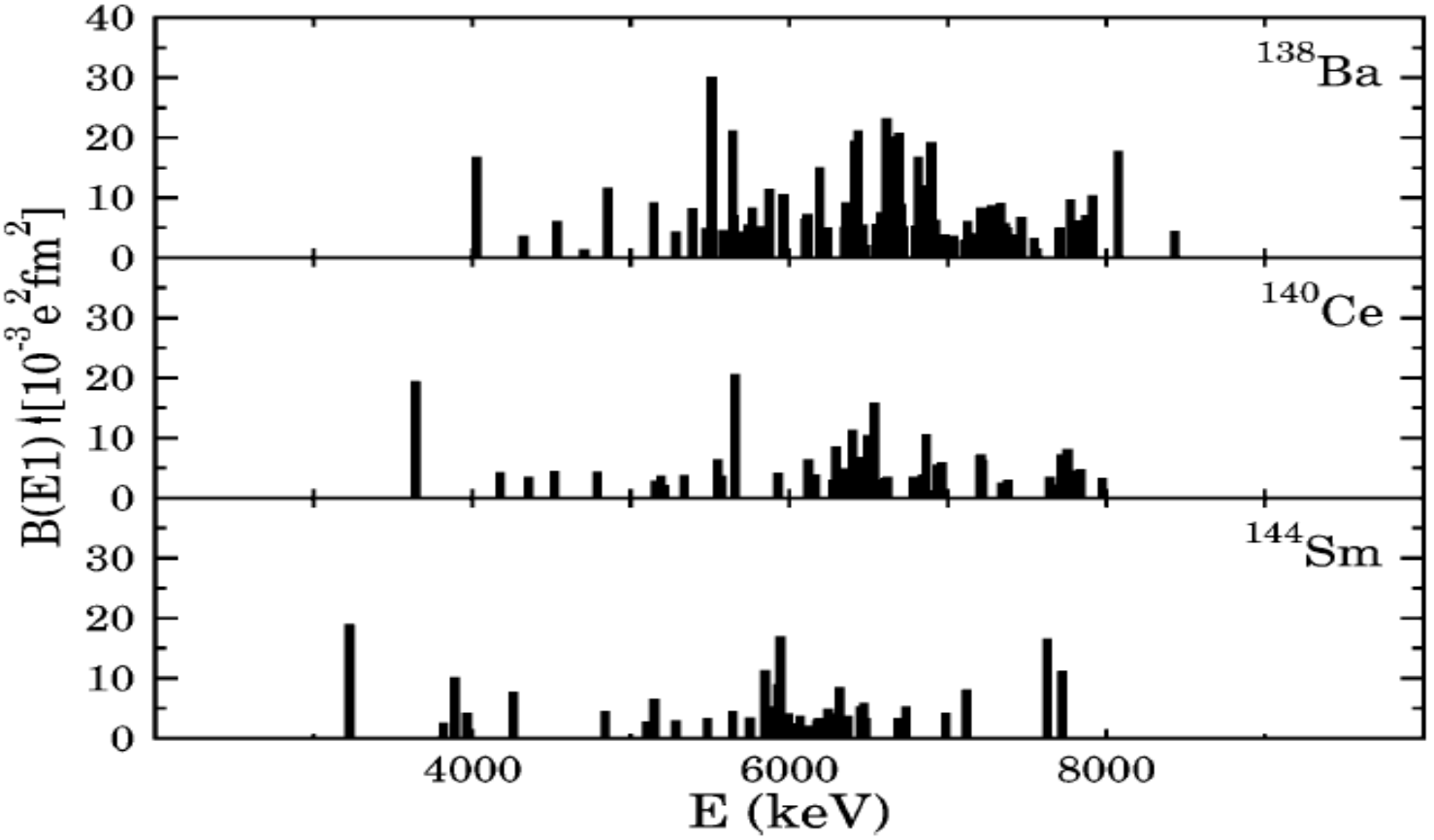
Z protons, Z neutrons, N-Z excess neutrons

Pygmy Dipole Resonance (PDR)

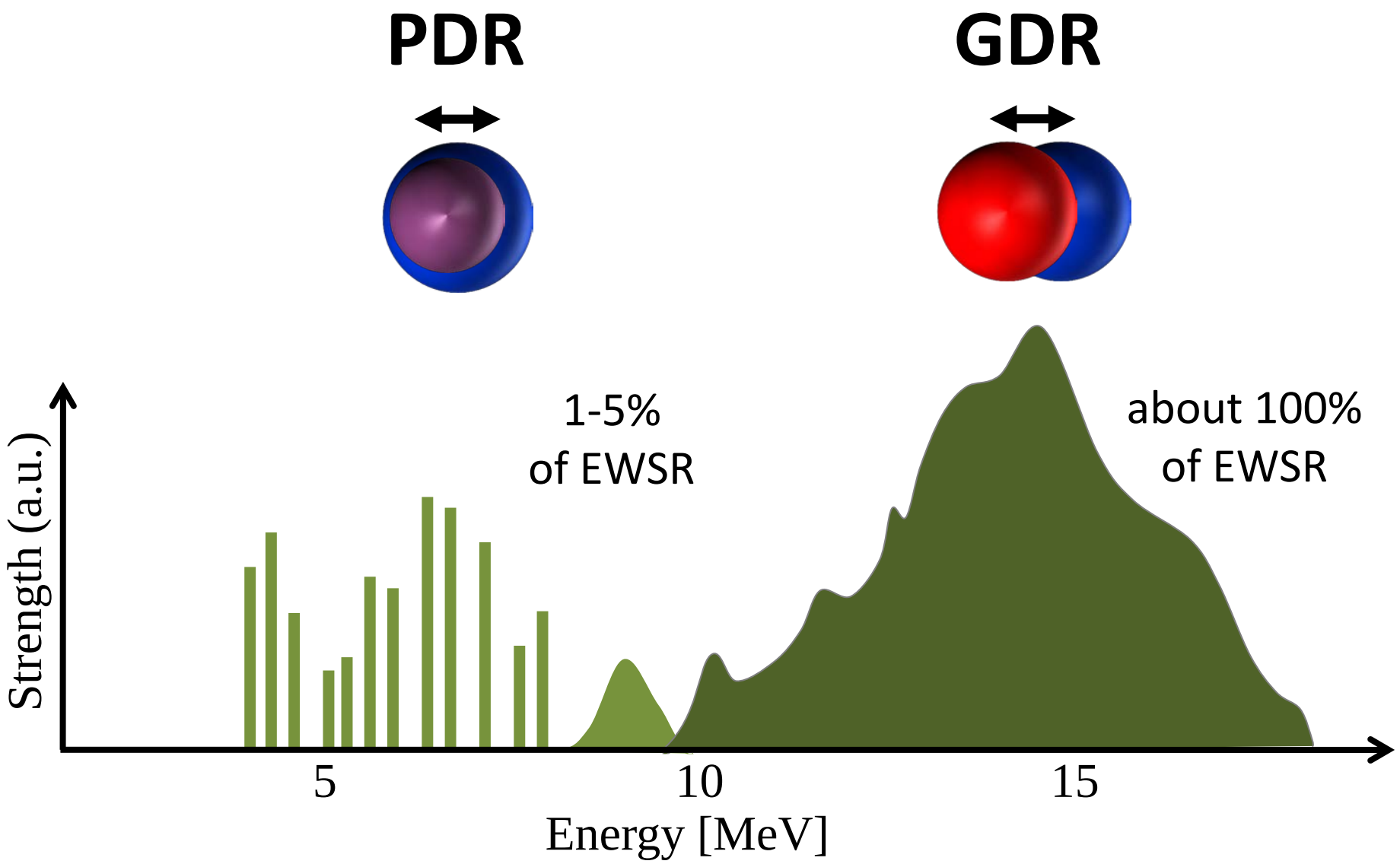
2002: Concentration of electric dipole strength below the neutron separation energy in $N = 82$ nuclei

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

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

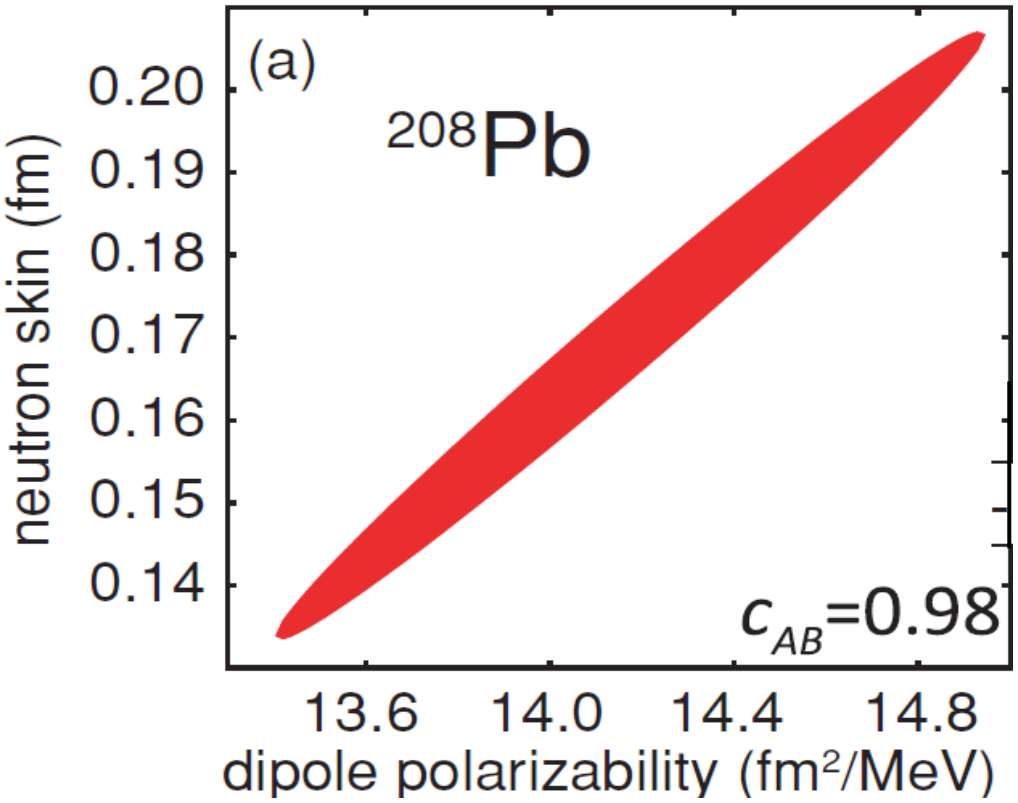


From giants to pygmies



Relevance of PDR

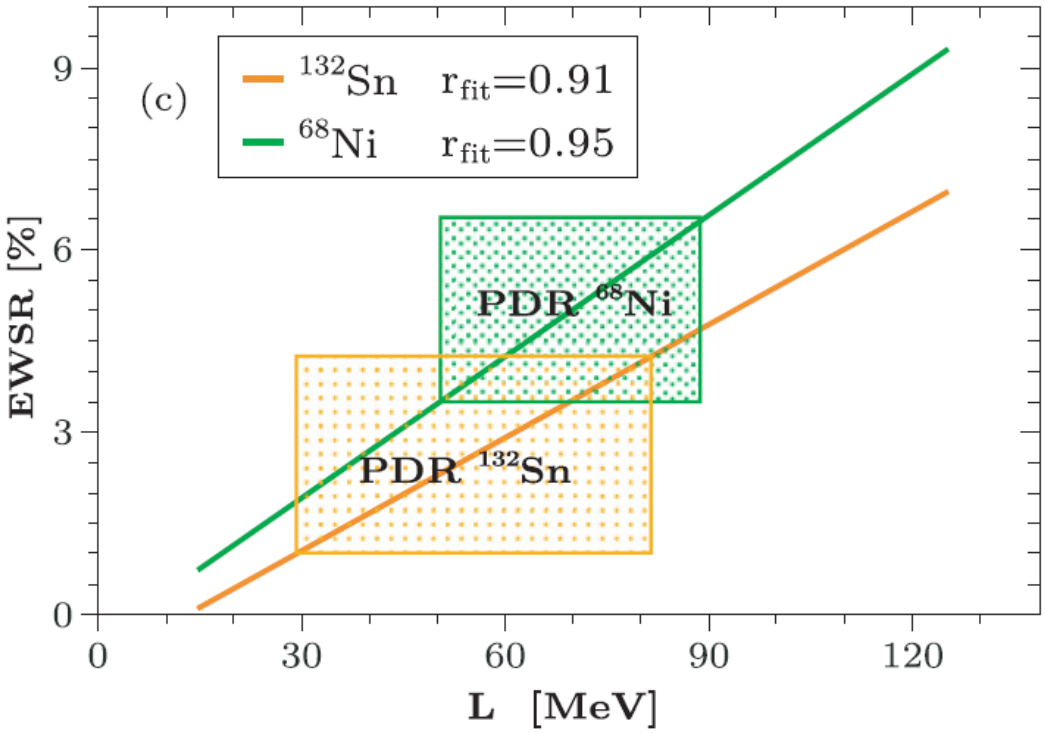
- Universal „collective“ excitation mode
- Connection to neutron star radius, neutron skin



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

Relevance of PDR

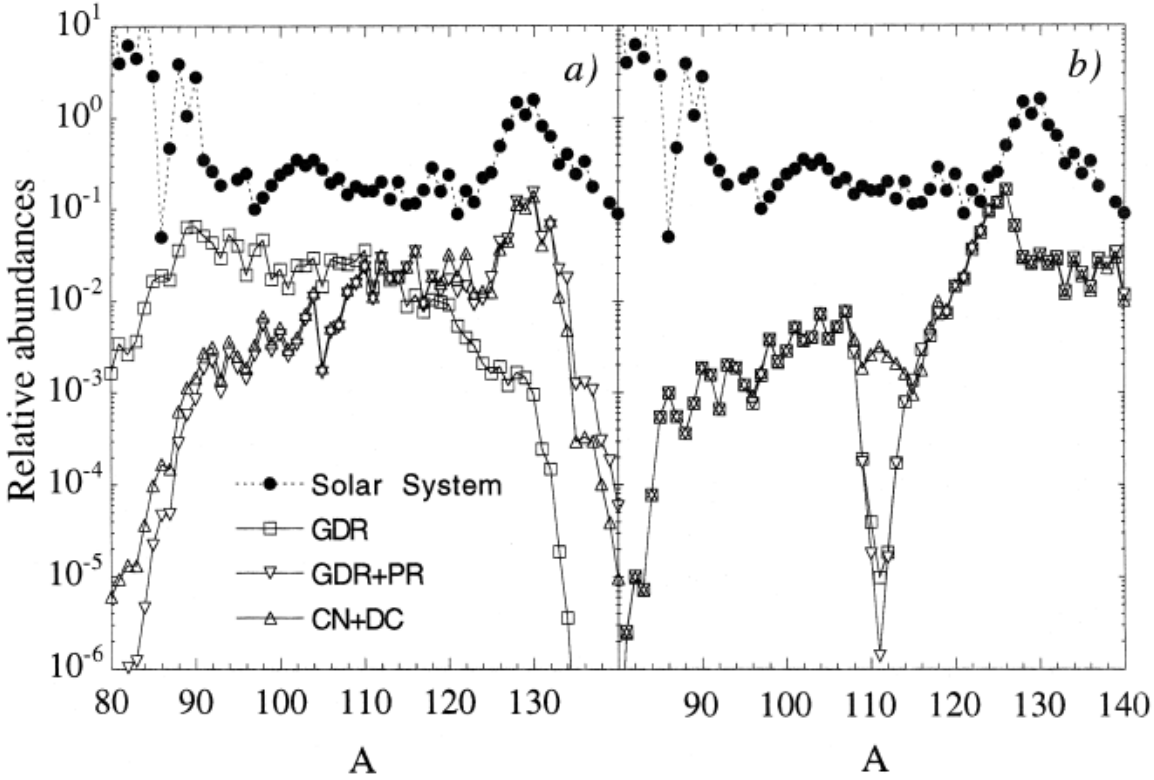
- Universal collective excitation mode
- Connection to neutron star radius, neutron skin
- Slope of symmetry energy in EoS



