Origin of Dipole Strength in Atomic Nuclei

- History of studies on E1 strength
- The Pygmy Dipole Resonance
- Outlook

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Bundesministerium für Bildung und Forschung (05P2015 ELI-NP)

Nuclear Photonics • Monterey • October 2016

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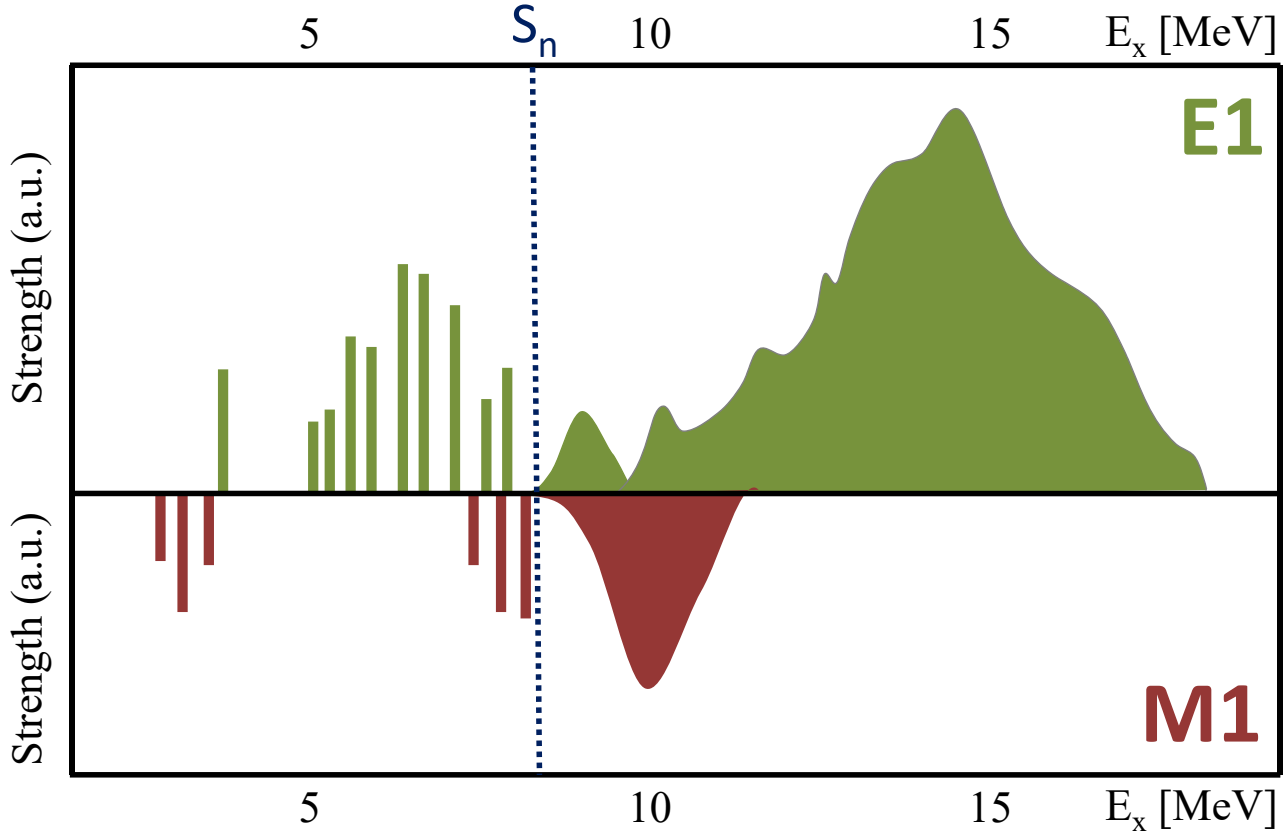
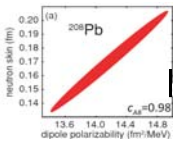
Dipole photoresponse of atomic nuclei

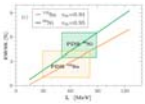


Relevance of E1 strength

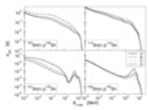
- Connection to neutron skin, neutron star radius
- Slope of symmetry energy in Equation of State
- Impact on nucleosynthesis
- Isotope identification



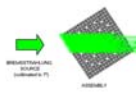
*P.-G. Reinhard and W. Nazarewicz, PRC **81** (2010) 051303(R)*
*J. Piekarewicz et al., PRC **85** (2012) 041302(R)*
*J. Erler et al., PRC **87** (2013) 044320*



*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*



*W. Bertozzi et al., NIM **B 241** (2005) 820*
*B.J. Quiter et al., IEEE Trans. Nucl. Science **58** (2011) 400*

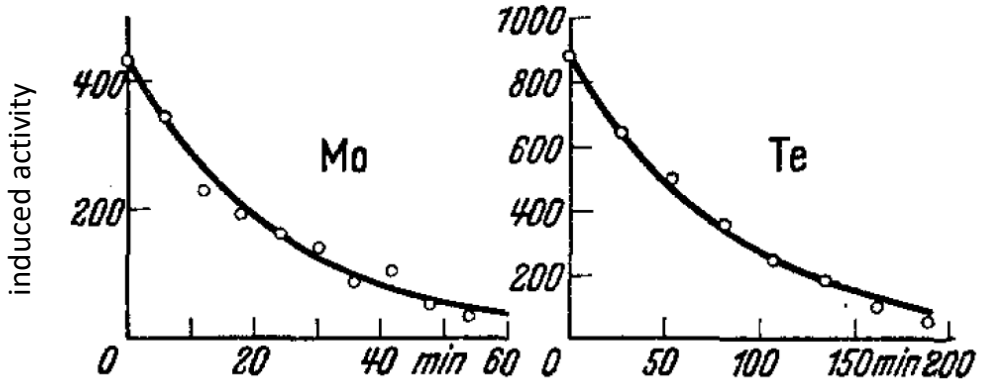
Giant Dipole Resonance (GDR)

1937: **Atomumwandlungen durch γ-Strahlen.**

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

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

irradiation with photons with E_γ~ 17 MeV from ^{7}Li(p,γ)



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*

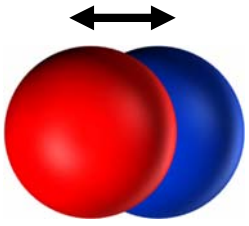
Giant Dipole Resonance (GDR)

1944:

QUADRUPOLE AND DIPOLE γ-RADIATION OF NUCLEI

By A. MIGDAL

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



Giant Dipole Resonance (GDR)

