

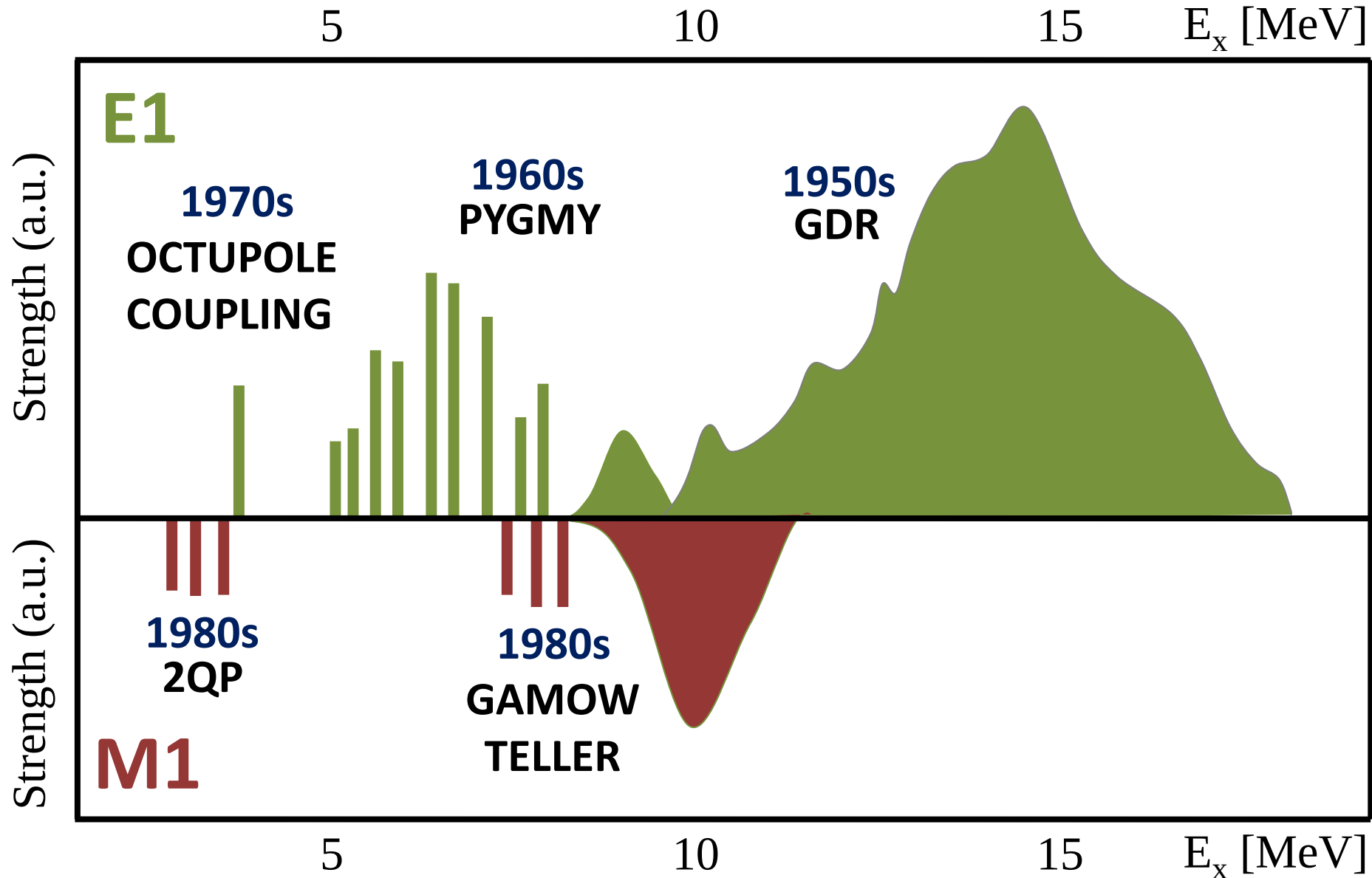
Electric Dipole Strength below the Particle Threshold – Status and Perspectives

- Introduction – from octupoles to giants
- Electromagnetic and strong interaction studies
- Open questions and new developments

Andreas Zilges - University of Cologne



Dipole response of atomic nuclei

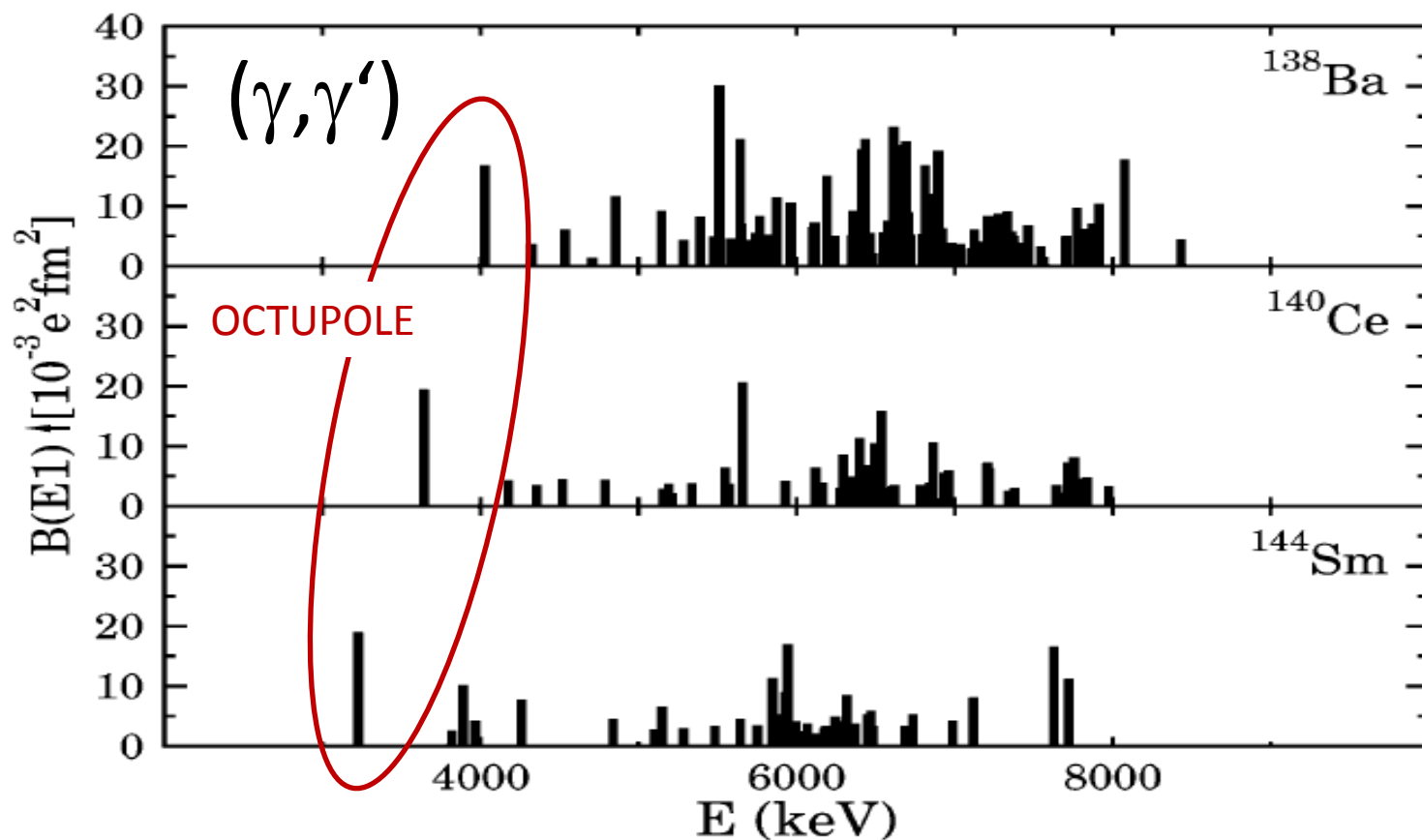


Pygmy Dipole Resonance (PDR)

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

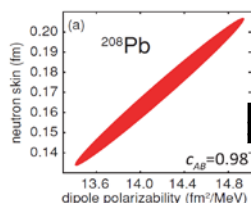
A.Z., S. Volz, M. Babilon, T. Hartmann, P. Mohr, K. Vogt

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

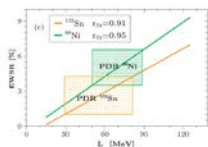


Relevance of low-lying E1 strength

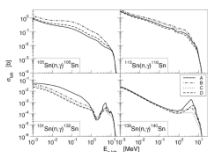
- Universal „collective“ excitation modes
- Connection to neutron skin, neutron star radius
- Slope of symmetry energy in EoS
- Impact on nucleosynthesis