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

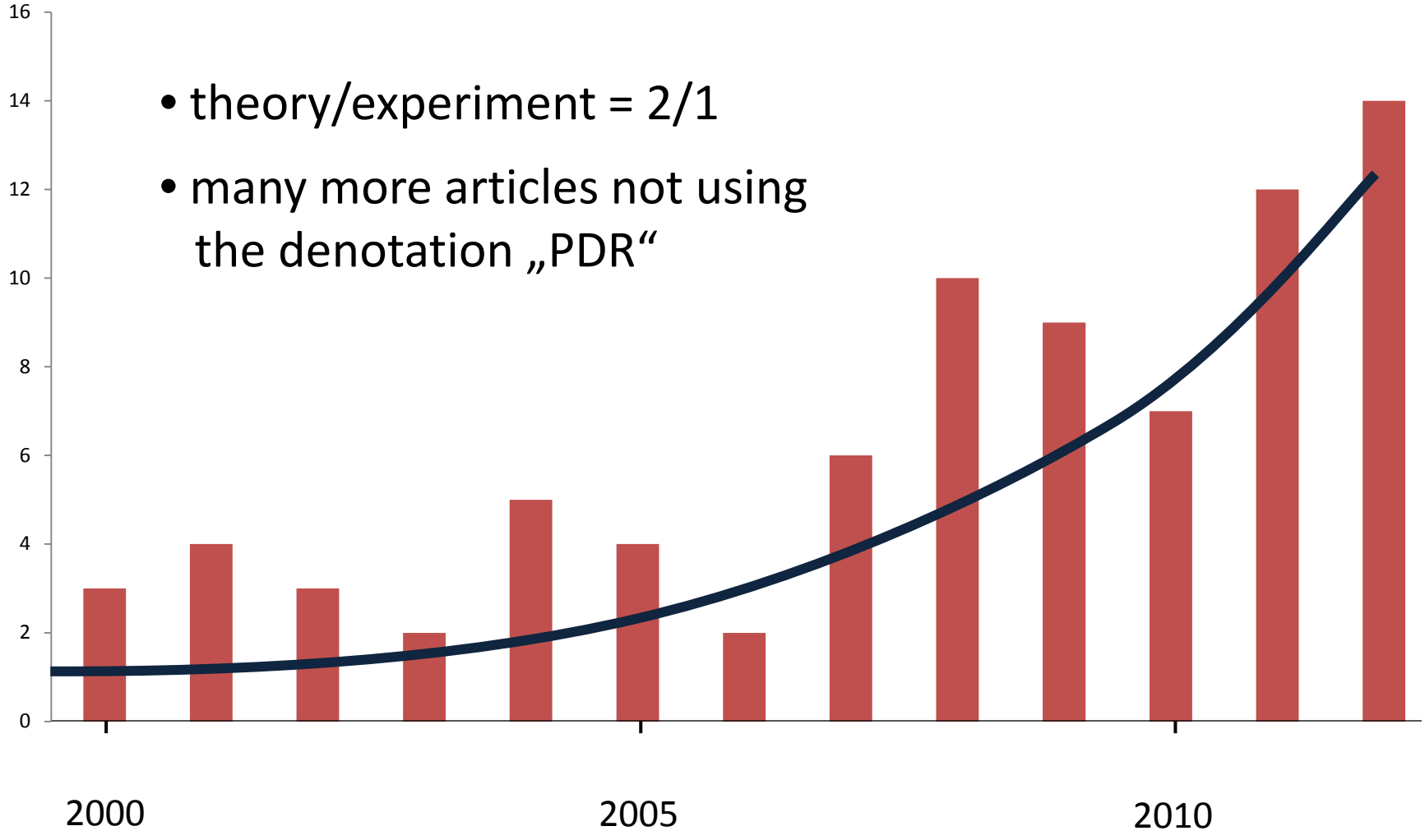
Relevance of PDR

- Universal collective excitation mode
- Connection to neutron star radius, neutron skin
- Slope of symmetry energy in EoS
- Impact on nucleosynthesis



*S. Goriely, PLB **436** (1998) 10*

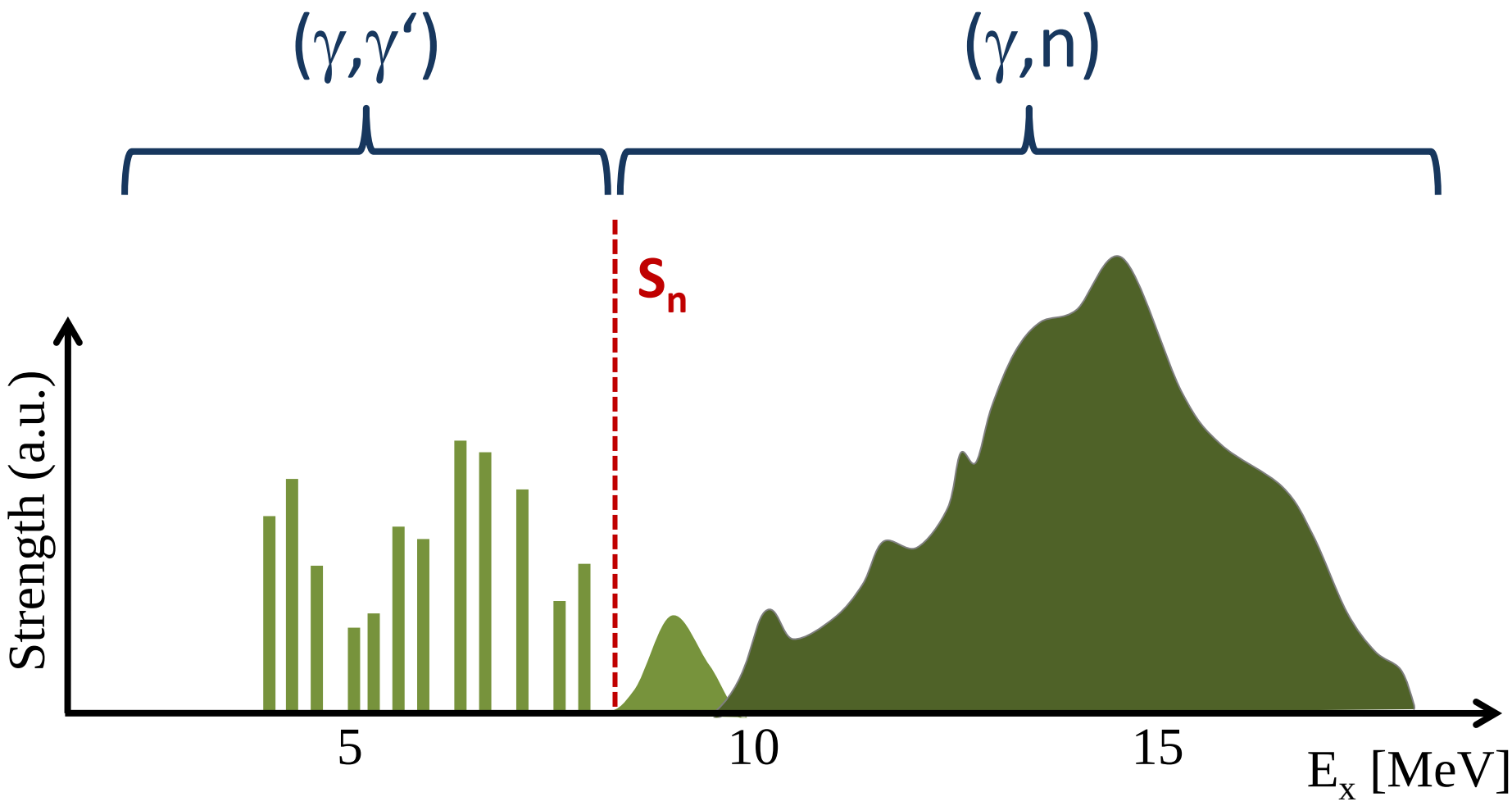
„PDR“ in title or abstract of PRL, PRC, PLB, NPA



The Electric Dipole Response of Atomic Nuclei – from Giants to Pygmies

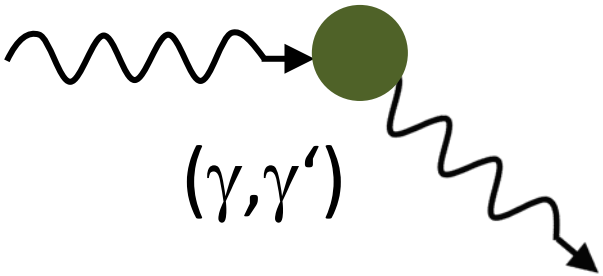
- From Giants to Pygmies – a short history
- Electromagnetic interaction:
  Method and experimental status
- Hadronic interaction:
  Method and experimental status
- Open questions and new experiments

Study of the E1 strength distribution via electromagnetic interaction

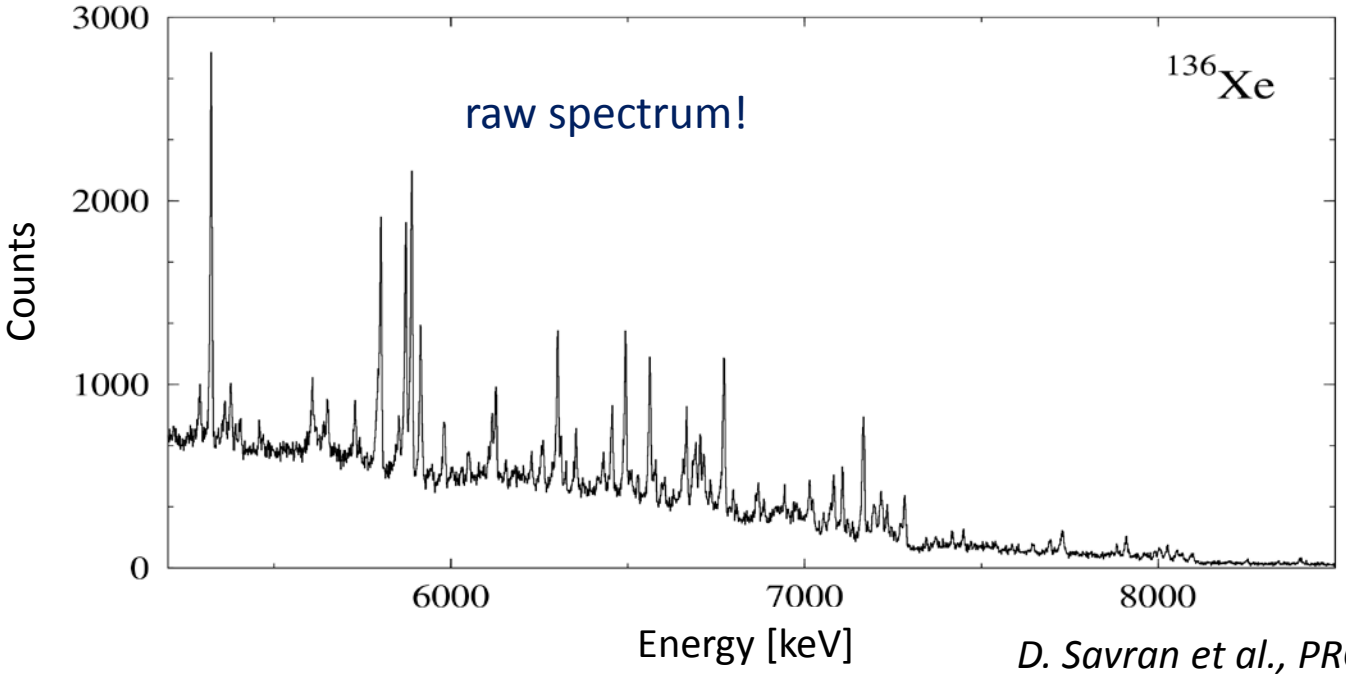


The photons can be real or virtual!

Scattering of real photons (γ,γ')



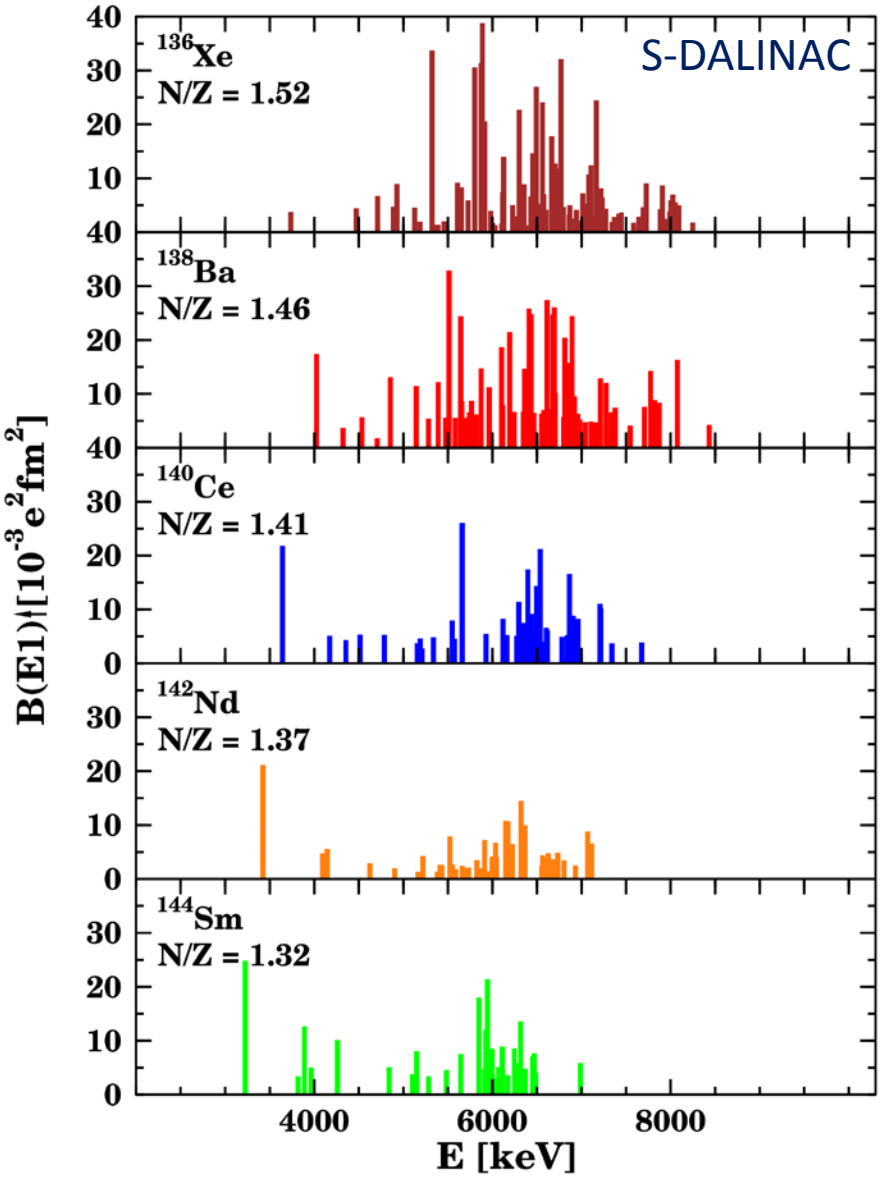
- $E_\gamma = 0 - S_n$
- very selective excitation (ΔJ=1 or 2)
- energy resolution ΔE=5-10 keV
- complex sensitivity limit
- only stable nuclei can be studied