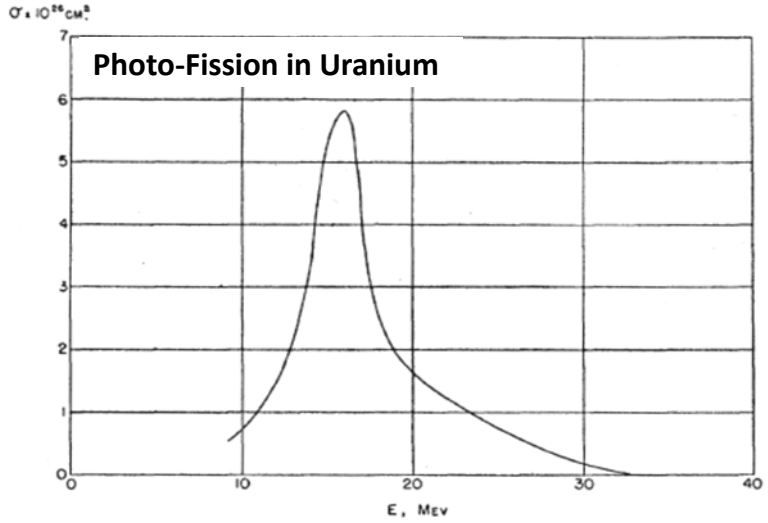
1947:

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*

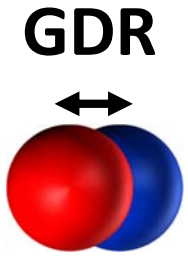
irradiation with bremsstrahlung photons
from 100 MeV betatron

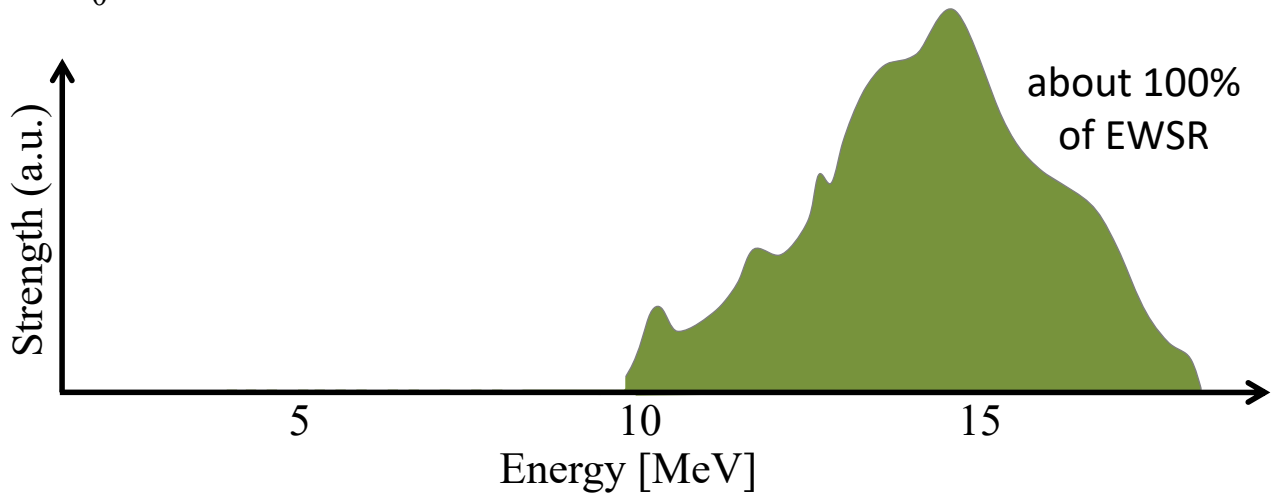


Giant Dipole Resonance (GDR)

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

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





M.N. Harakeh and A. van der Woude, „Giant Resonances", Oxford University Press, Oxford, UK, 2001

Pygmy Dipole Resonance (PDR)

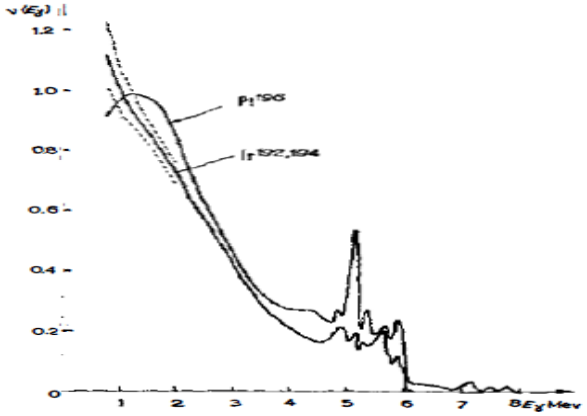
1961:

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*



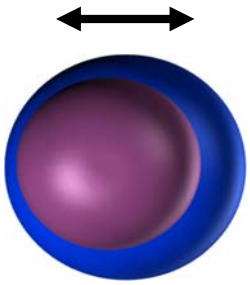
Pygmy Dipole Resonance (PDR)

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)

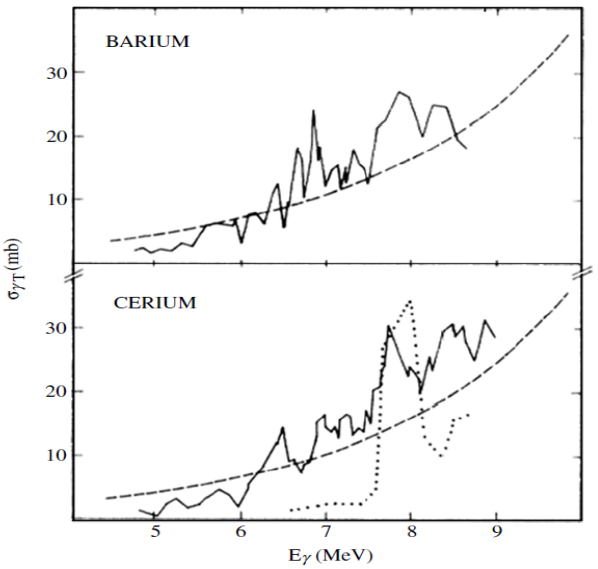
1986:

Photon interactions below 9 MeV in Ba and Ce

R. M. Laszewski
Nuclear Physics Laboratory and Department of Physics, University of Illinois at Urbana-Champaign, Champaign, Illinois 61820
(Received 20 March 1986)

*Phys. Rev. C **34** (1986) 1114*

(γ,γ') using tagged photons



Pygmy Dipole Resonance (PDR)

1997:

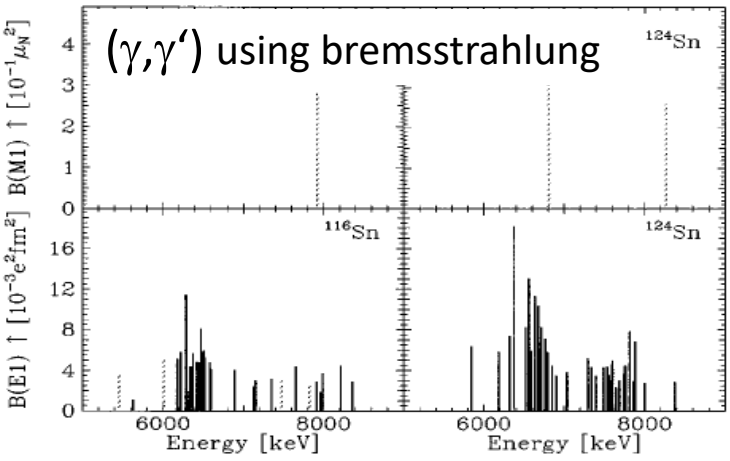
Dipole excitations to bound states in ^{116}Sn and ^{124}Sn