*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*

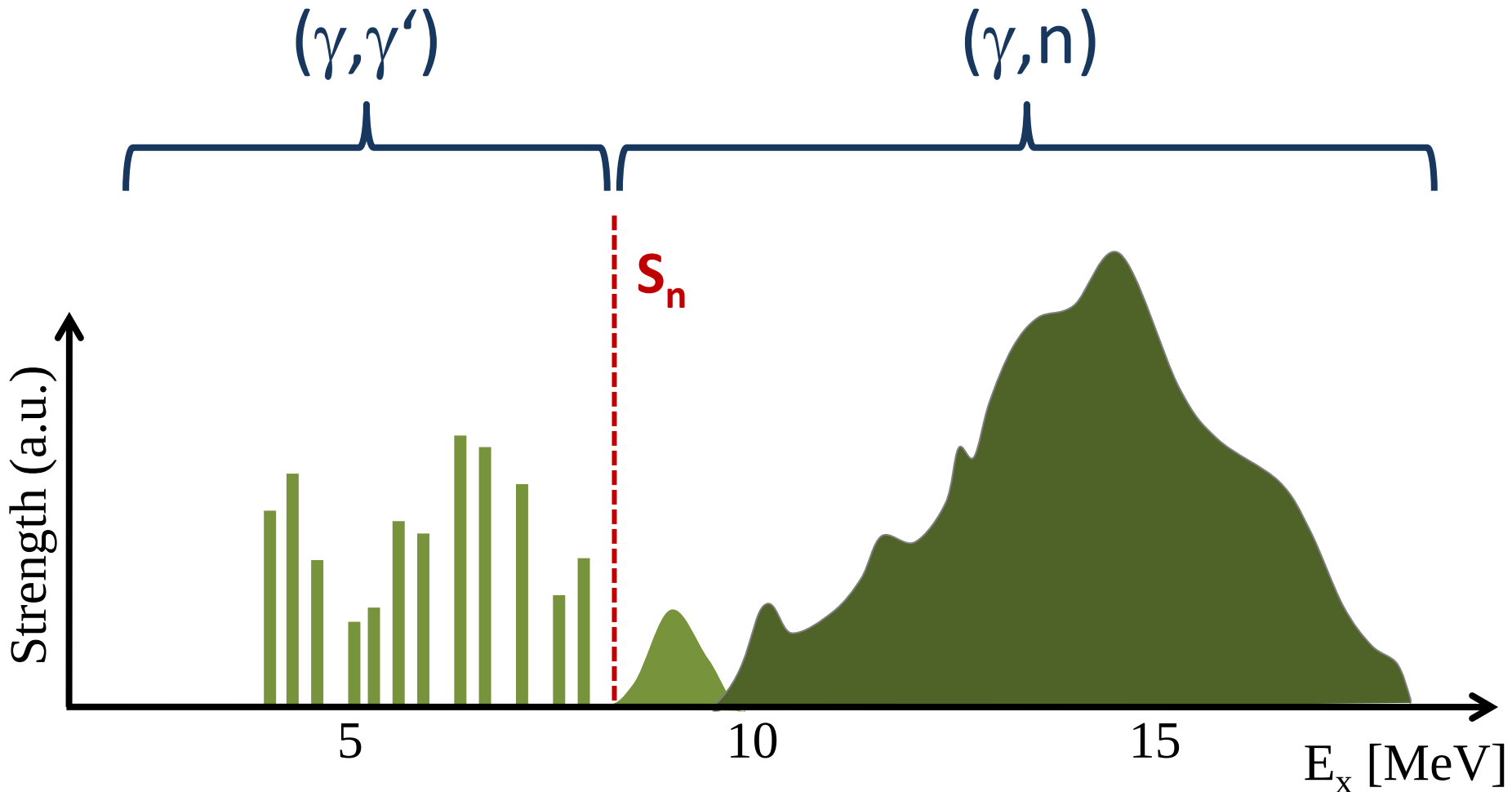


*A. Carbone et al. PRC **81** (2010) 041301(R)*
*B.A. Brown and A. Schwenk, PRC **89** (2014) 011307(R)*



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

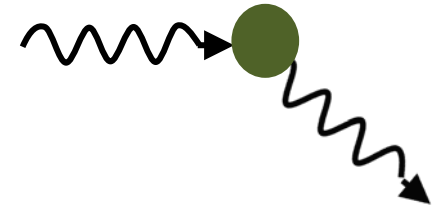
Study of the E1 strength distribution via electromagnetic interaction



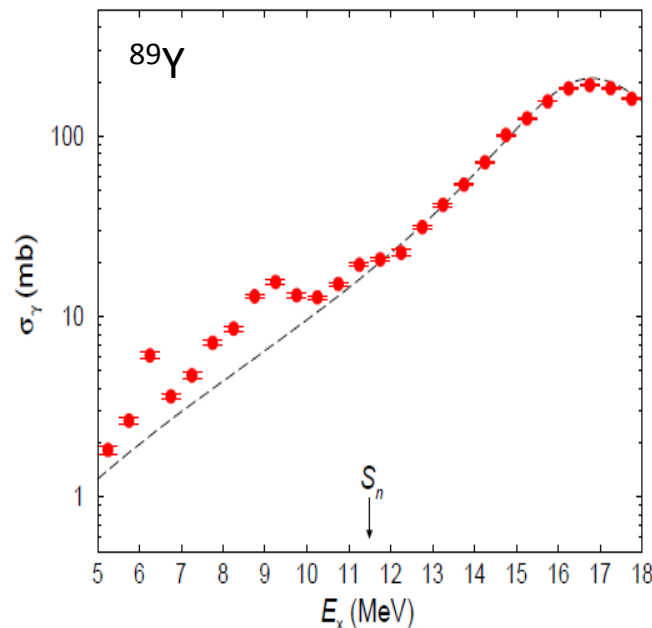
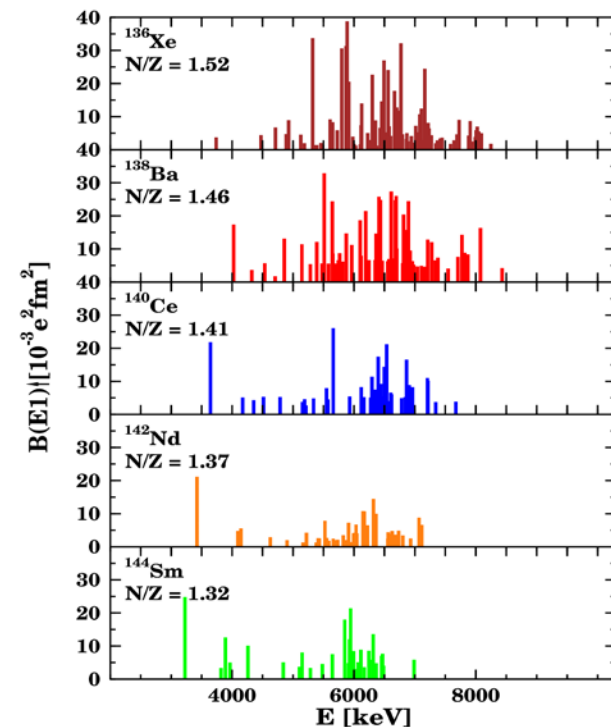
The photons can be real or virtual!