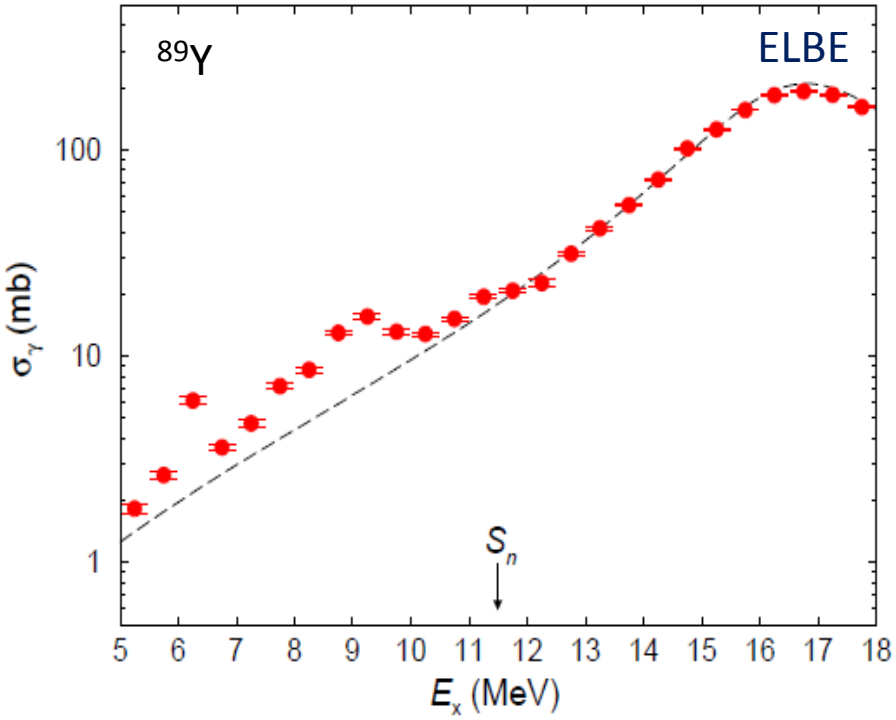


S-DALINAC@TUD
ELBE@HZDR
HIGS@DUKE
ELI@Bukarest

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

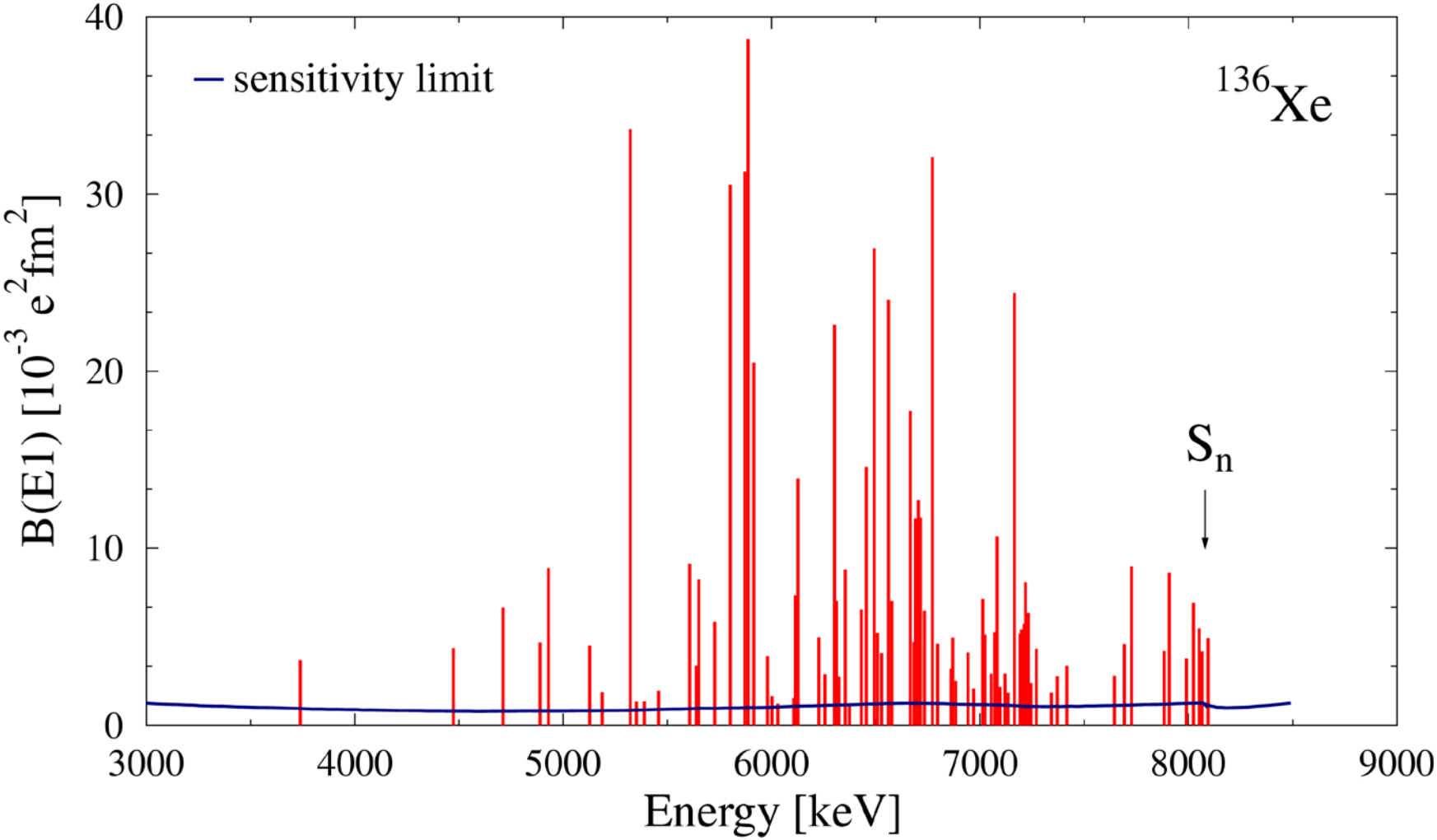
E1 distribution in stable nuclei: (γ,γ')



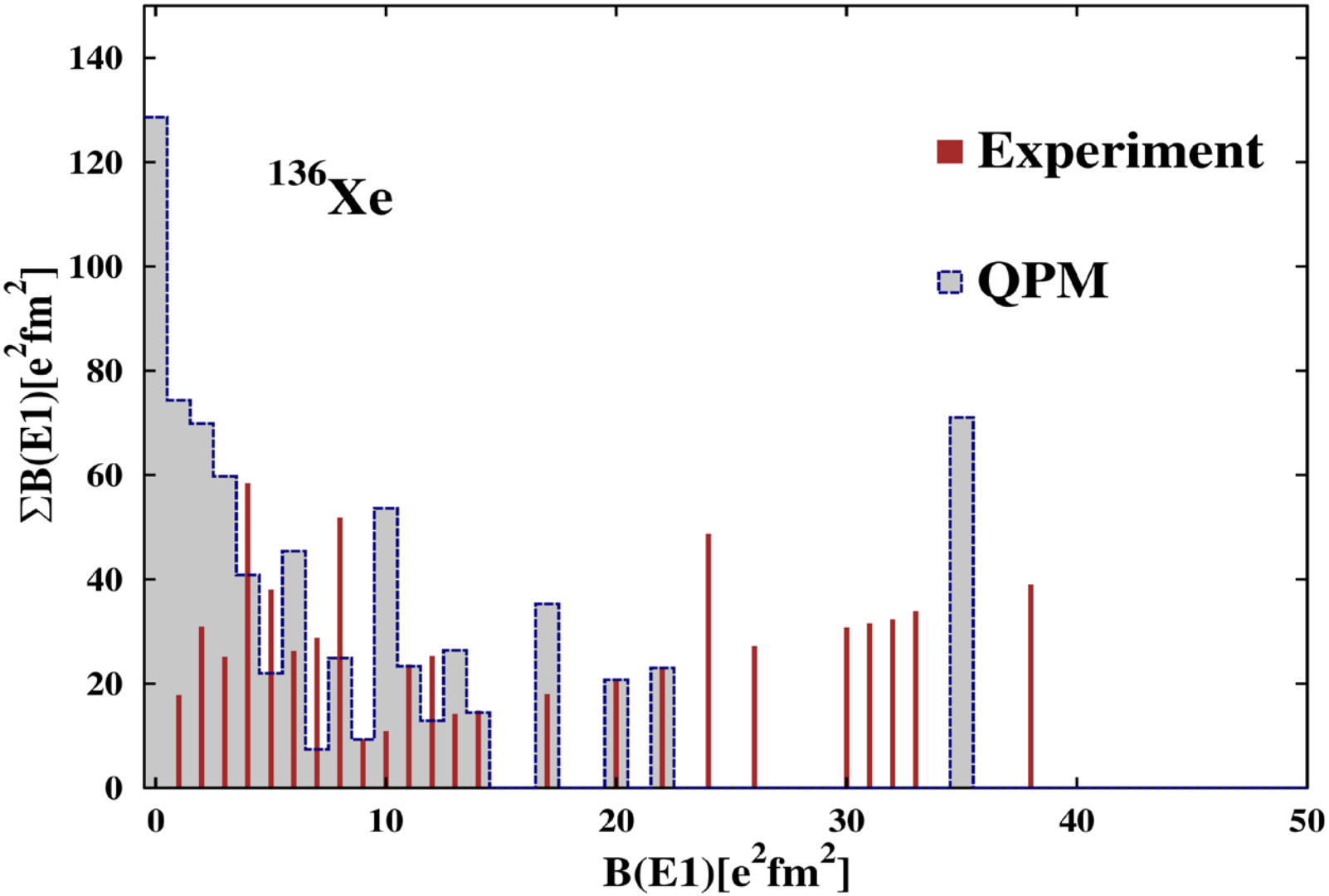


*N. Benouaret et al., PRC **79** (2009) 014303*
*D. Savran et al., PRC **84** (2011) 024326*
*S. Volz et al., NPA **779** (2006) 1*
*A. Zilges et al., PLB **542** (2002) 43*

Sensitivity of (γ,γ') experiments

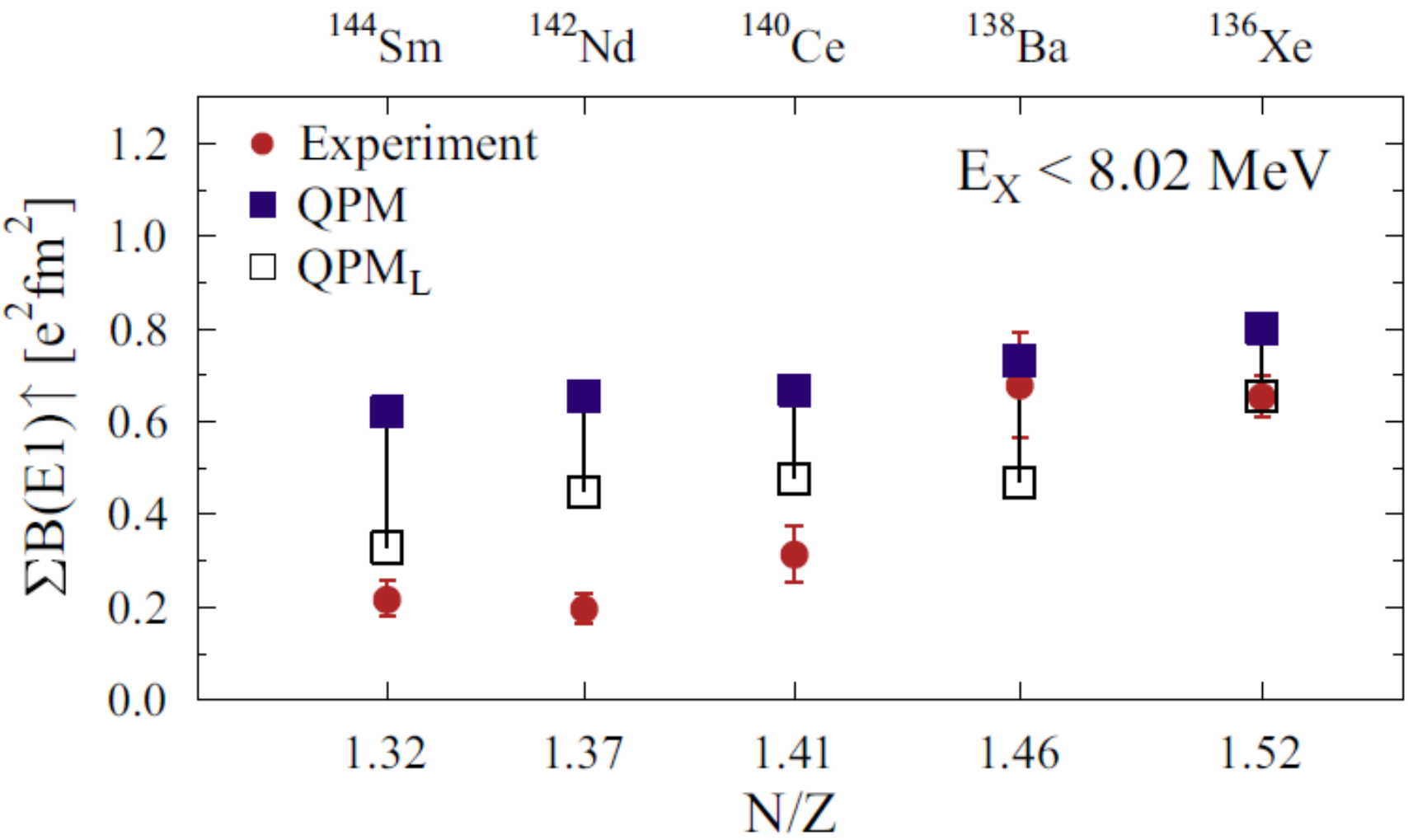


Sensitivity of (γ,γ') experiments



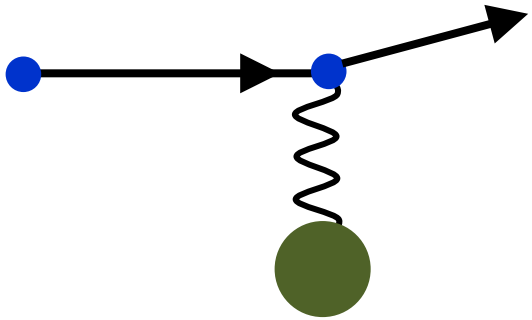
*D. Savran, V. Yu. Ponomarev et al., PRC **84** (2011) 024326*