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)

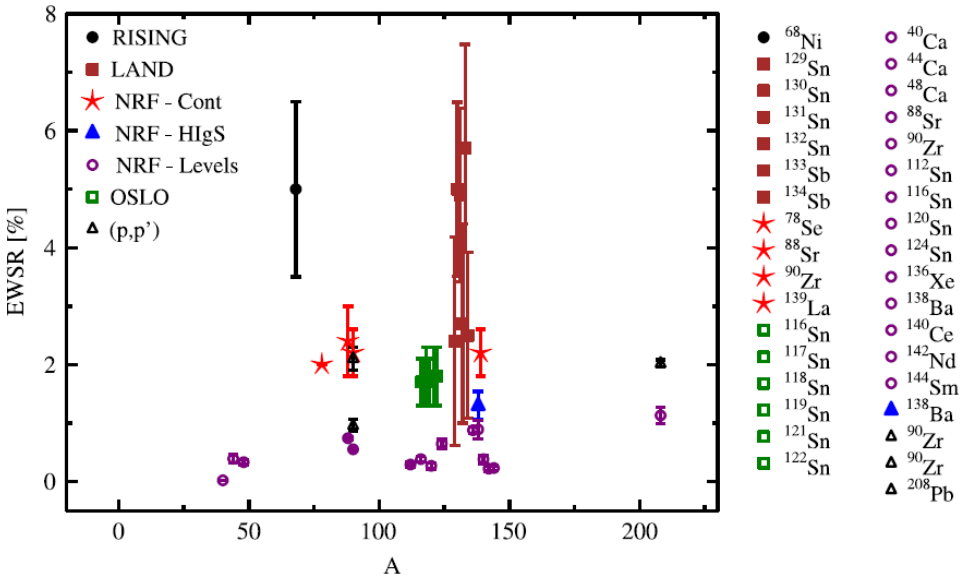
2013:

Review

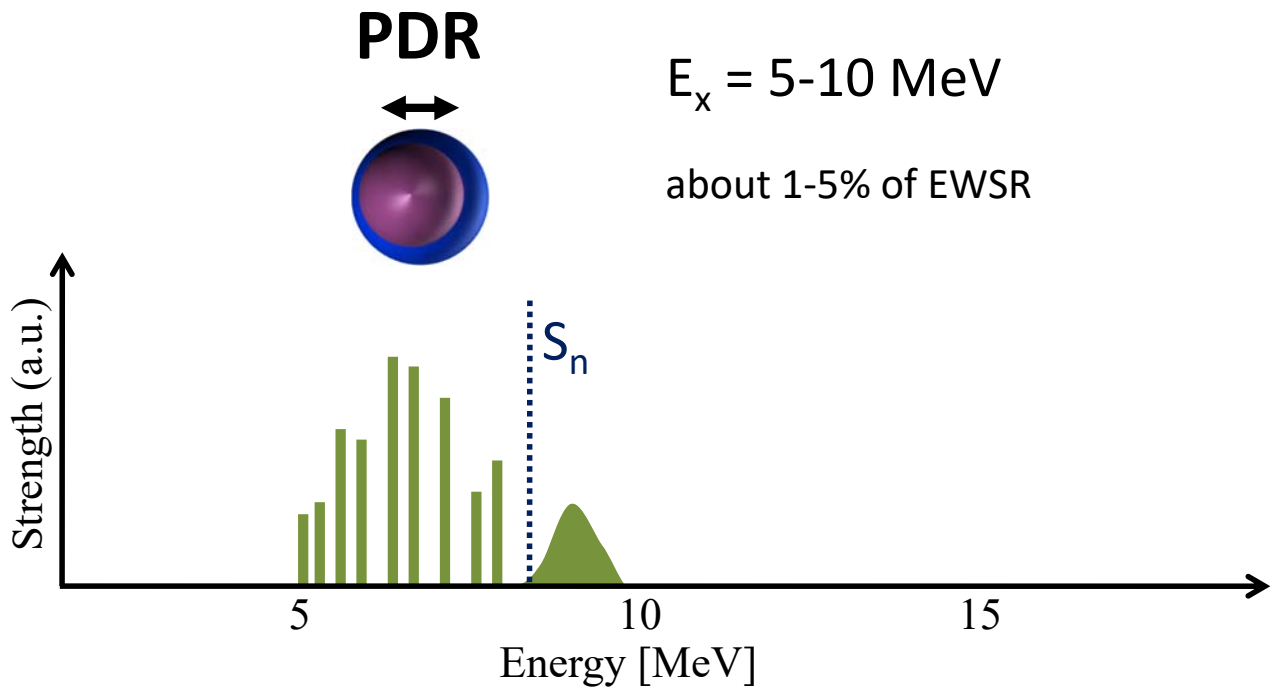
Experimental studies of the Pygmy Dipole Resonance

D. Savran [a,b,*], T. Aumann [c,d], A. Zilges [e]

Prog. Part. Nucl. Phys. ***70*** *(2013) 210*



Pygmy Dipole Resonance (PDR)



Two phonon excitations: quadrupole-octupole ($2^+ \otimes 3^-$)

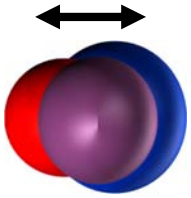
1962:

SCATTERING OF ALPHA-PARTICLES BY A VIBRATIONAL NUCLEUS*

By L. J. Tassie†

[*Manuscript received February* 8, 1962]

Austr. J. Phys. 15 (1962) 135



Two phonon excitations ($2^+ \otimes 3^-$)

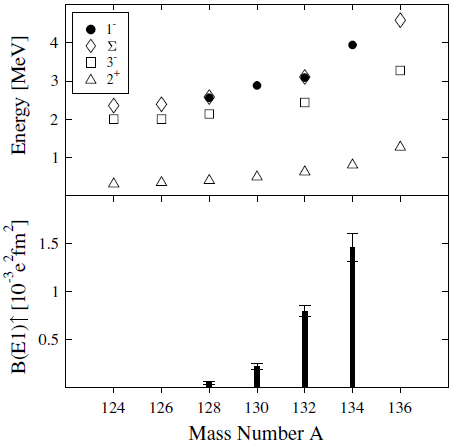
2006:

TOPICAL REVIEW

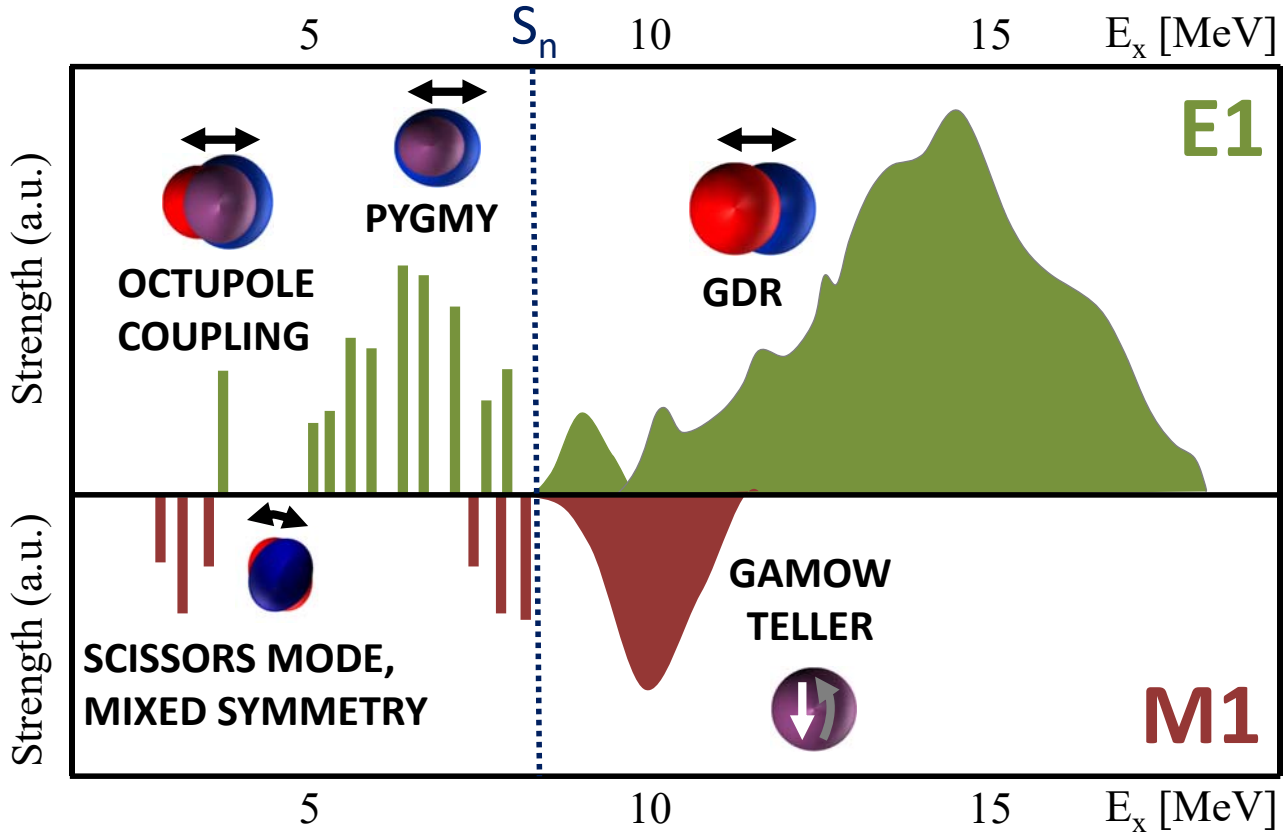
Low-lying dipole modes in vibrational nuclei studied by photon scattering

Ulrich Kneissl[1], Norbert Pietralla[2] and Andreas Zilges[3]