Scattering of real photons (γ, γ') - NRF

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

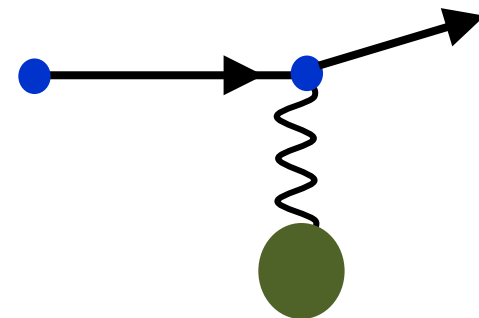


S-DALINAC@TUD
ELBE@HZDR
HIGS@DUKE
ELI@Bucharest

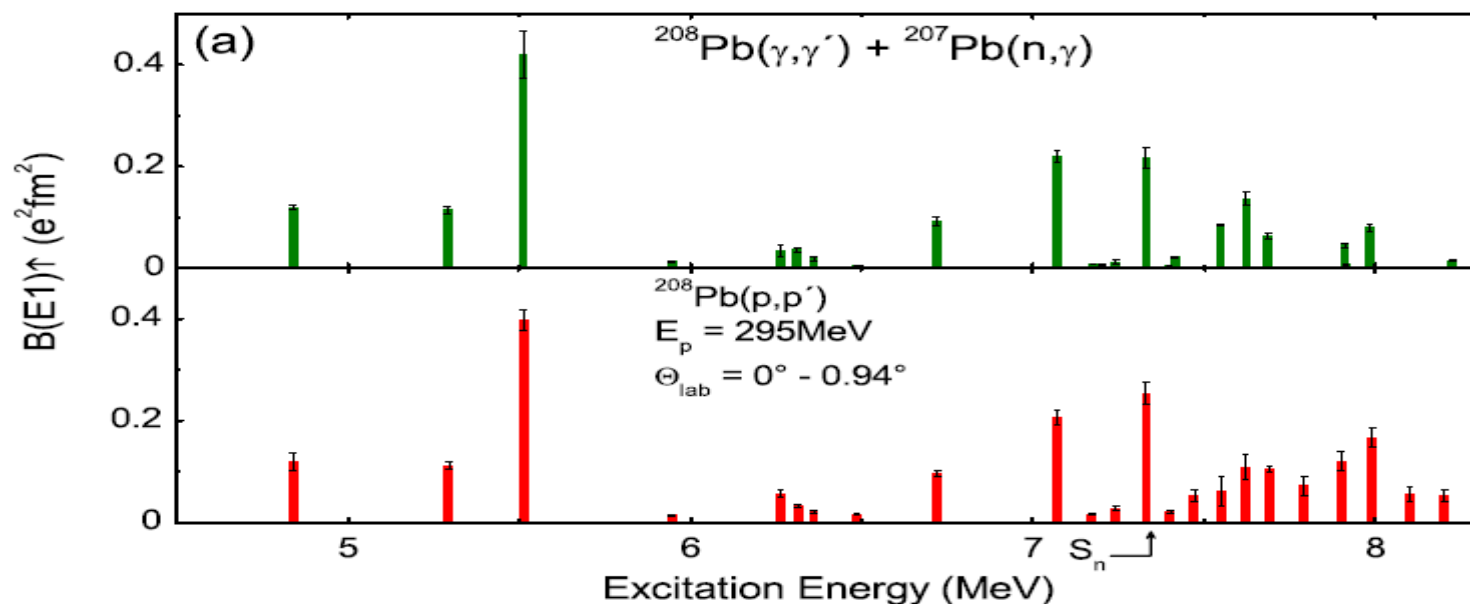


Scattering of virtual photons via (p,p')

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



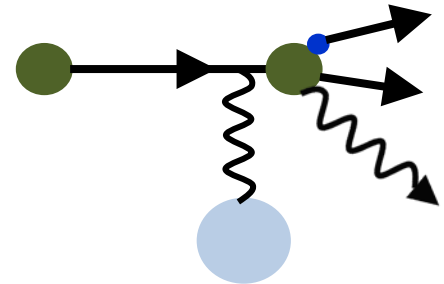
GRAND RAIDEN
@RCNP



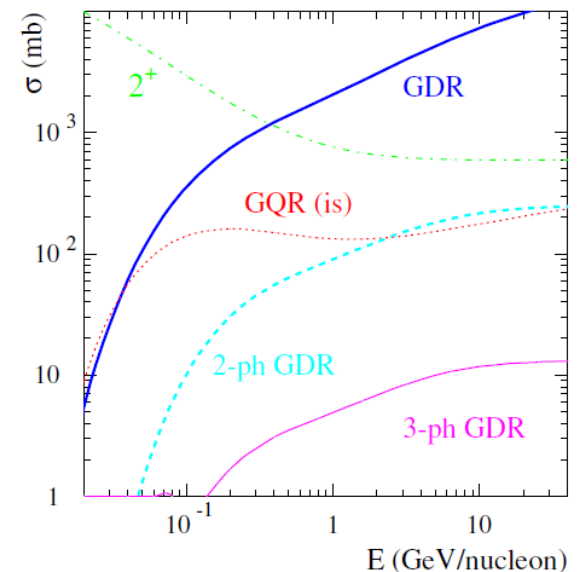
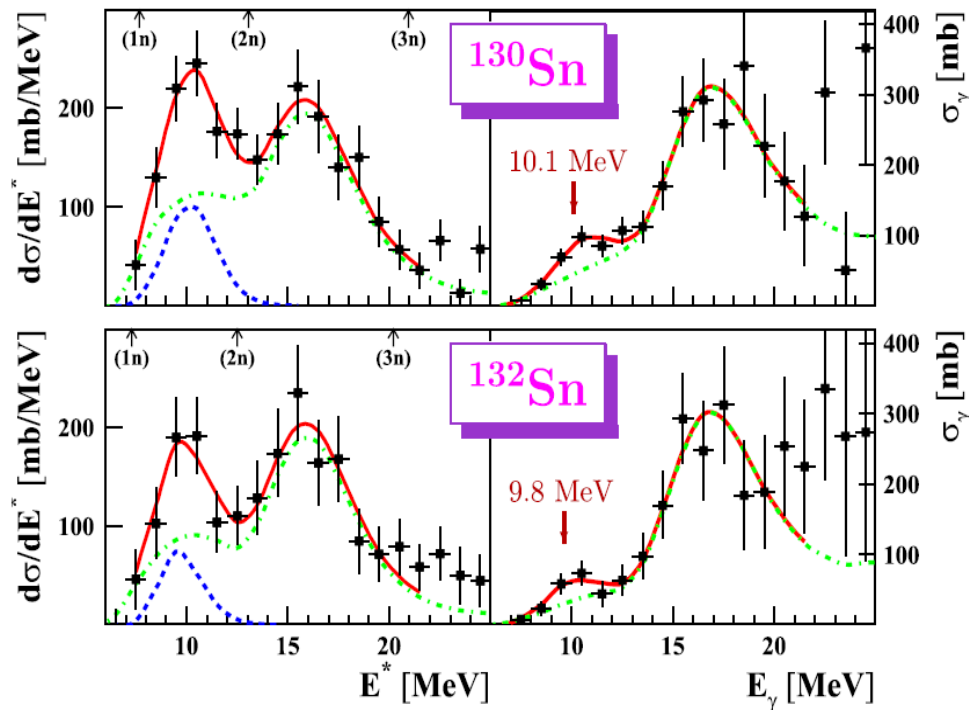
A. Tamii et al., PRL **107** (2011) 062502

Coulomb interaction in inverse kinematics

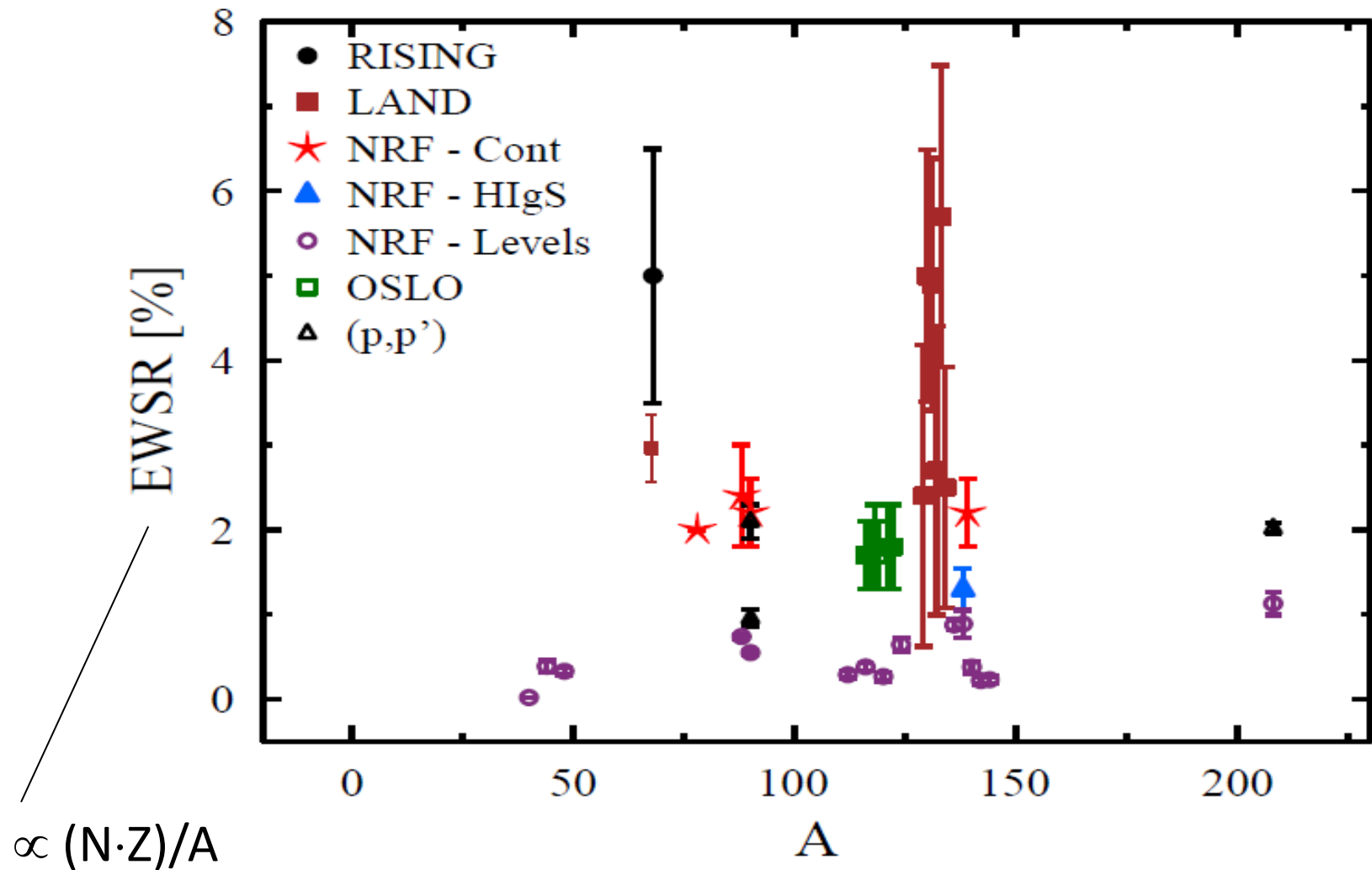
- $E_{\text{cm}} = \text{few } 100 \text{ MeV/A}$
- radioactive nuclei can be studied
- energy resolution $\Delta E = 500 \text{ keV}$
- complex data evaluation