Importance of sensitivity limit

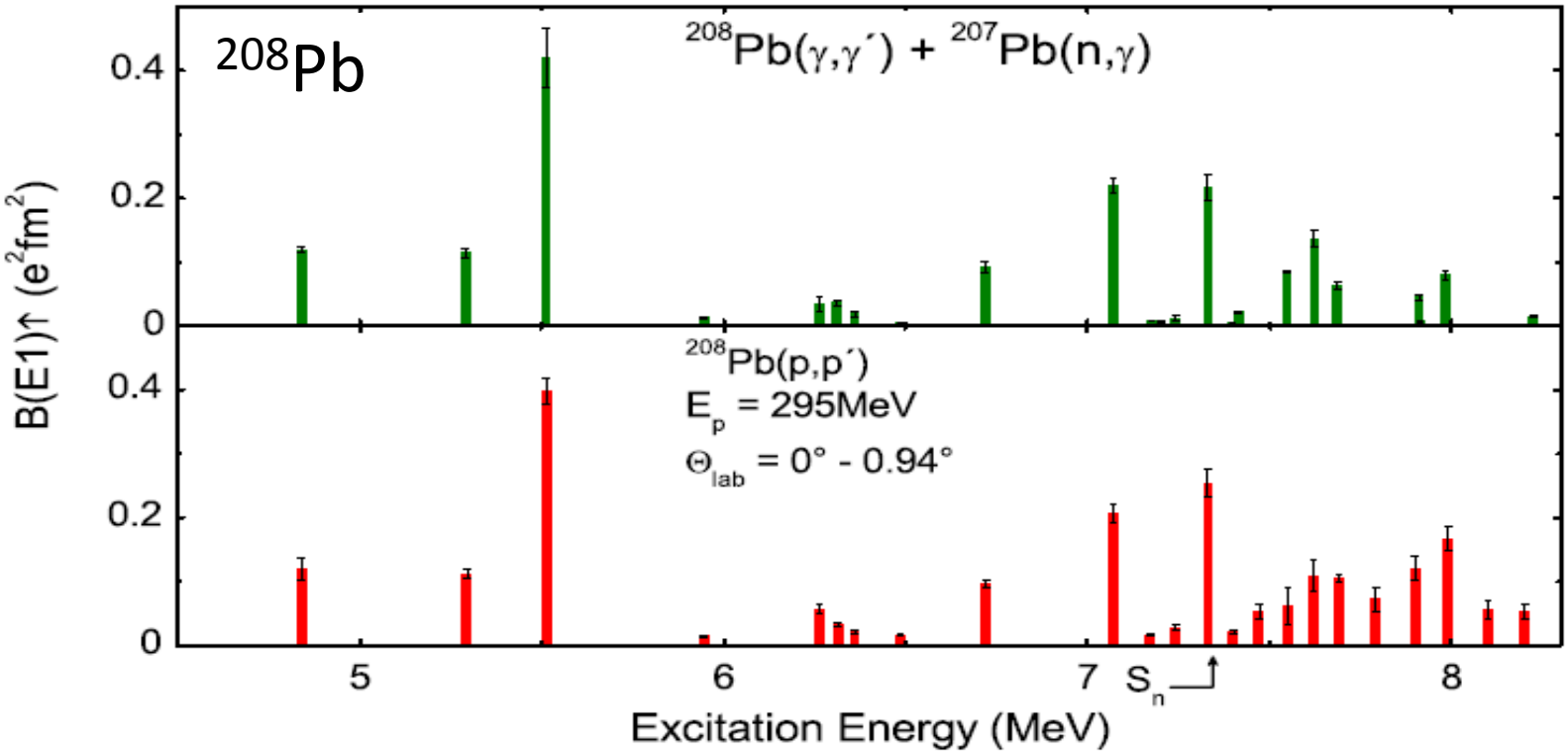


*D. Savran, V. Yu. Ponomarev et al., PRC **84** (2011) 024326*

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



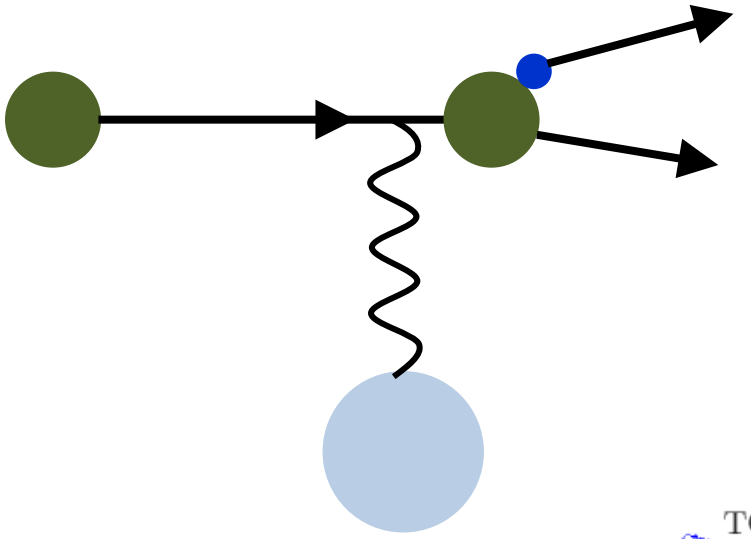
- E_x = 0 – 25 MeV
- energy resolution ΔE=25 keV
- less selective, complex disentanglement
- only stable nuclei can be studied



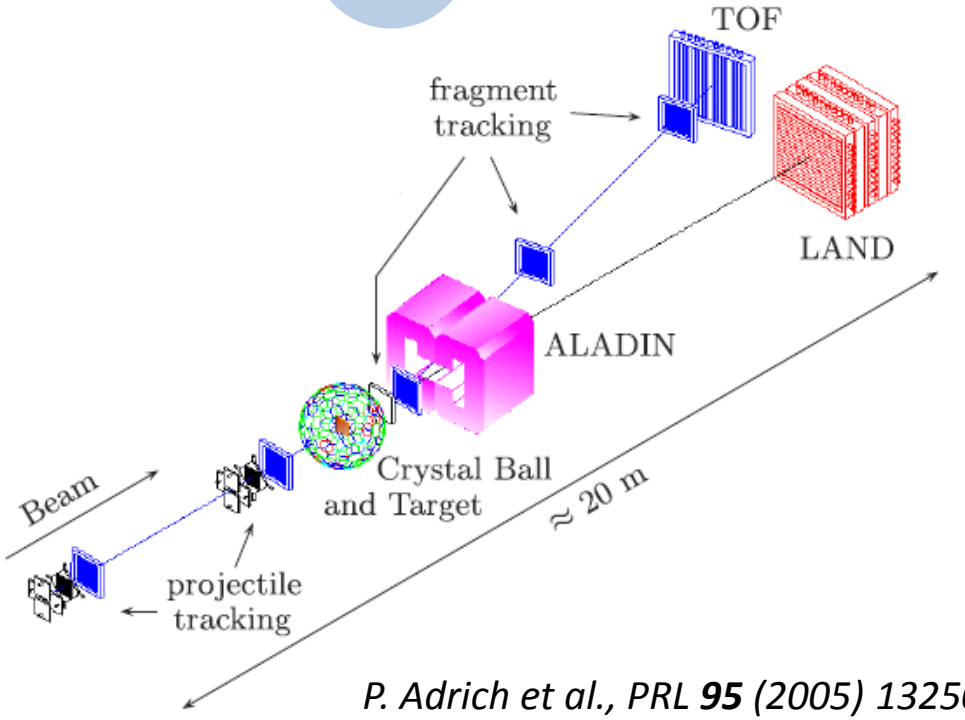
GRAND RAIDEN @RCNP

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

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

NeuLAND@R3B@FAIR

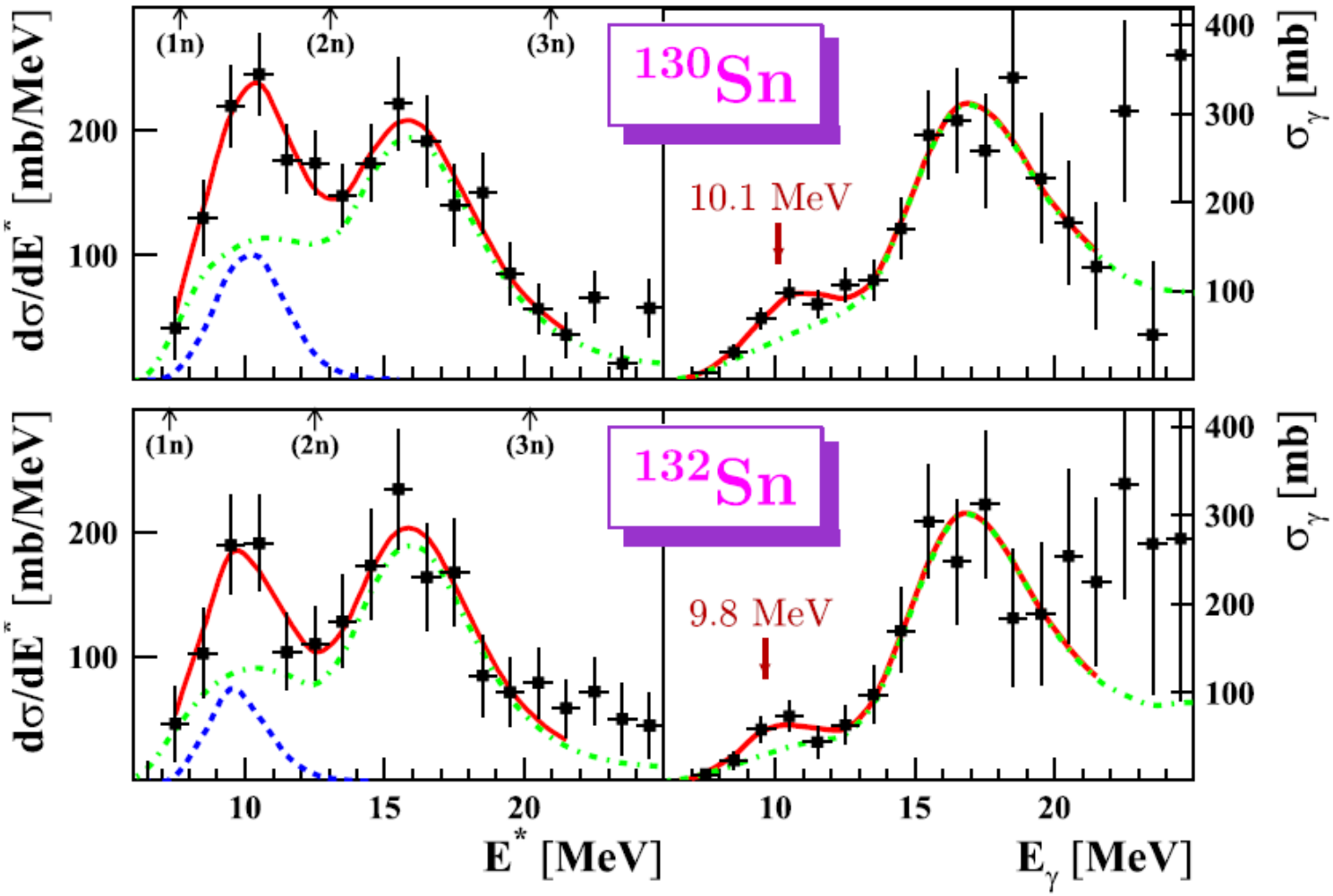
...