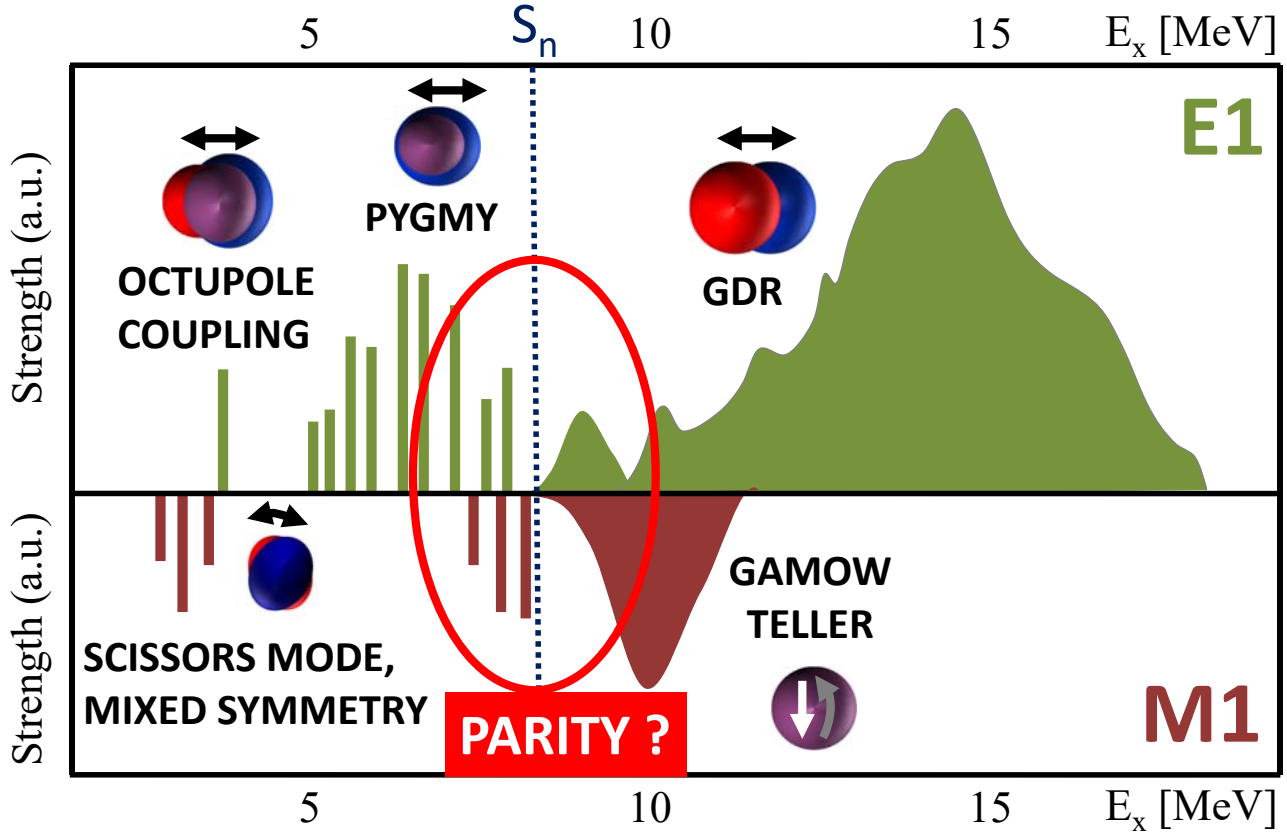
J. Phys. G. ***32*** *(2006) R217*



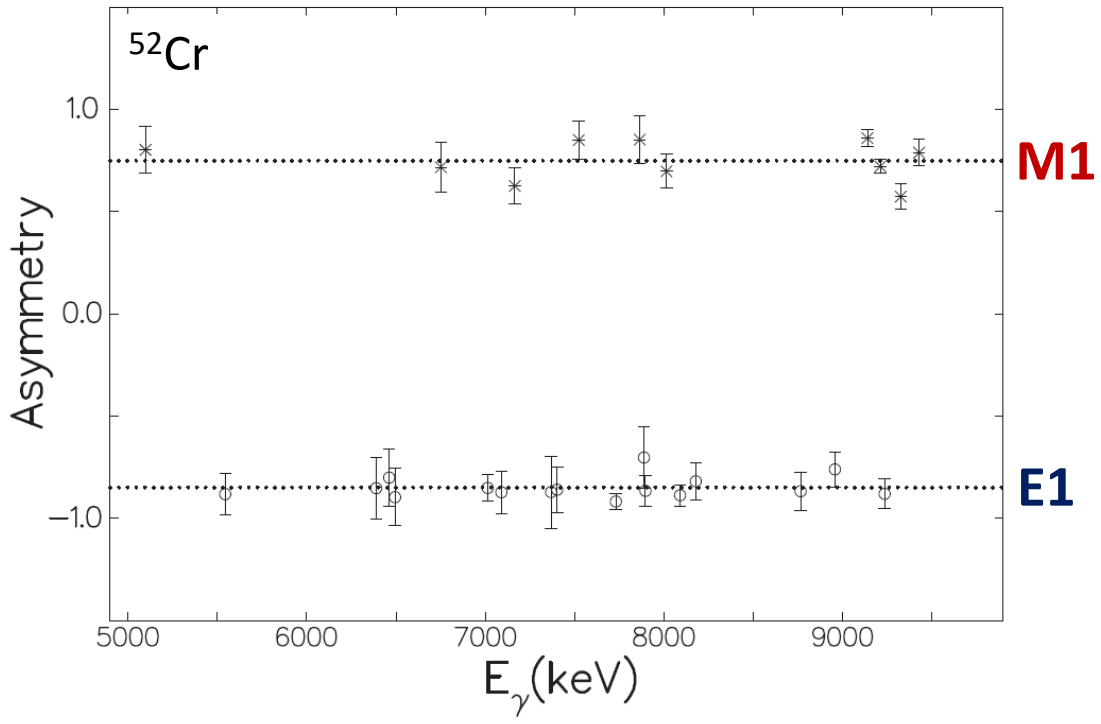
Dipole photoresponse of atomic nuclei



Dipole photoresponse of atomic nuclei

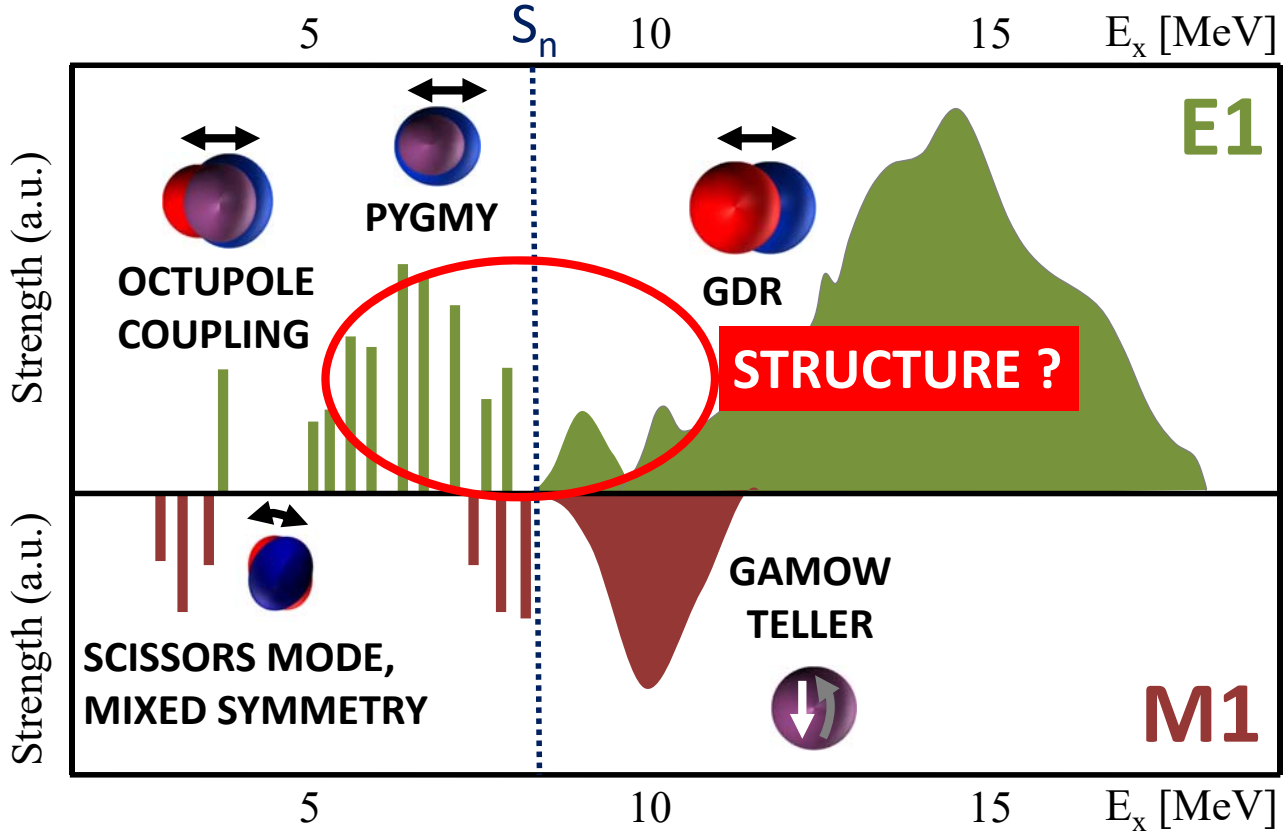


Polarized photons: A parity-meter

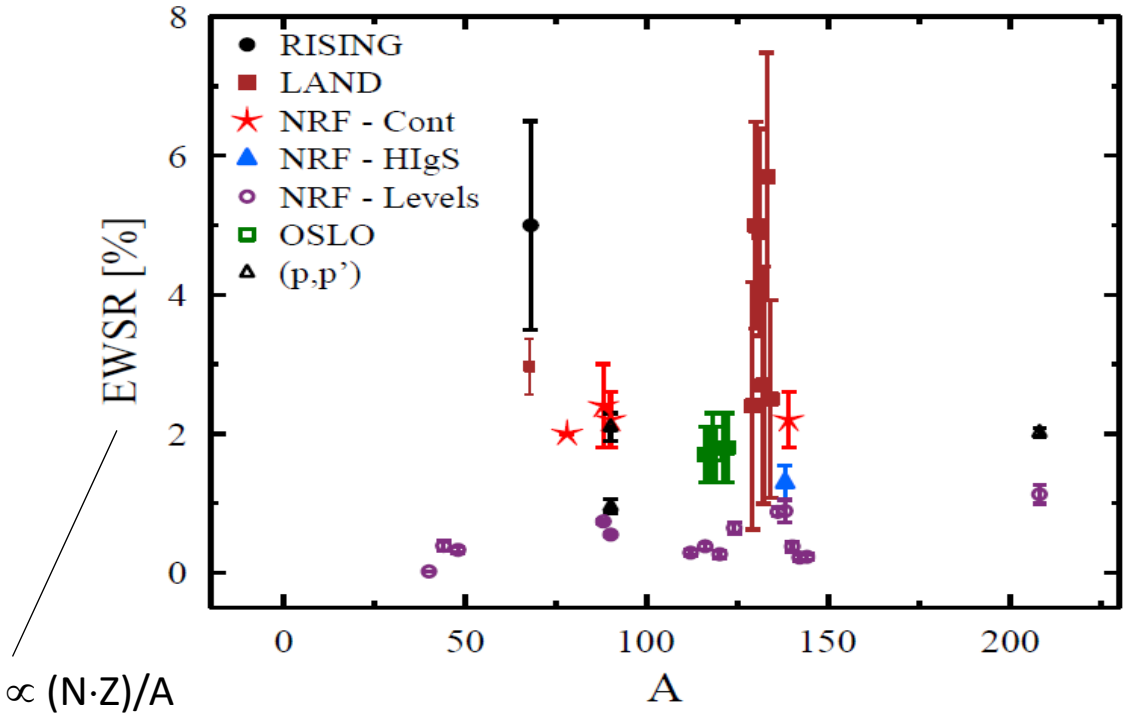


*Krishichayan et al., Phys. Rev. C **91**, 044328 (2015)*

Dipole photoresponse of atomic nuclei



Summed B(E1) strength of "Pygmy" excitations



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

Structure of the Pygmy Dipole Resonance

- **Response to isoscalar/isovector probes**
- **Decay to excited states → Deniz Savran: We1-2**
- **Single-particle structure**

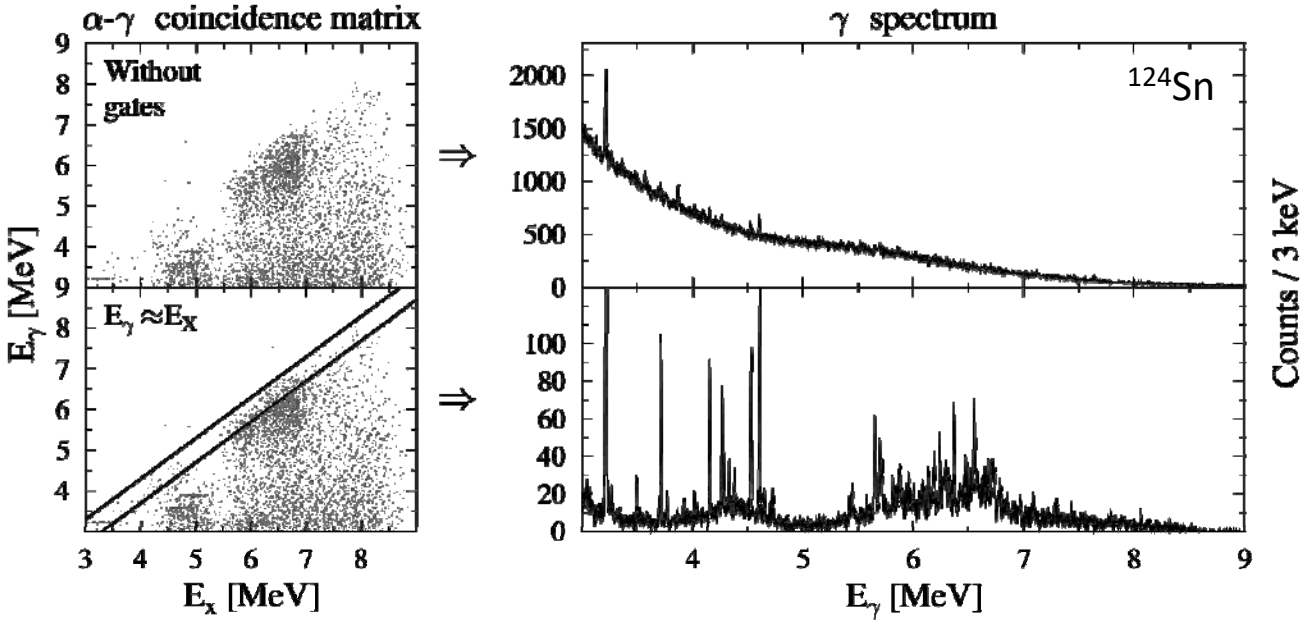