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

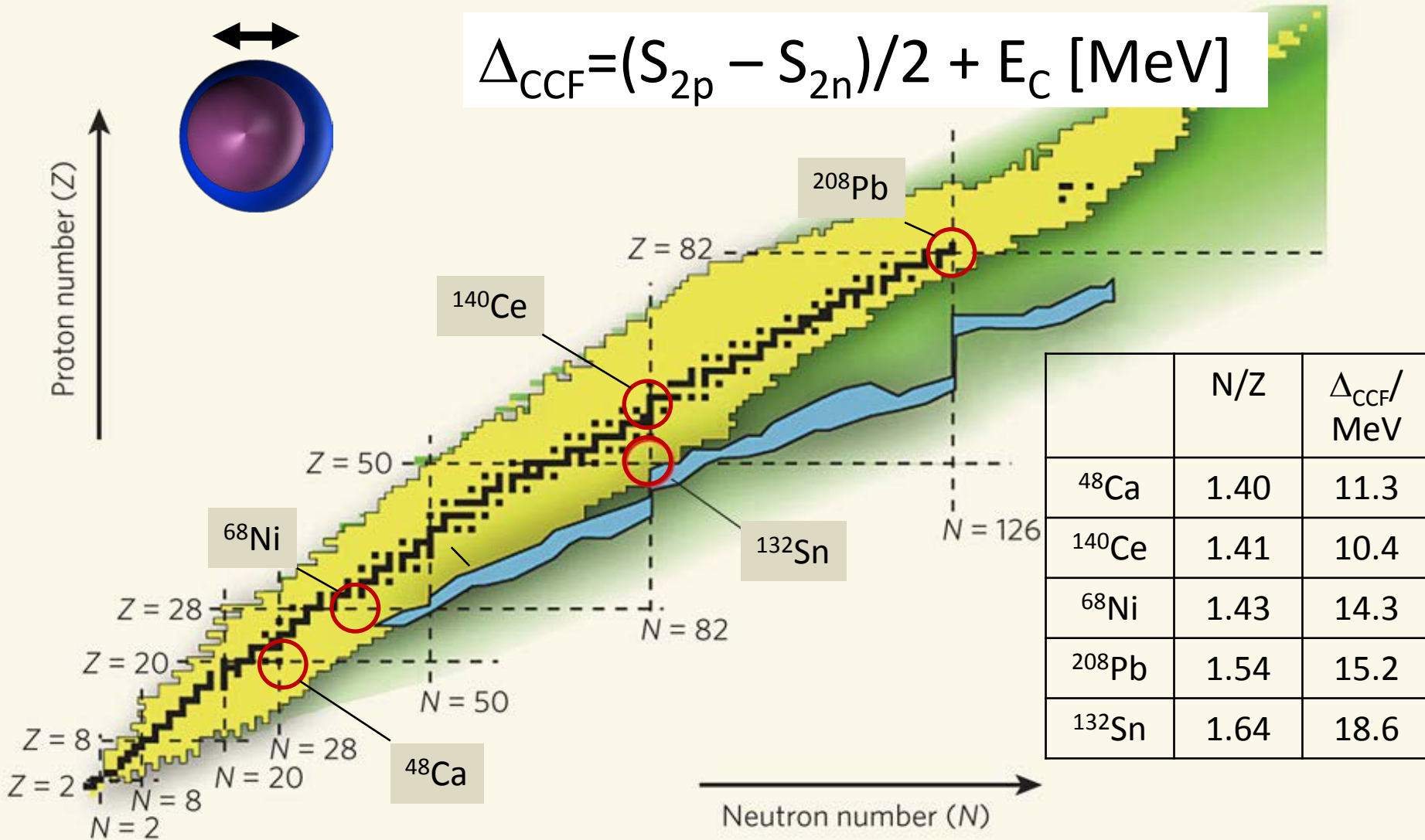


Summed B(E1) strength of Pygmy Dipole Resonance

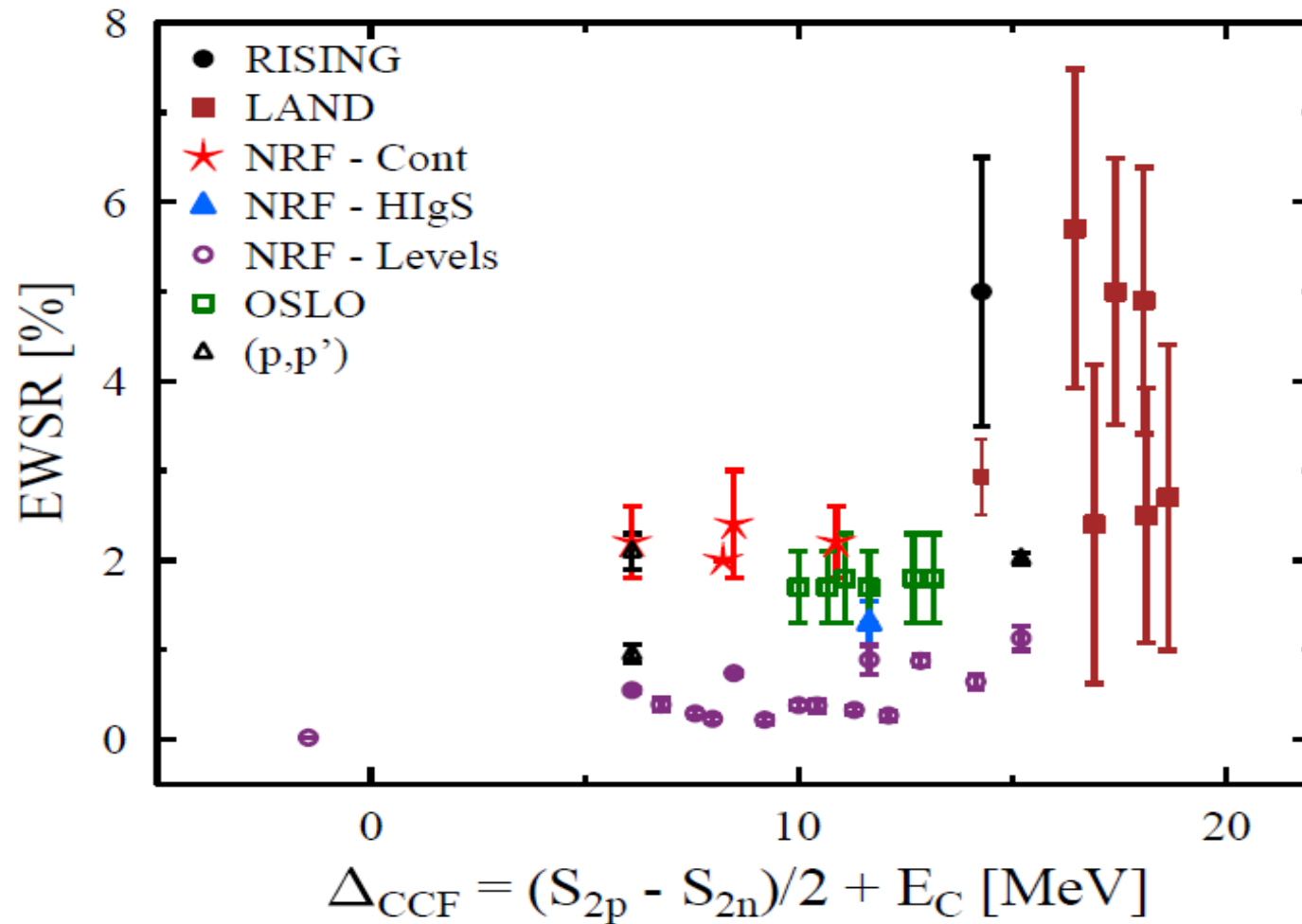


D. Savran, T. Aumann, and A. Zilges, PPNP 70 (2013) 210

Parametrization of „exoticity“



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



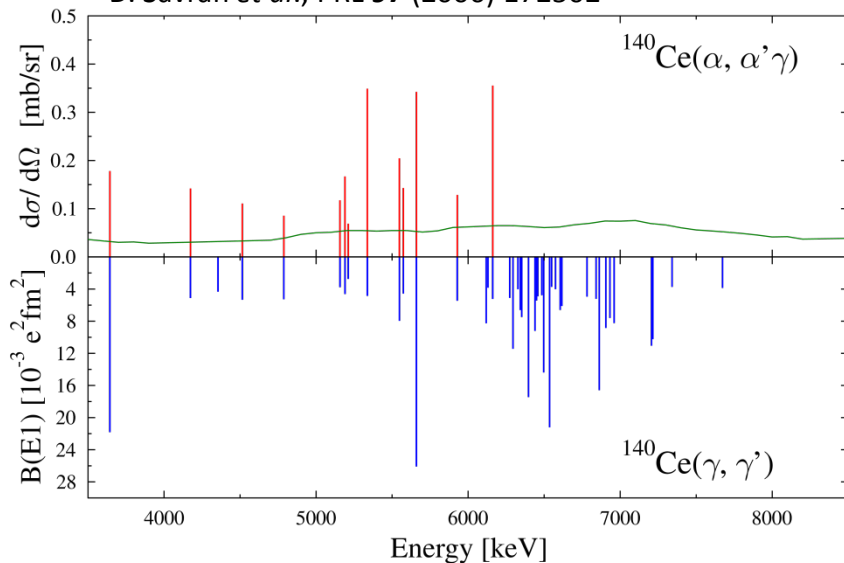
Testing the structure: (γ, γ') vs. (α, α')