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

PDR in radioactive nuclei

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

LAND plus ALADIN plus Crystal Ball

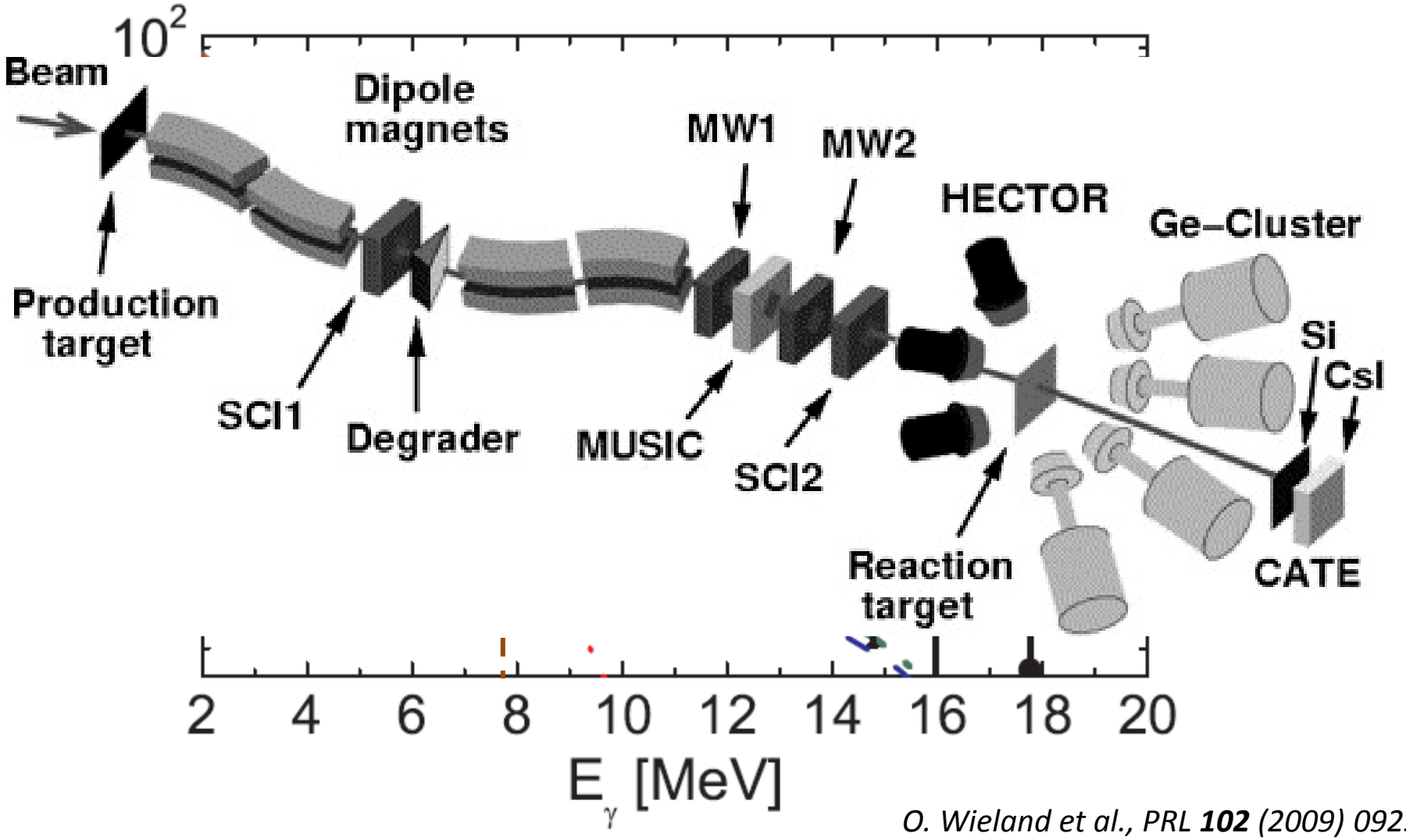


*P. Adrich et al., PRL **95** (2005) 132501*

PDR in radioactive nuclei

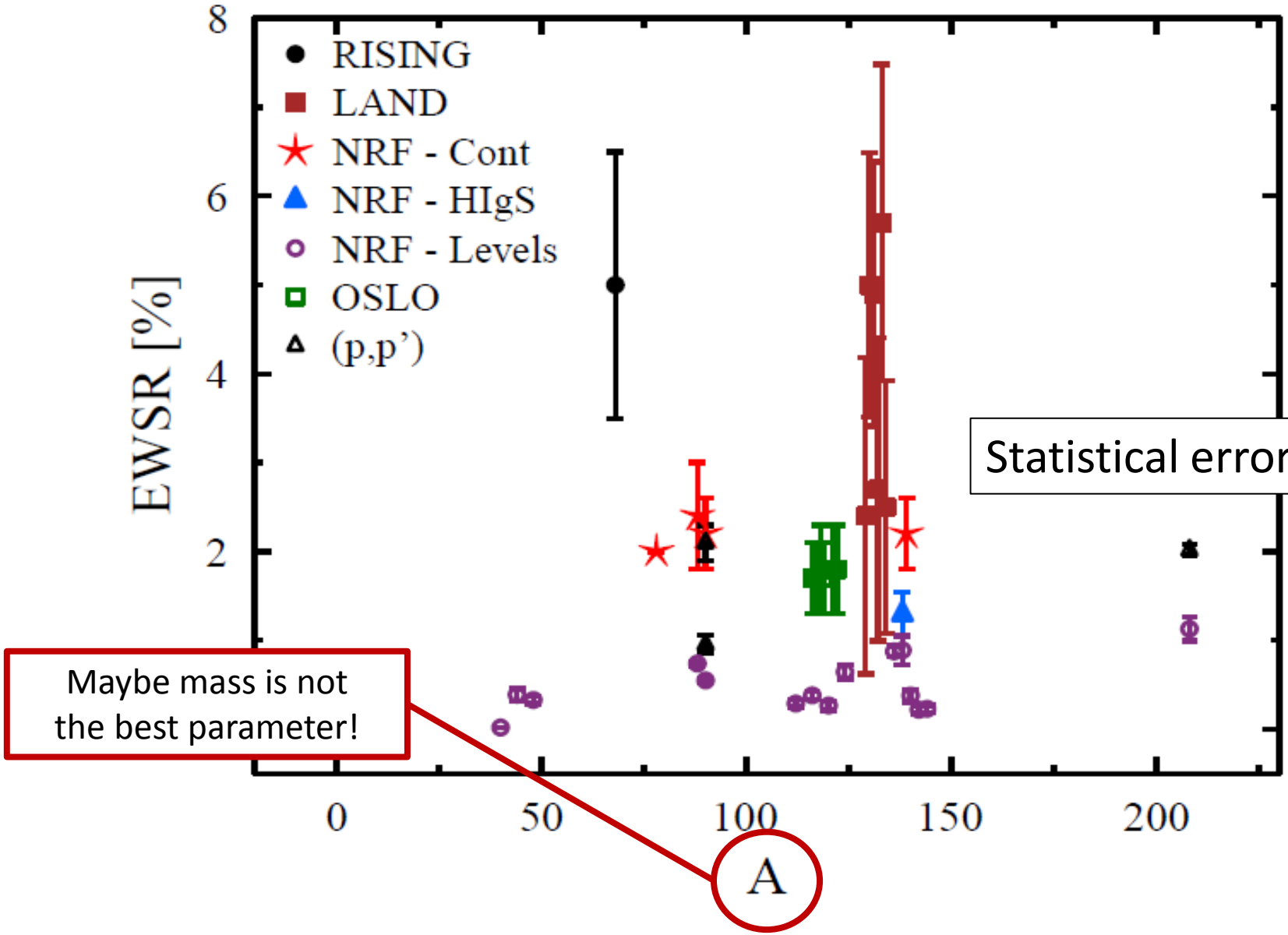
^{68}Ni @ 600 MeV/A on Au

RISING HPGe array, HECTOR BaF_2 array



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

Summed B(E1) strength of Pygmy Dipole Resonance



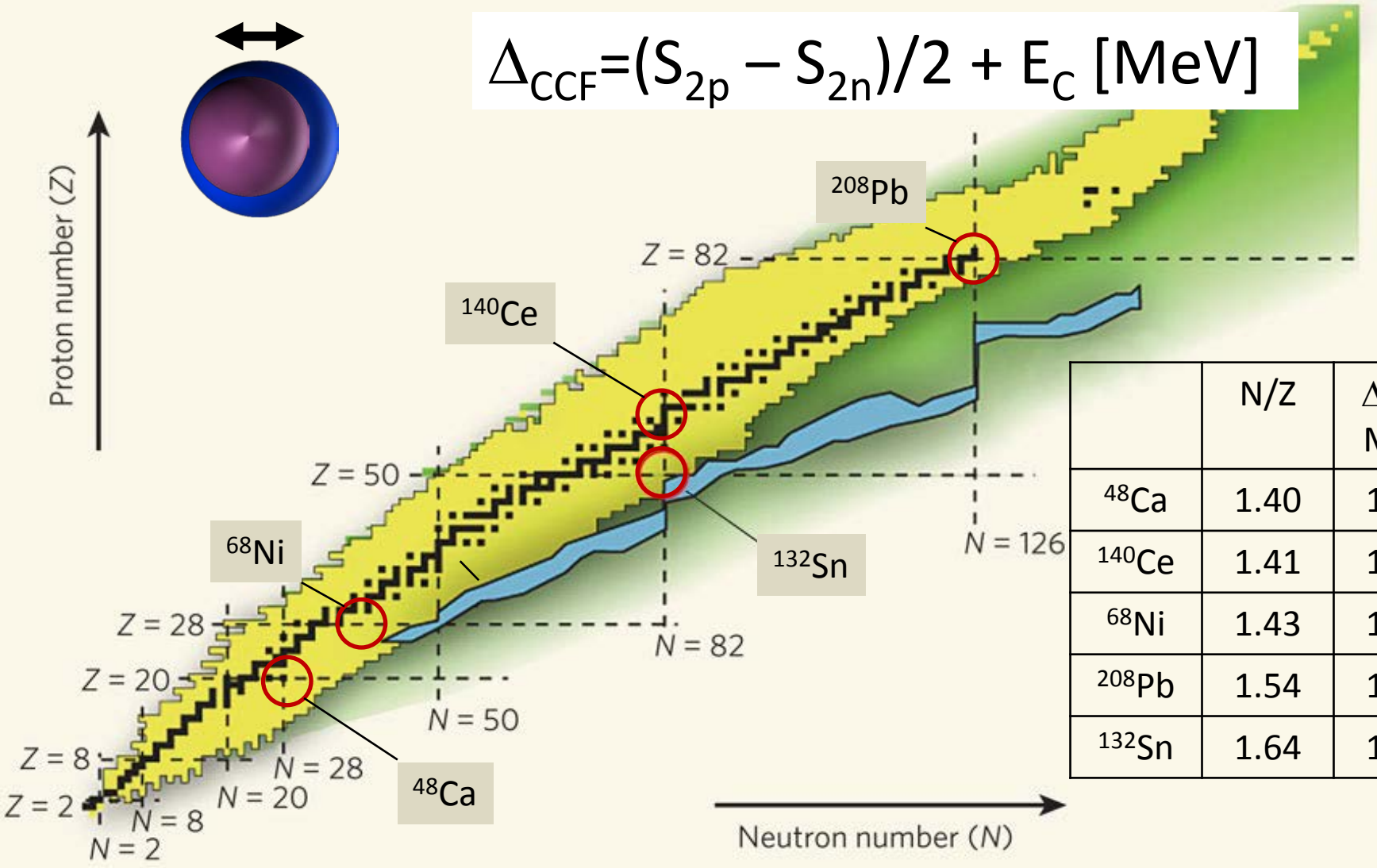
Statistical errors only !

Maybe mass is not the best parameter!

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

Parametrization of „exoticity“

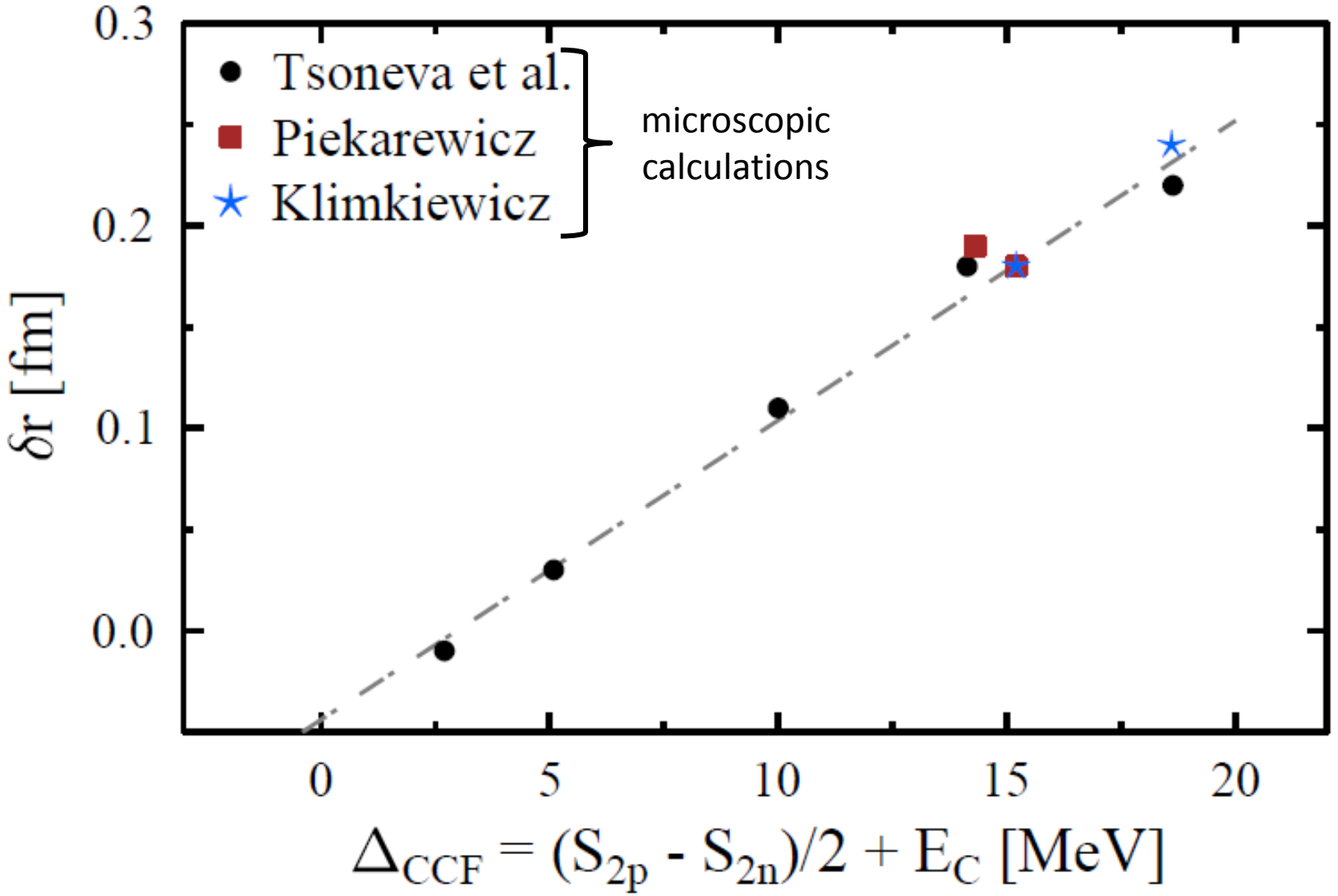
$$\Delta_{CCF}=(S_{2p}-S_{2n})/2+E_C\ [MeV]$$



	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

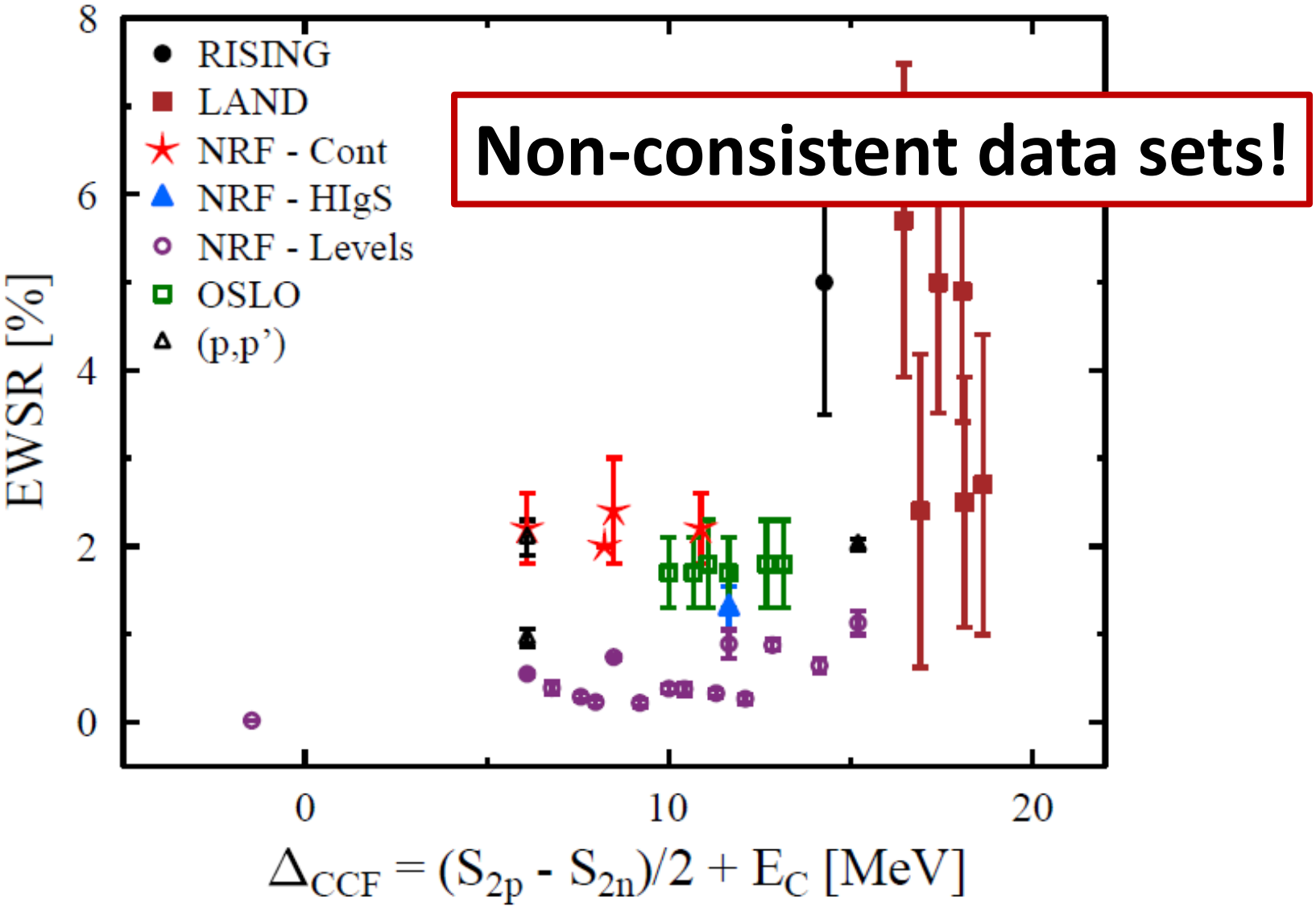
*chart of nuclides from: P.D. Cottle, nature **465** (2010) 430*

The calculated neutron skin scales with the Coulomb corrected Fermi energy differences



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

PDR vs. Coulomb corrected Fermy energy



Non-consistent data sets!