Testing the isospin structure: (γ,γ') vs. (α,α') or (p,p')

	(γ,γ') or Coulex	(α,α') @ 30 MeV/A or (p,p') @ 80 MeV/A
Interaction	**electromagnetic**	**strong**
Location of interaction	**whole** nucleus (kR << 1)	**surface**
Isospin	**isovector** E1 excitations	dominant **isoscalar**
Multipolarity	E1, M1, E2	E0, E1, E2, E3, …

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

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

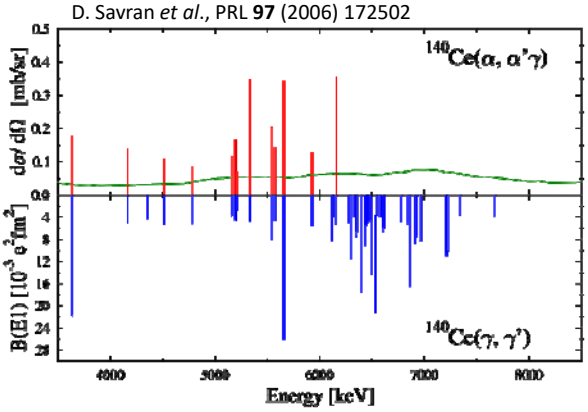
Selectivity of (α,α'γ) experiments



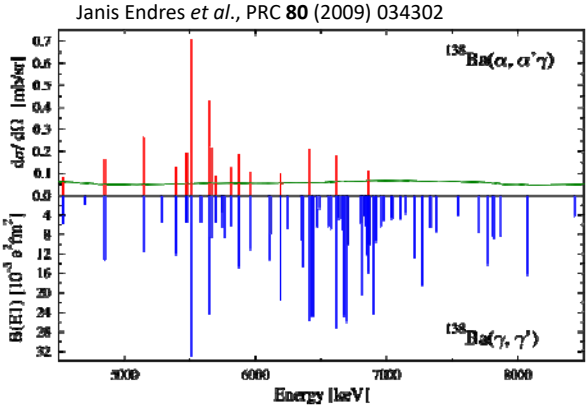
*J. Endres et al., PRL **105** (2010) 112503*
*J. Endres et al., PRC **85** (2012) 064331*

Splitting of strength: Experimental results

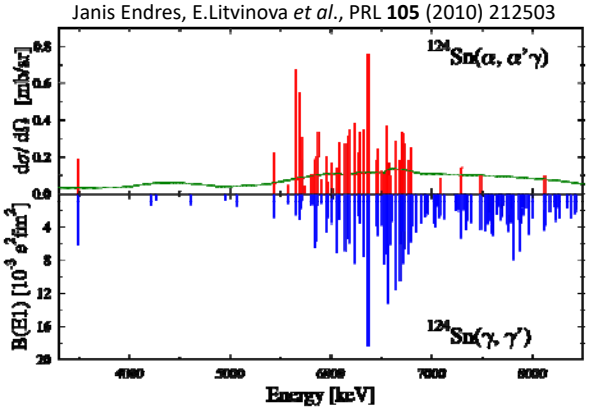
D. Savran *et al.*, PRL **97** (2006) 172502