	(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	<u>3</u> -500 keV	50-200 keV

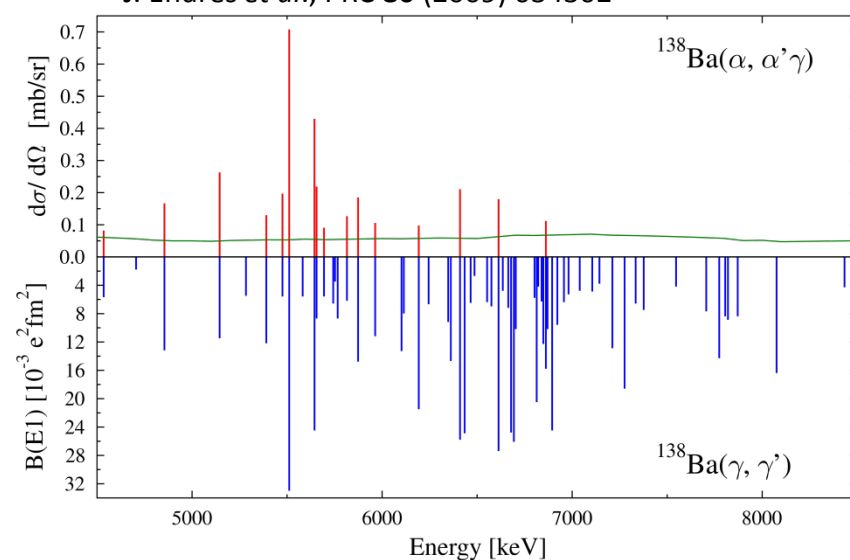
A coincident detection of the γ decay enhances the selectivity
(and possibly the energy resolution) $\rightarrow (\alpha, \alpha' \gamma)$

Splitting of strength: Experimental results

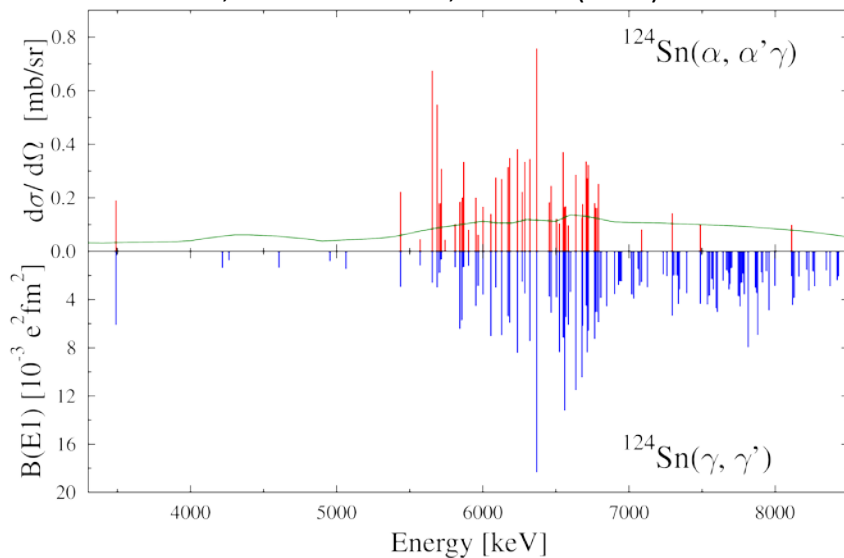
D. Savran *et al.*, PRL **97** (2006) 172502



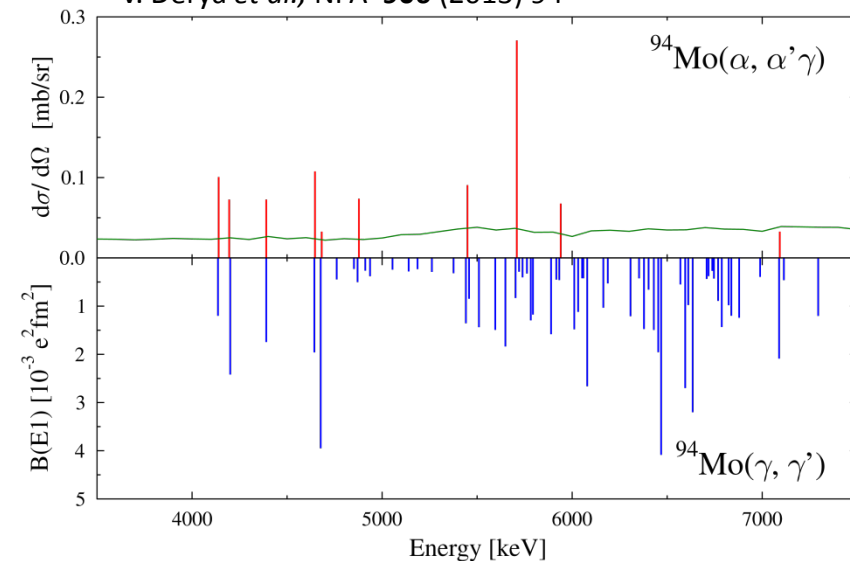
J. Endres *et al.*, PRC **80** (2009) 034302