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

Some open questions

- What is the connection between the E1 strength below and above neutron threshold and in stable and radioactive nuclei?

  → systematic studies

- Is there an experimental approach to separate the low lying dipole strength (or PDR) from the GDR?

  → alternative excitation mechanism

The Electric Dipole Response of Atomic Nuclei – from Giants to Pygmies

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

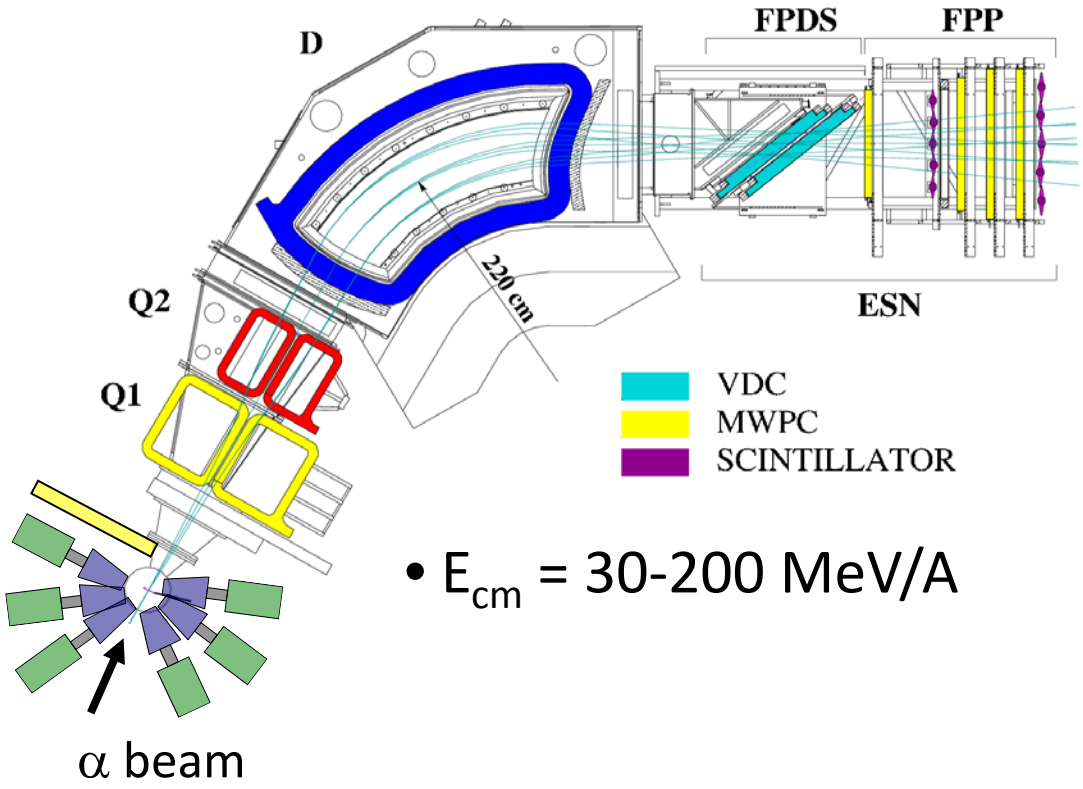
Structure of the PDR: (γ,γ‘) vs. (α,α‘) vs. (p,p‘)

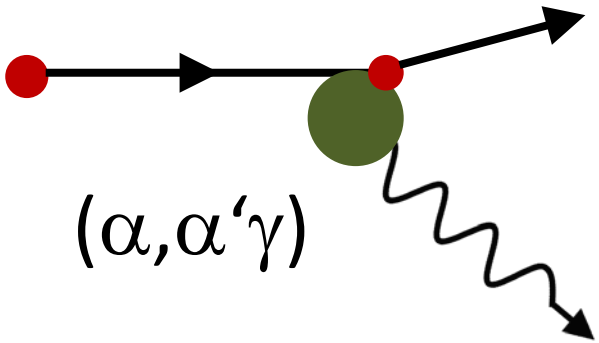
	(γ,γ′)	(α,α′) @ 30 MeV/A	(p,p‘) @ 80 MeV/A
Interaction	Electromagnetic	Strong	Strong
Location of interaction	Whole nucleus	Surface	Surface
Isospin	Isovector E1 excitations	Isoscalar	Isoscalar/ Isovector
Multipolarity	E1, M1, E2	E0, E1, E2, E3, …	E0, E1, E2, …
ΔE	3-500 keV	50-200 keV	50-200 keV

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

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

(α,α'γ) and (p,p'γ) experiments



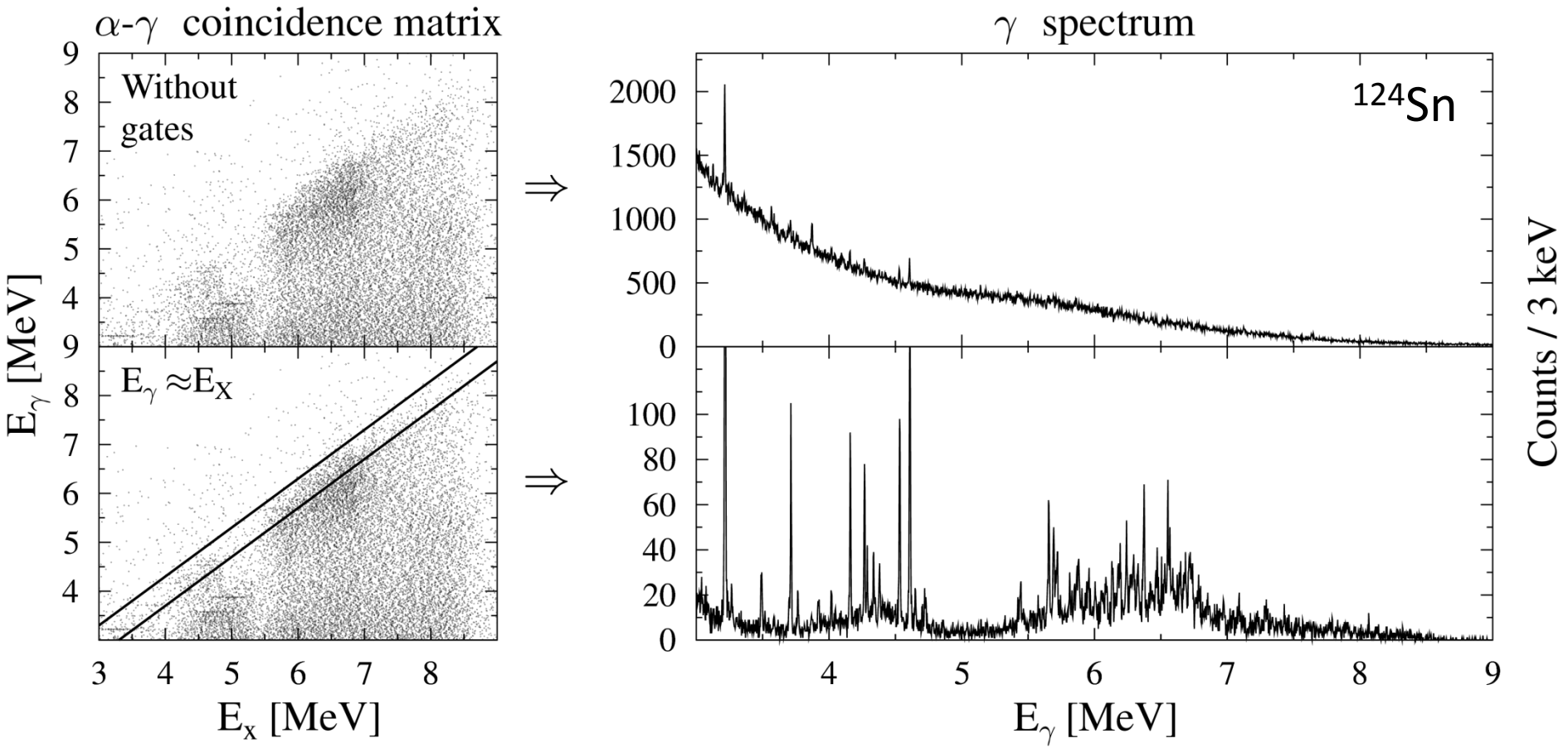


- E_{cm} = 30-200 MeV/A

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

BBS@KVI (deceased 15/11/12)
0° facility @ iThemba LABS
BigRIPS@RIKEN

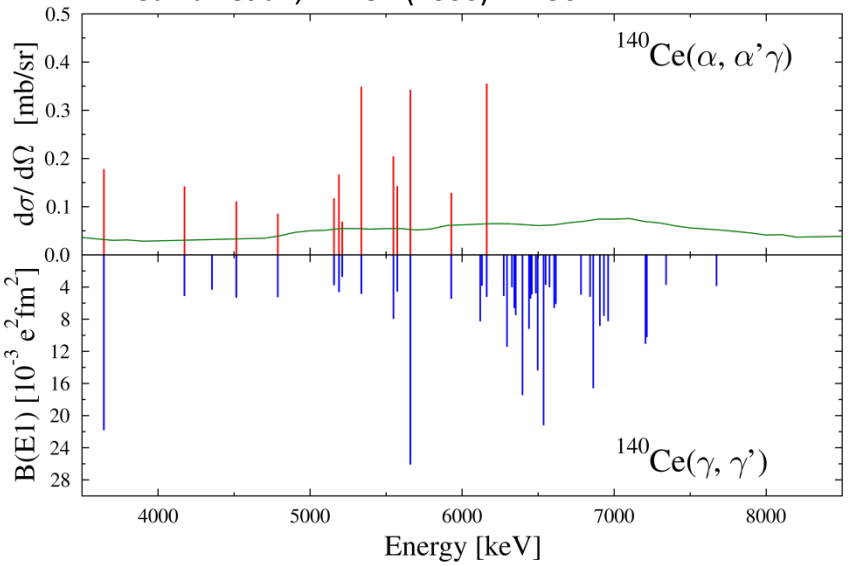
Structure of the PDR: (α,α'γ) experiments



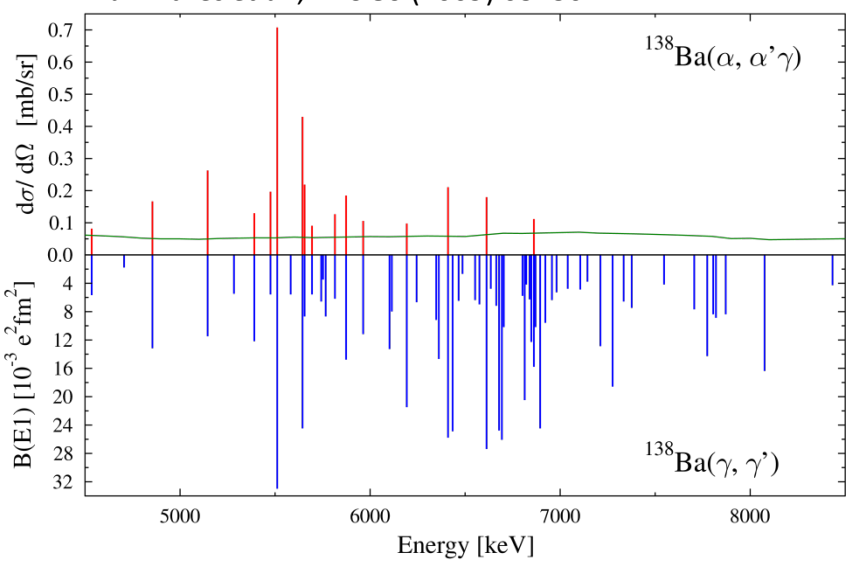
*Janis Endres et al., PRL **105** (2010) 112503*
*Janis Endres et al., PRC **85** (2012) 064331*

Splitting of the PDR: Experimental results

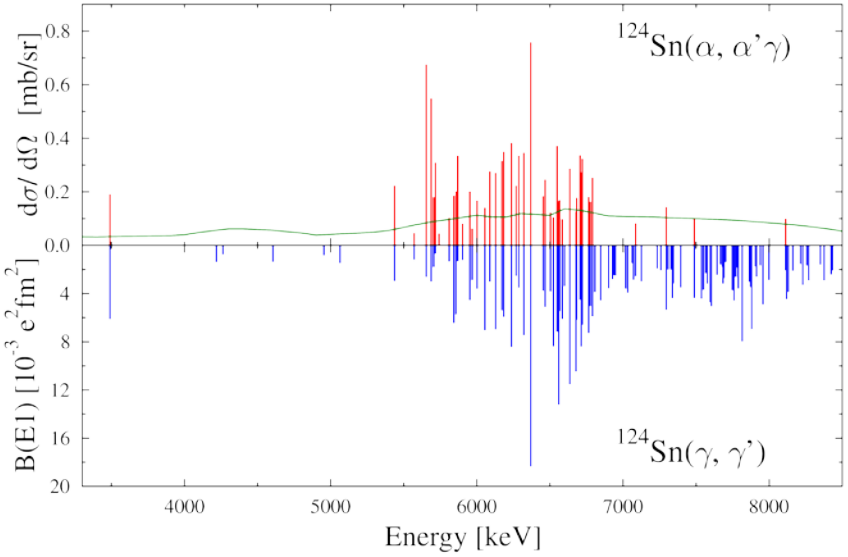
D. Savran *et al.*, PRL **97** (2006) 172502



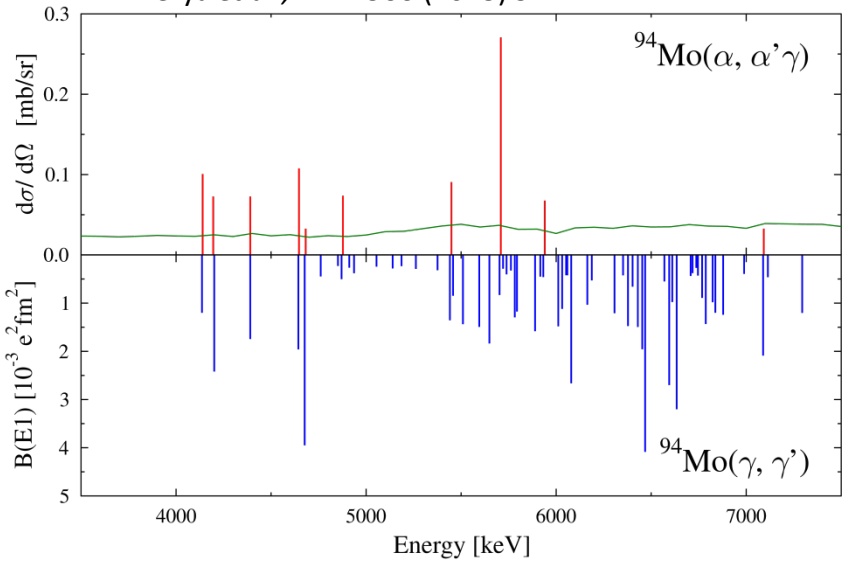
J. Endres *et al.*, PRC **80** (2009) 034302