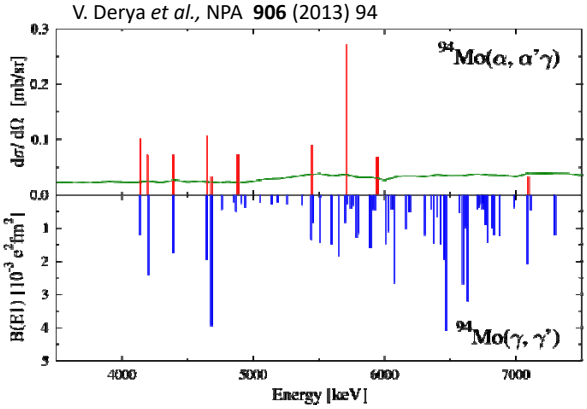
Janis Endres *et al.*, PRC **80** (2009) 034302



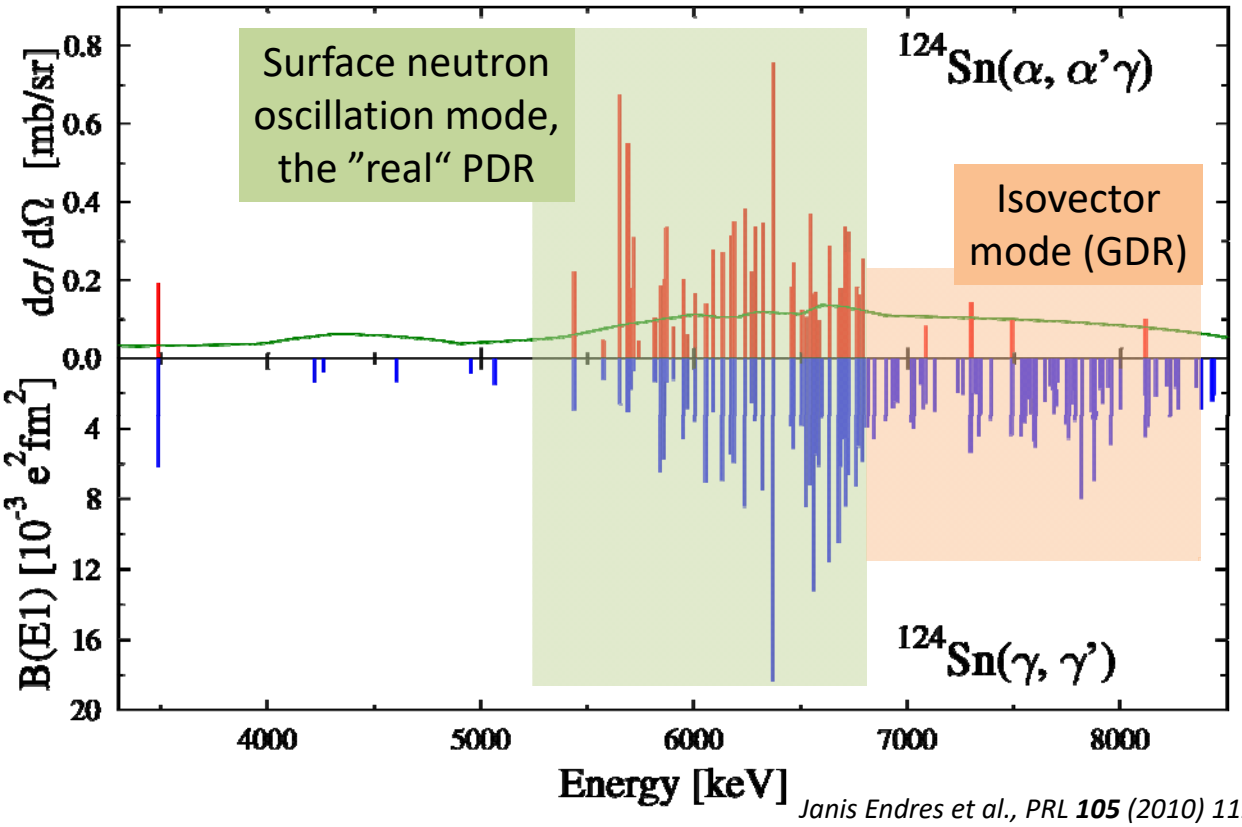
Janis Endres, E.Litvinova *et al.*, PRL **105** (2010) 212503