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

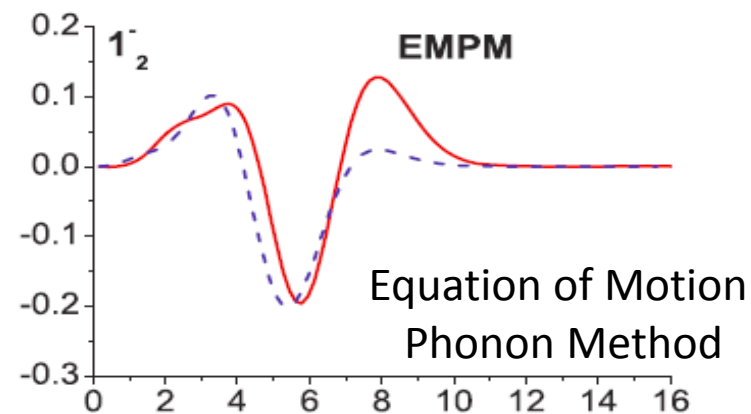
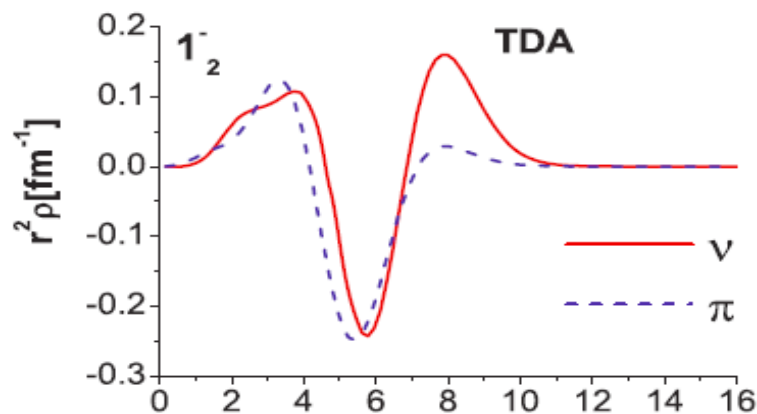


V. Derya *et al.*, NPA **906** (2013) 94

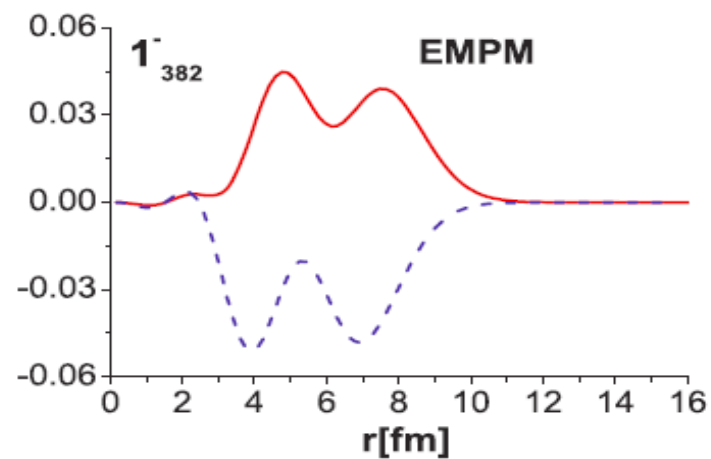
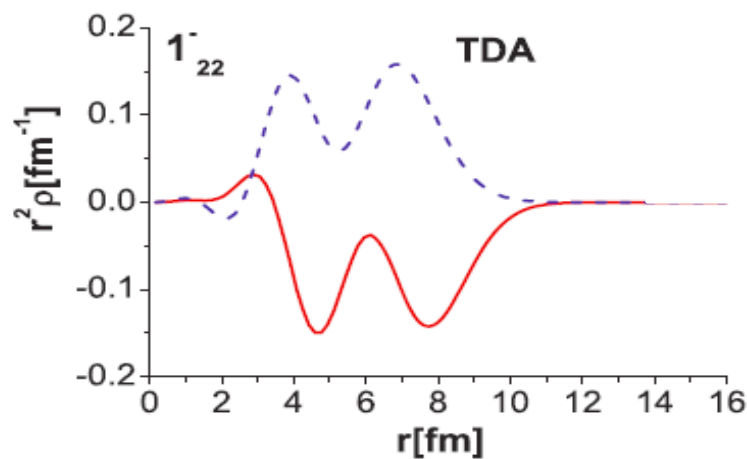