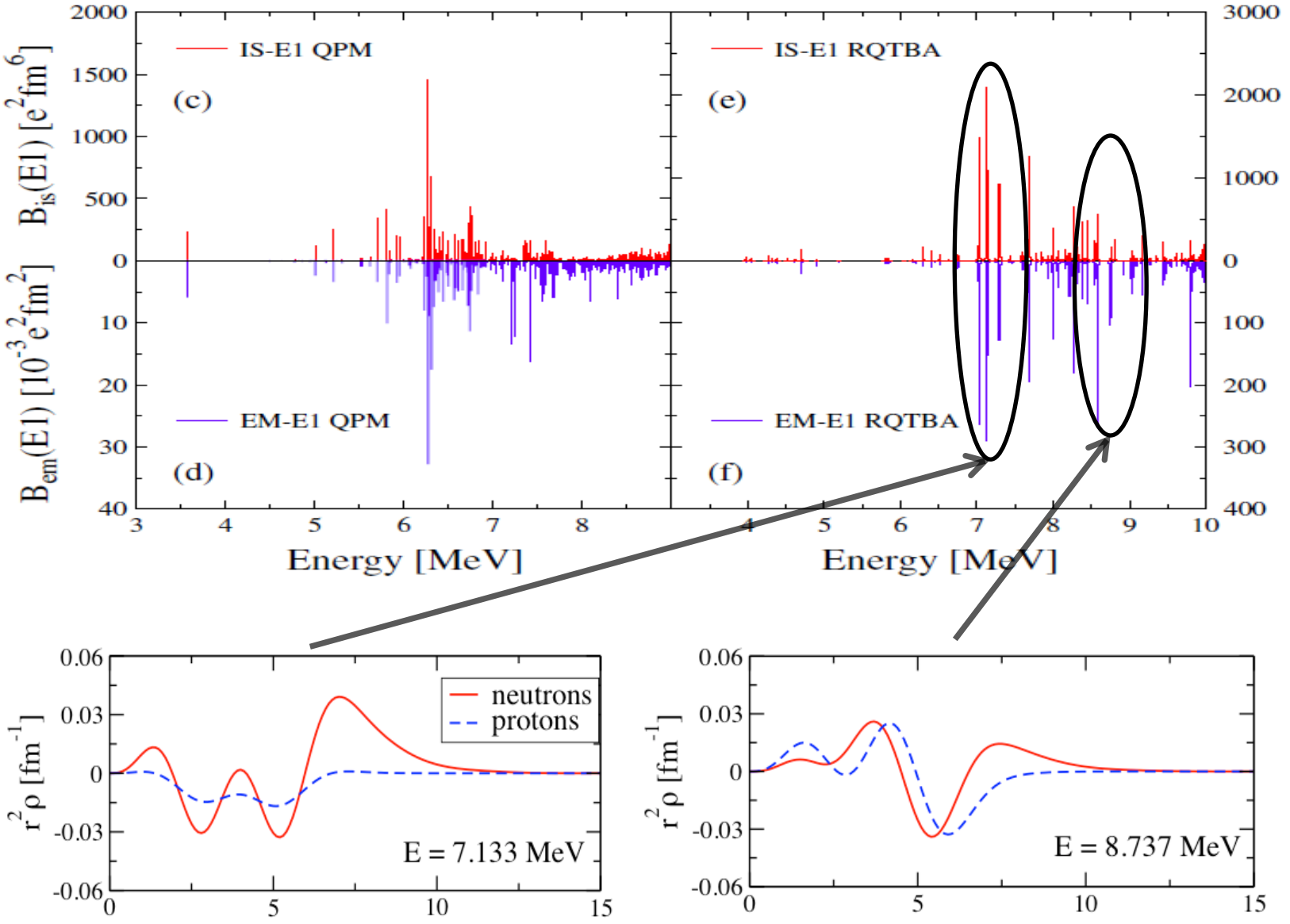
J. Endres, E.Litvinova *et al.*, PRL **105** (2010) 212503



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

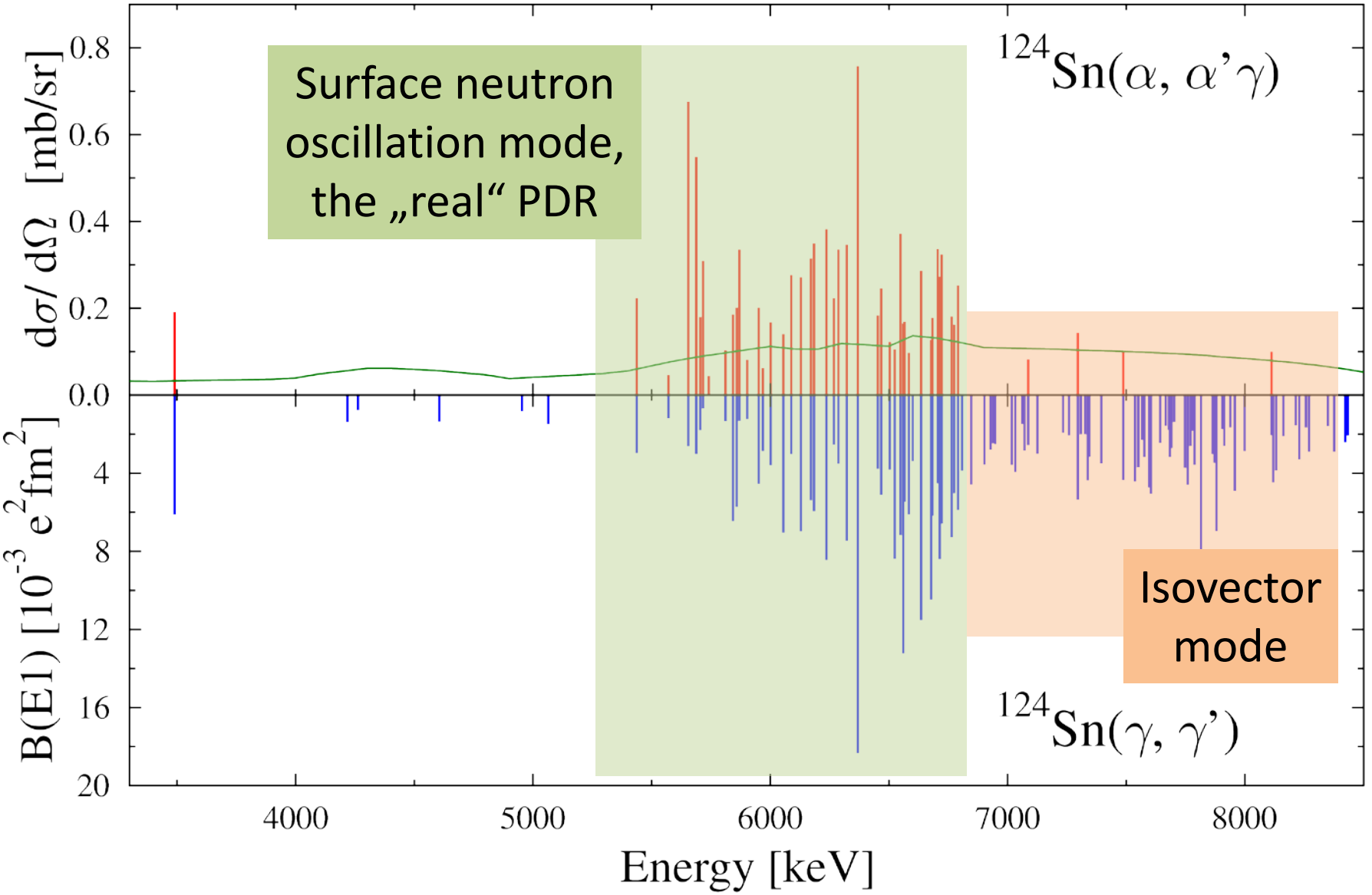


Splitting of the PDR: Theory for ^{124}Sn



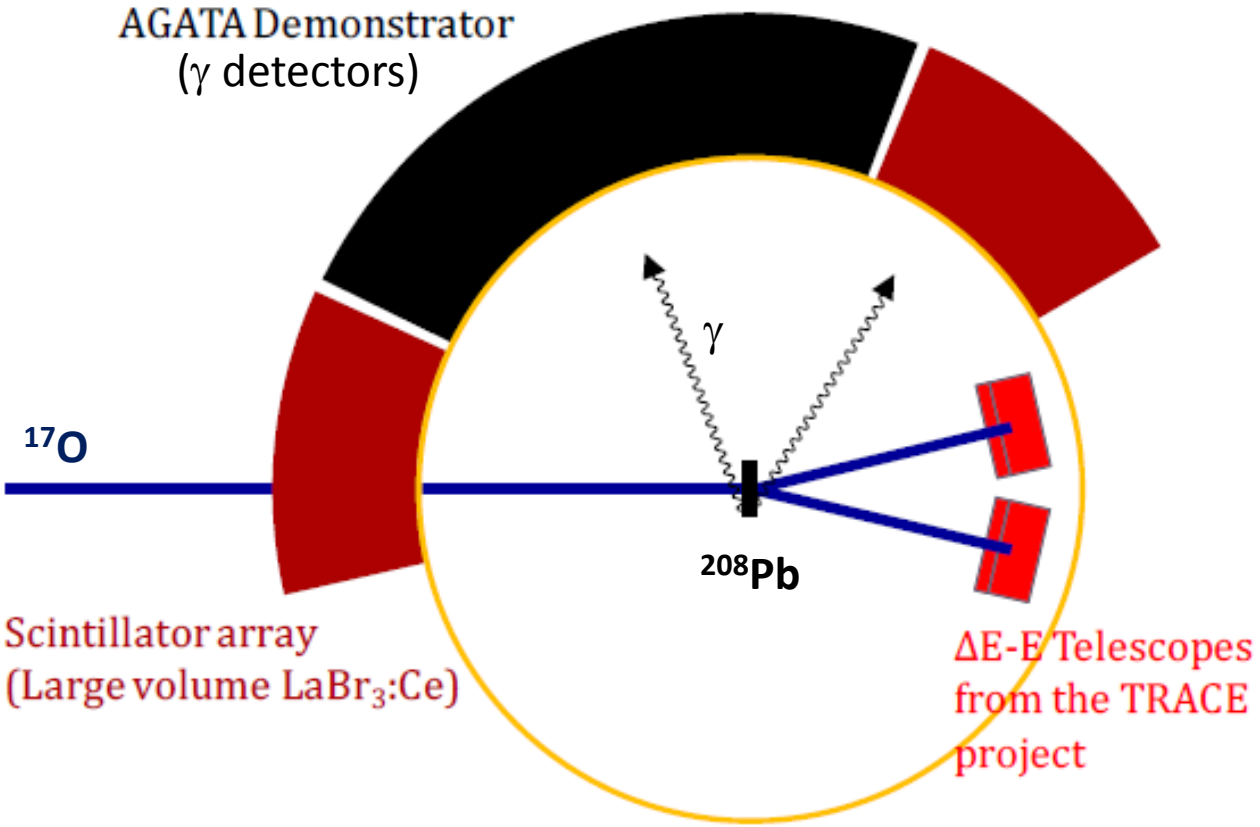
*J. Endres, E. Litvinova, V. Ponomarev et al., PRC **85** (2012) 064331*

Splitting of the PDR: Interpretation from RQTBA



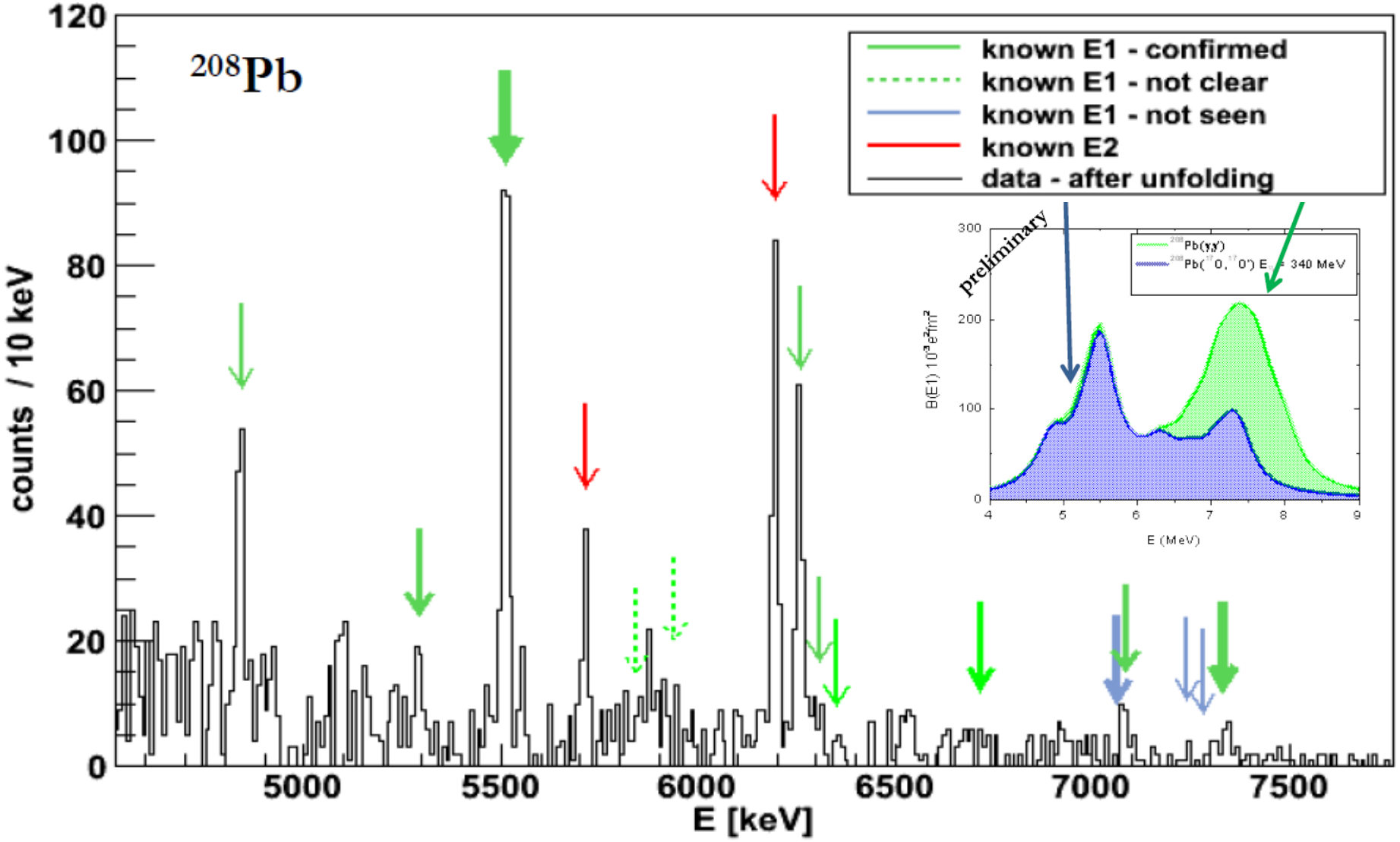
*Janis Endres et al., PRL **105** (2010) 112503*
*Janis Endres et al., PRC **85** (2012) 064331*