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

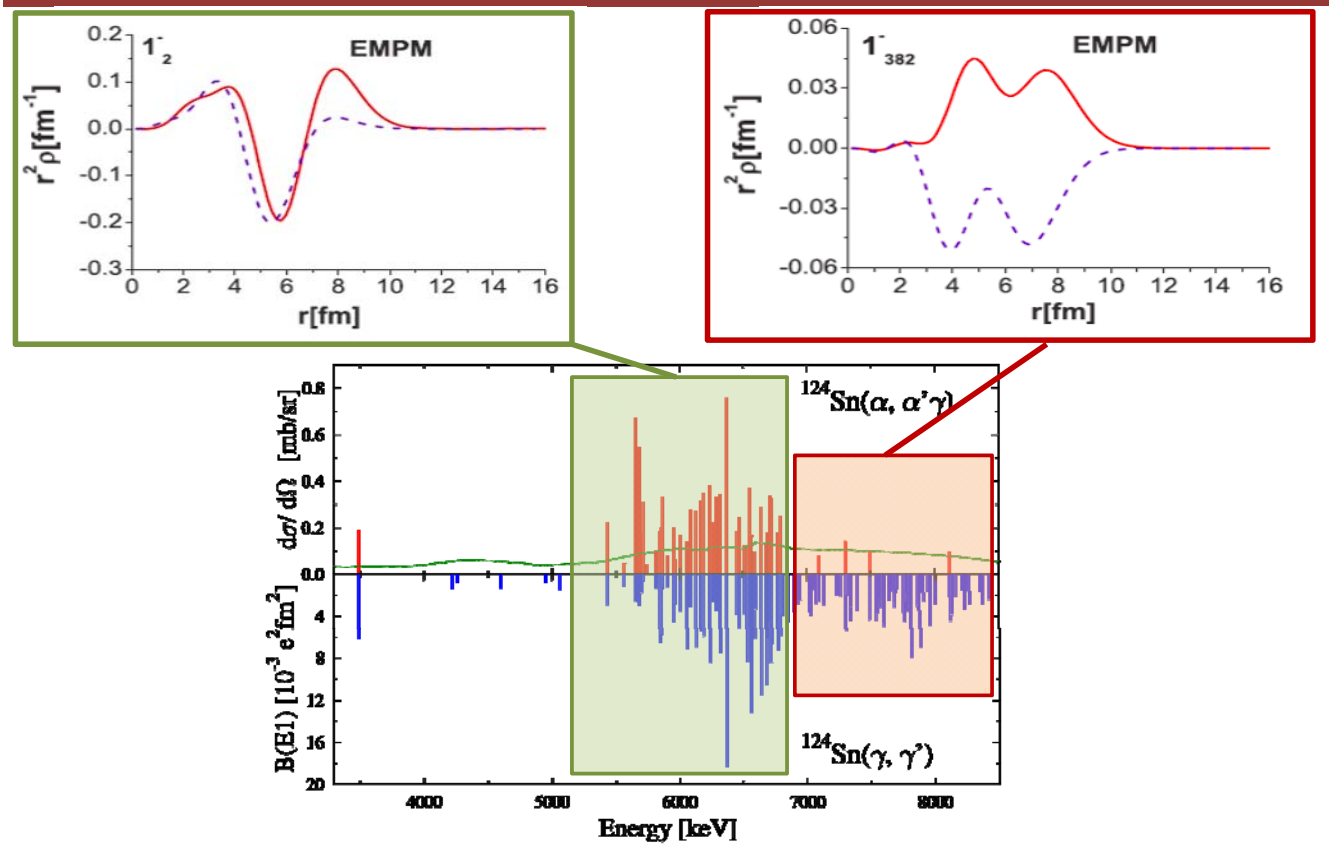


Splitting of the PDR: Interpretation from RQTBA



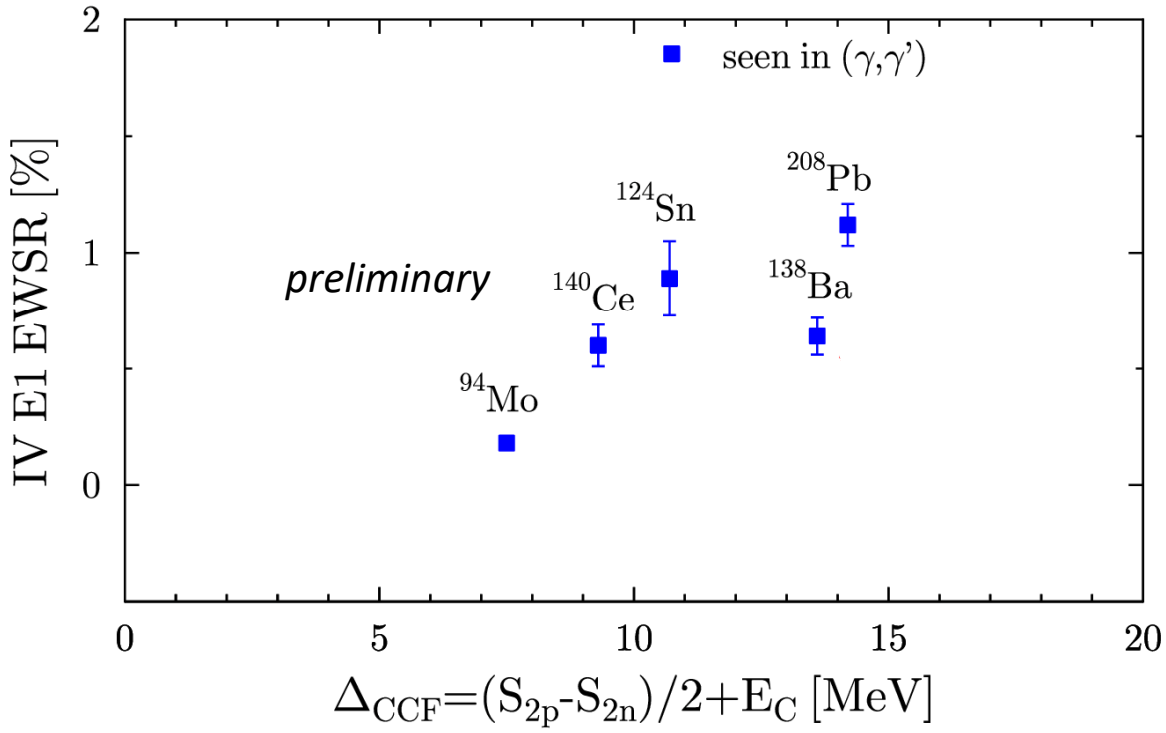
*Janis Endres et al., PRL **105** (2010) 112503*
*Janis Endres et al., PRC **85** (2012) 064331*

Splitting of the PDR: Theoretical interpretation



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

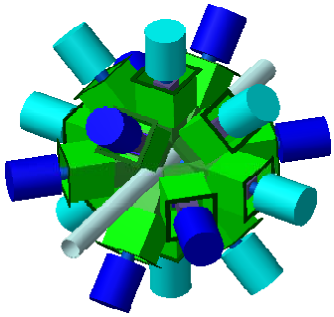
Summed E1 strength derived from (α,α')



Isospin structure of the PDR in stable nuclei: The CAGRA campaign 2016 @ RCNP

$(\alpha,\alpha'\gamma)$ @ E_α= 130 MeV and $(p,p'\gamma)$ @ E_p= 80 MeV
combining Grand Raiden spectrometer and
16 Compton suppressed HPGe Clover detectors

CAGRA

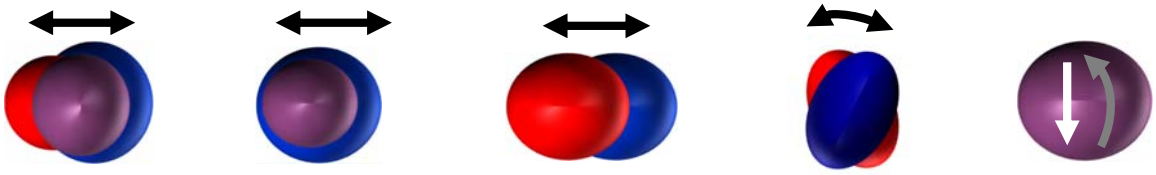


GRAND RAIDEN

Collaboration: *Argonne – Cologne – KVI – Darmstadt – Milano –* ***Osaka*** *– NSCL*

Conclusions

- The dipole response of atomic nuclei is complex including various fine structures.
- Different "collective" features emerge: Two-phonon excitations, PDR, GDR, mixed-symmetry states, scissors mode.
- Parity determination is mandatory.
- Measurements of various observables enable to determine structural differences and test theoretical models.



Potential of a polarized, tunable, high-intensity photon beam with very narrow band width

- Sensitive scanning of the photoresponse from the lowest energies to the 15-20 MeV region.
- Examination of smallest target samples including radioactive isotopes.
- Selective population and observation of all decay channels (γ-decay branchings, neutrons, protons, fission).

Looking forward to ELI-NP!

Origin of Dipole Strength in Atomic Nuclei

V. Derya, M. Färber, J. Mayer, M. Müscher, **S.G. Pickstone**, P. Scholz, **M. Spieker**, **M. Weinert**, J. Wilhelmy, and A. Z.

Institut für Kernphysik, University of Cologne

M.N. Harakeh

KVI Groningen, The Netherlands

B. Löher, **D. Savran**

Extreme Matter Institute EMMI, Darmstadt

supported by: DFG **(ZI 510/7-1, INST 216/544-1, and BCGS)**

Bundesministerium für Bildung und Forschung **(05P2015 ELI-NP)**