Transition densities for 1^- states in ^{208}Pb

PDR
region



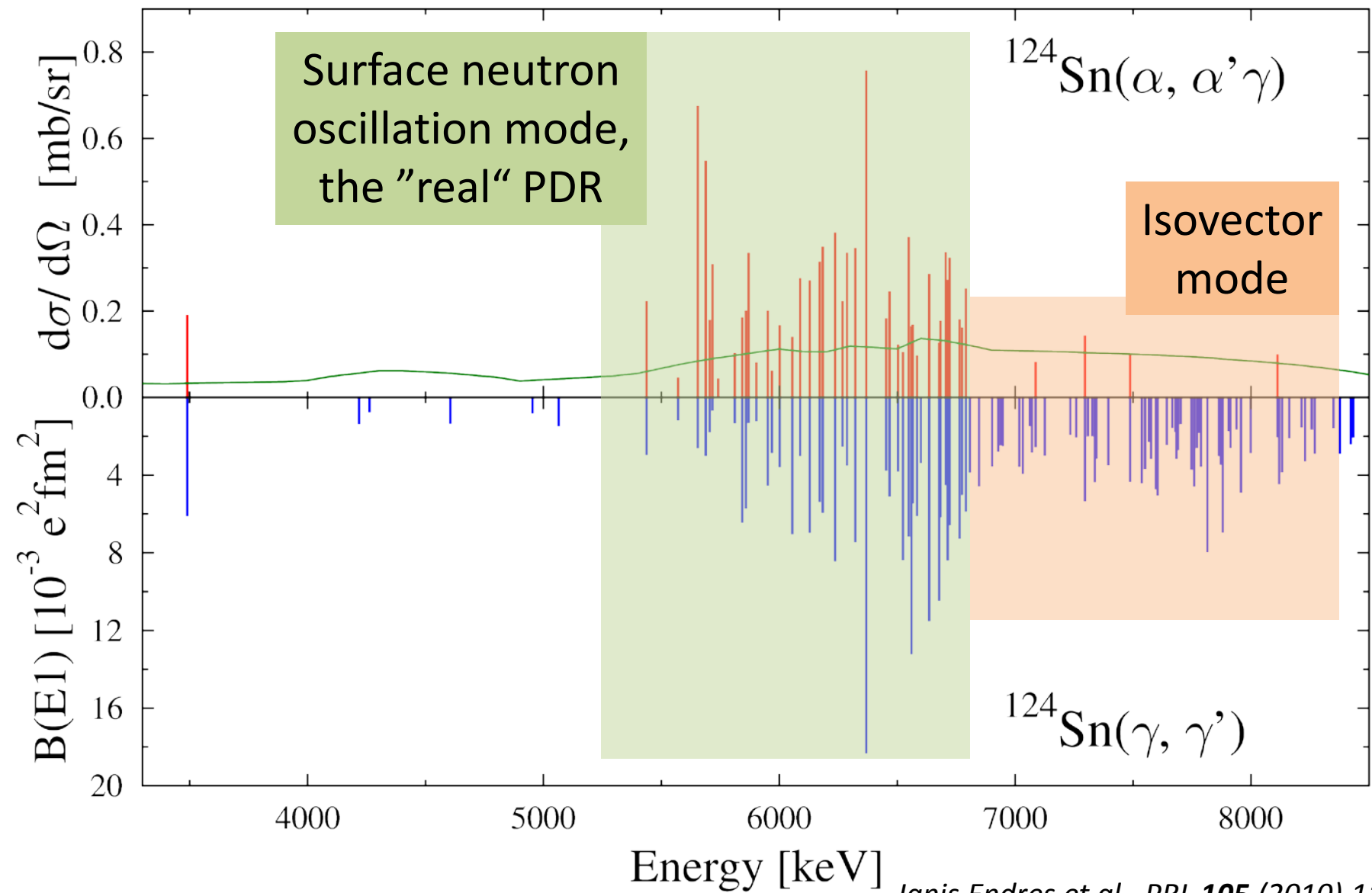
GDR
region



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

*similar results in RQTBA: E.G. Lanza et al., PRC **89** (2014) 041601*

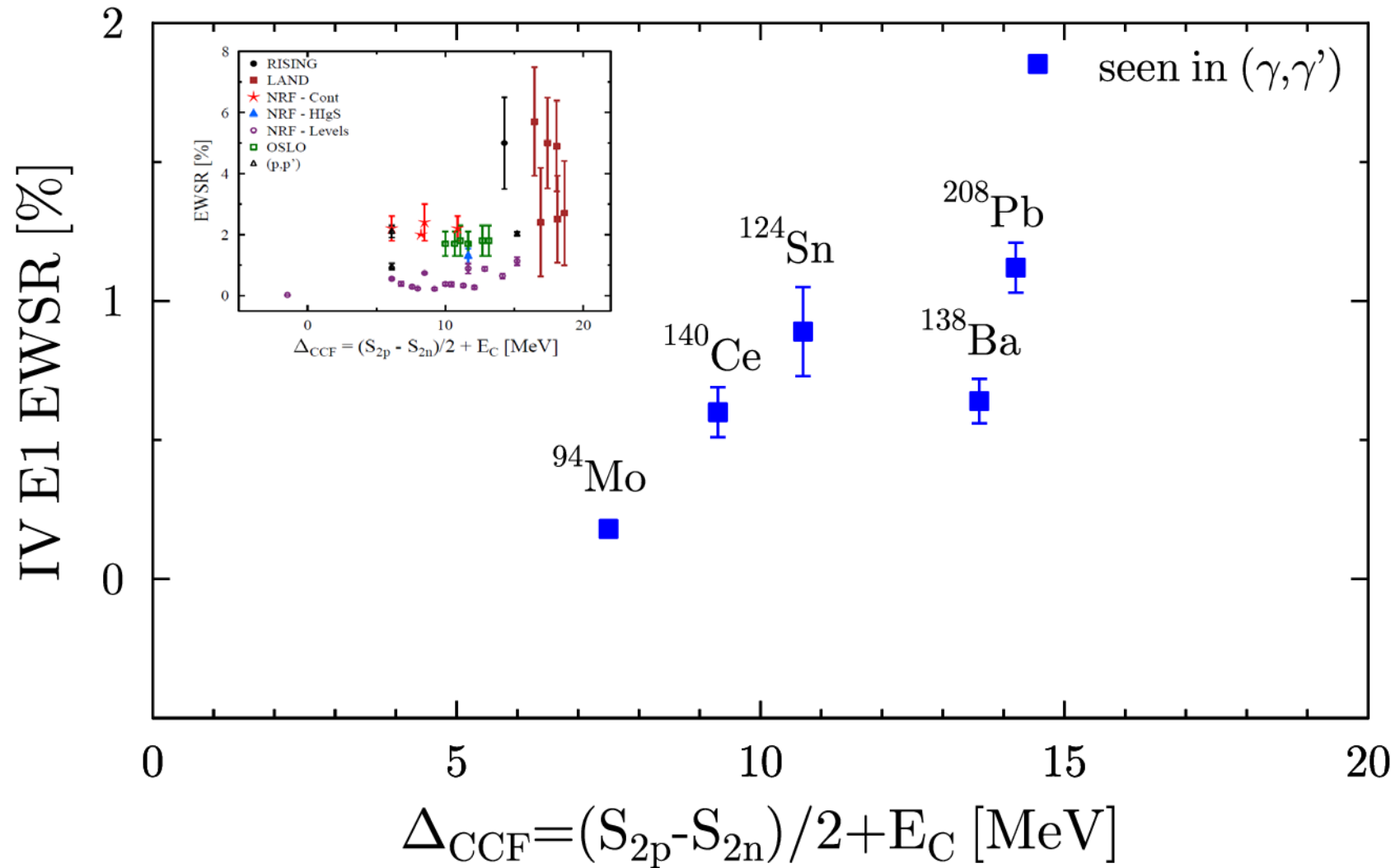
Splitting of the PDR: Interpretation from RQTBA



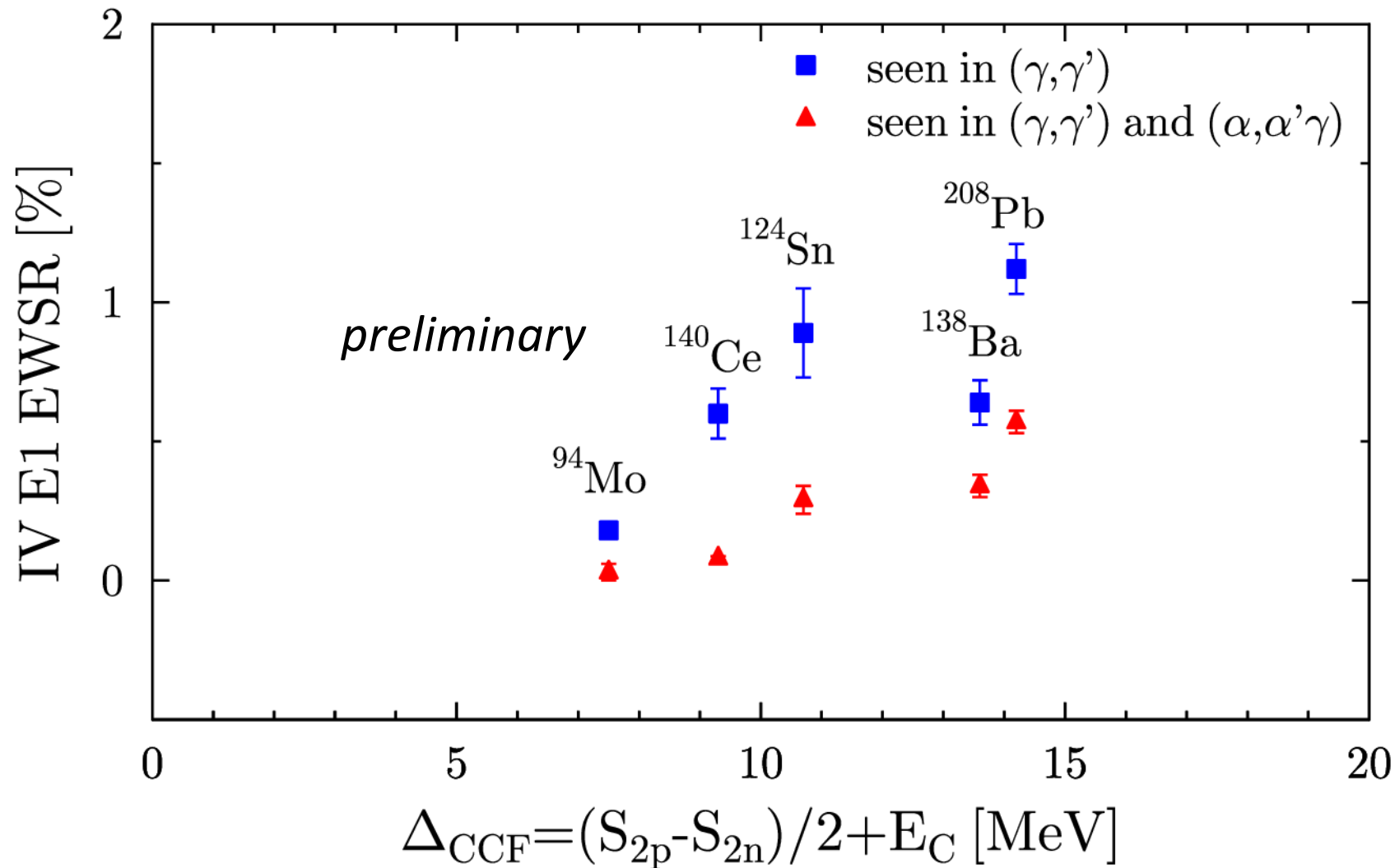
Janis Endres et al., PRL **105** (2010) 112503