Another hadronic probe: Inelastic scattering of ^{17}O



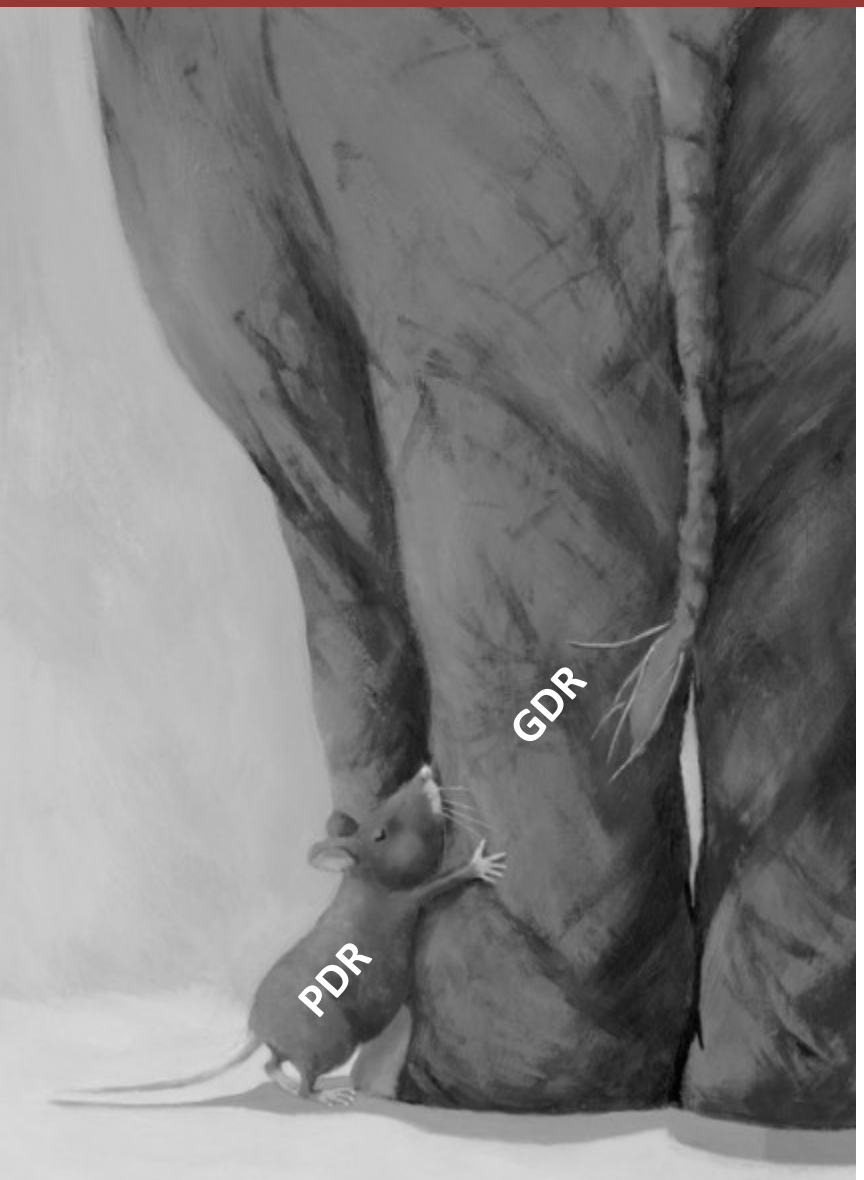
A. Bracco, et al., INFN Legnaro

γ decay after inelastic scattering of ^{17}O on ^{208}Pb



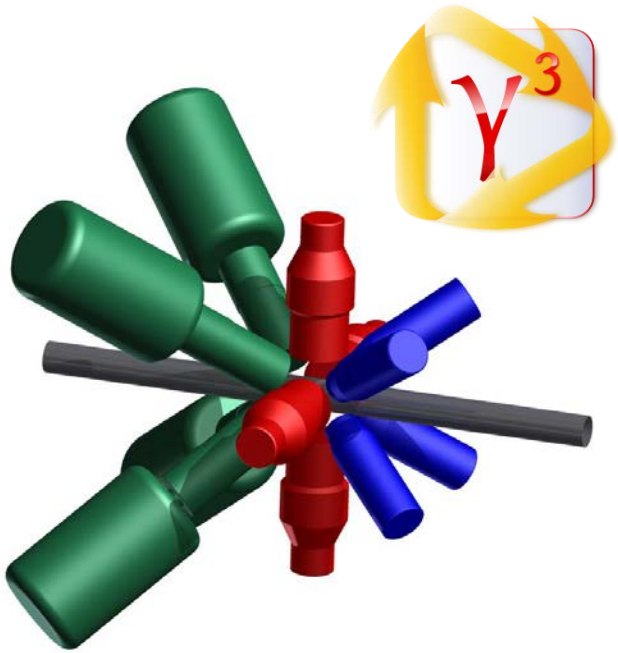
L. Pellegri, A. Bracco, et al., EUNPC 2012

Further experimental observables to clarify the structure of low lying E1 strength

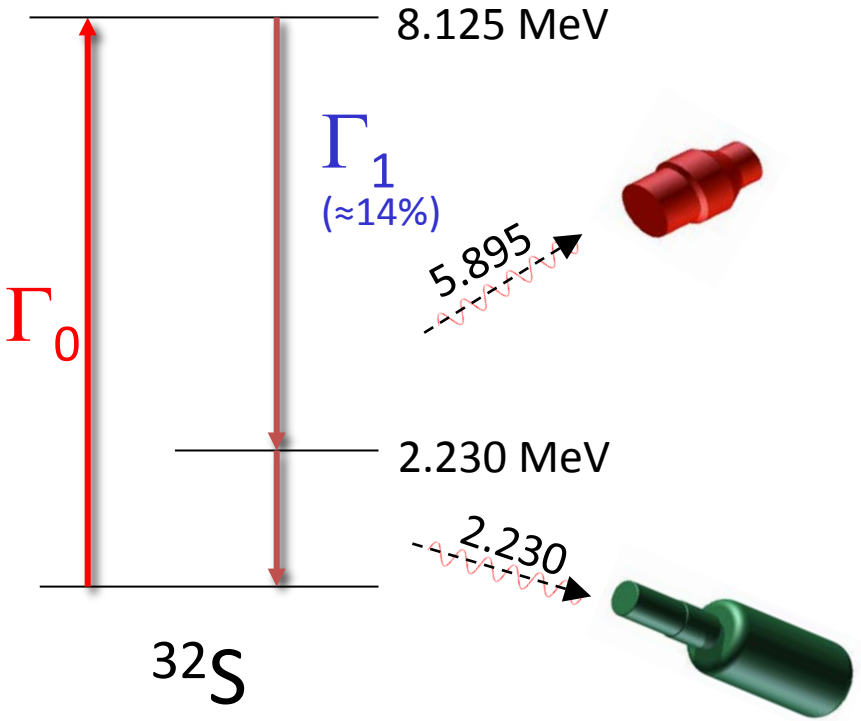


- Systematics (mass, N/Z, exoticity)
- Decay pattern, feeding
- Comparison of electromagnetic and hadronic excitation

Decay pattern of the PDR: γ^3 setup at HIGS



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



EMMI

Duke UNIVERSITY

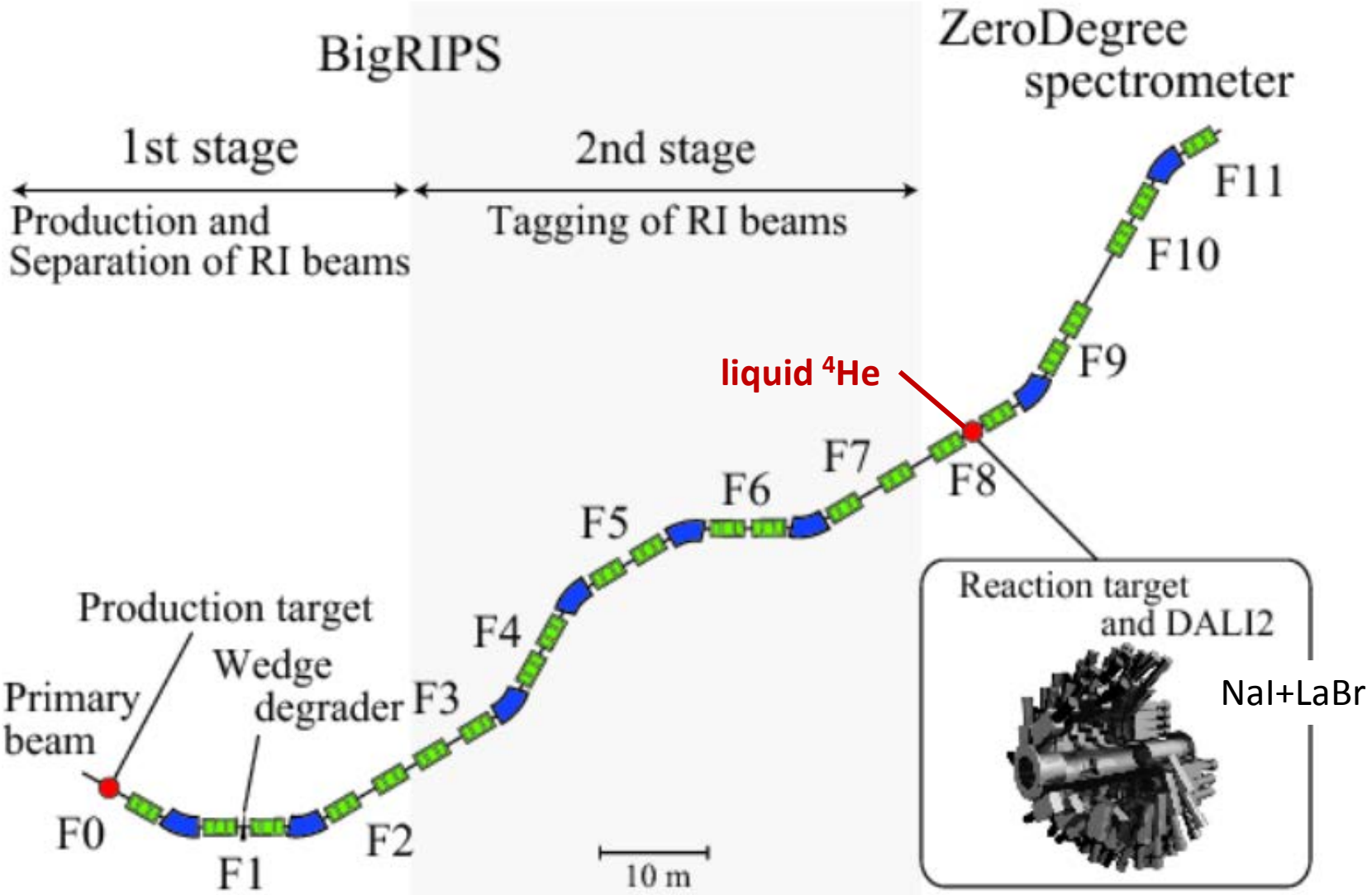
Universität zu Köln

Yale University

TECHNISCHE UNIVERSITÄT DARMSTADT

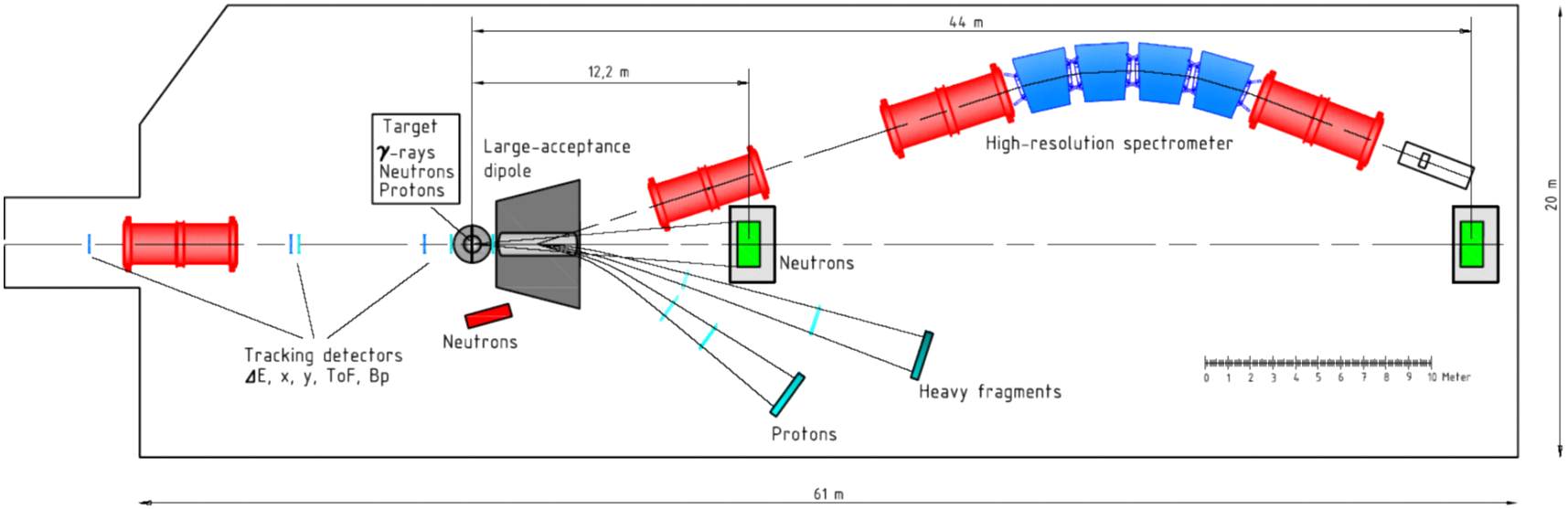
*B. Löher et al., NIM A **723** (2013) 136*

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



PDR in exotic nuclei: R3B at FAIR

Reactions with Relativistic Radioactive Beams

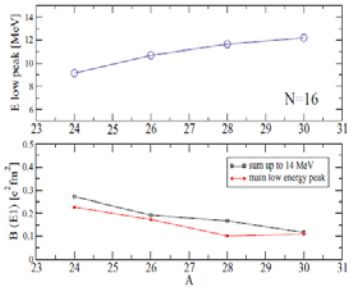


- Kinematically complete measurements of reactions with high-energetic secondary beams

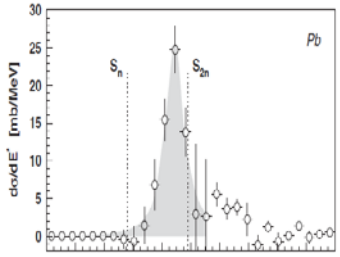
- Detection of all decay channels

PDR: Studies on lighter nuclei and theoretical aspects

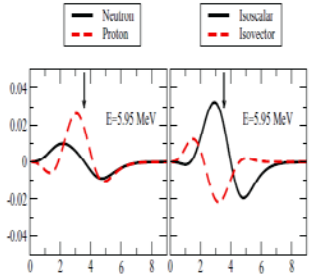
see following talks by:



Sophie Péru



Julie Gibelin



Danilo Gambacurta

The Electric Dipole Response of Atomic Nuclei – from Giants to Pygmies

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

Institut für Kernphysik, Universität zu Köln

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)**

EUROPEAN COMMISSION **(RII3-CT-2004-506065)**