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

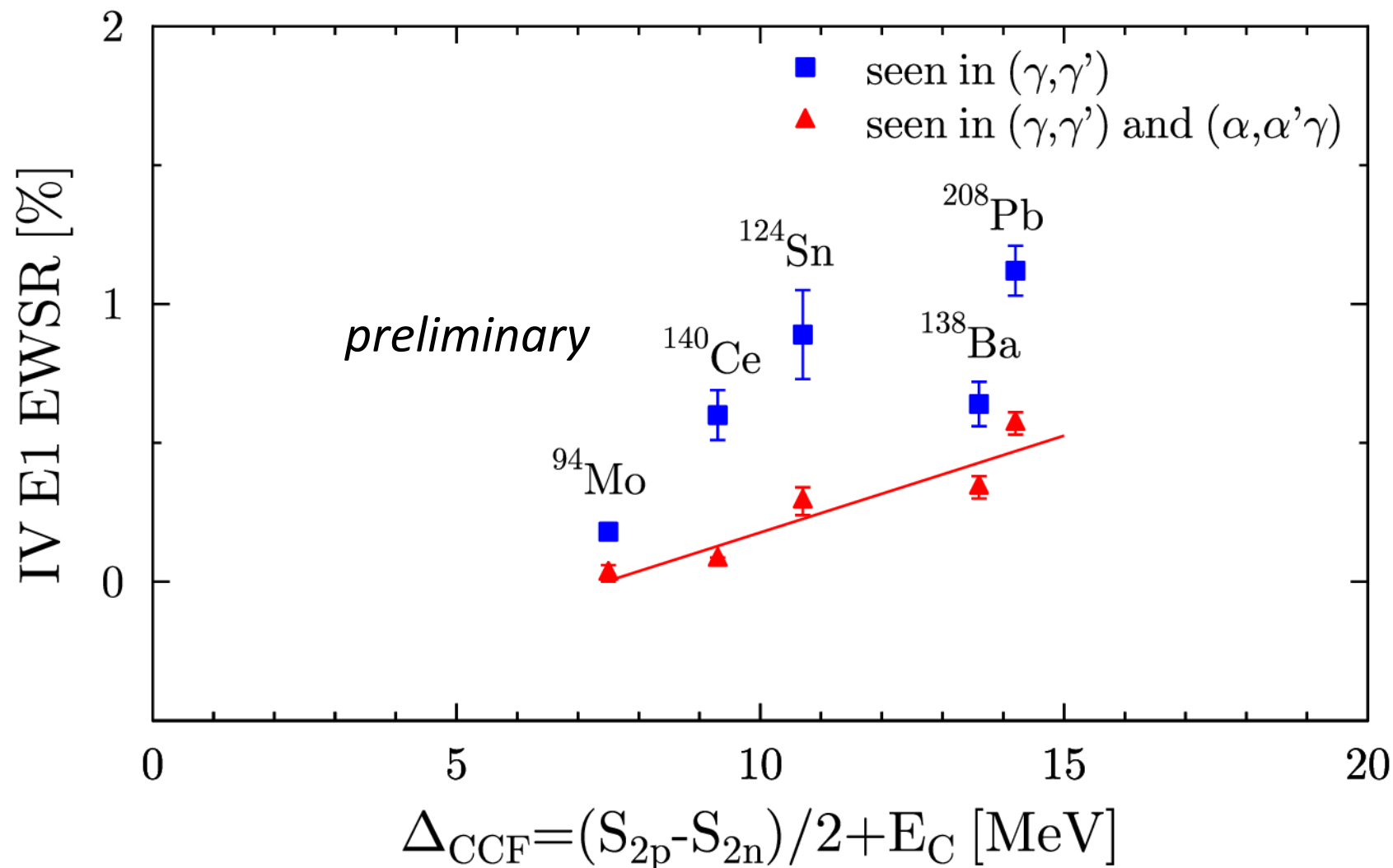
Summed E1 strength derived from EM excitation



Summed E1 strength derived from (α,α')



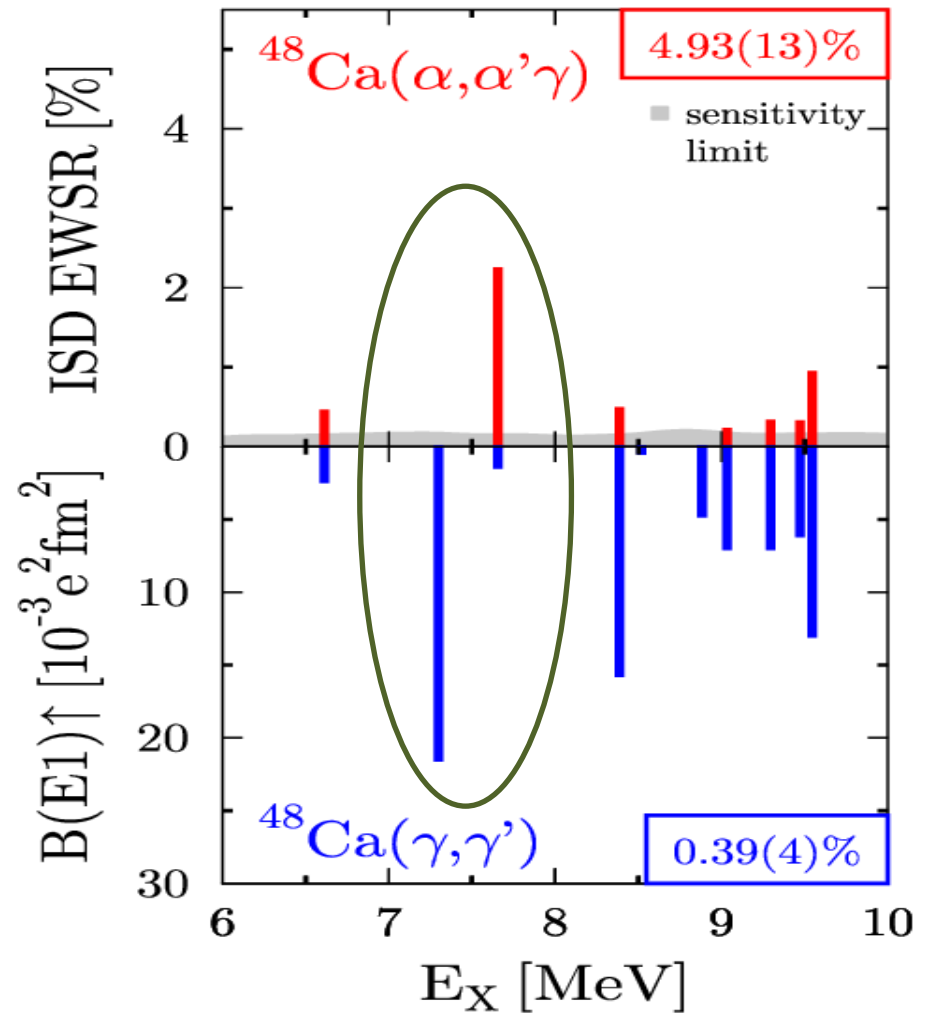
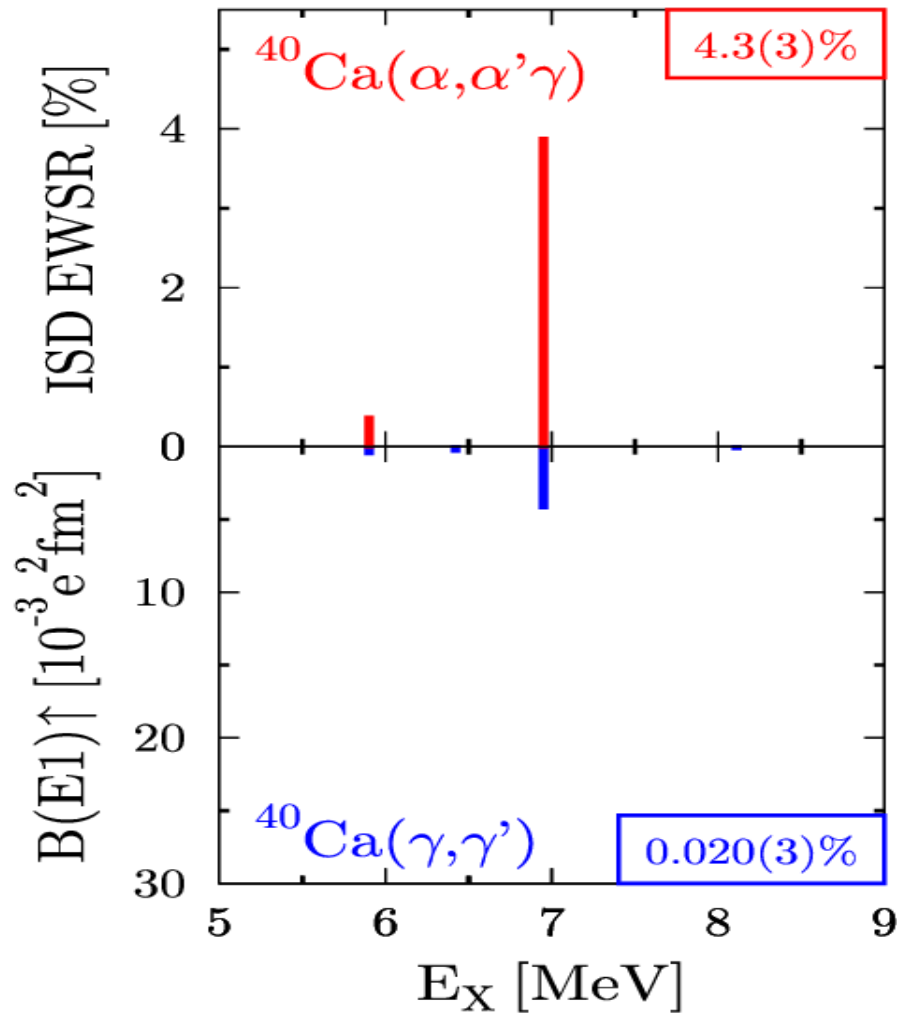
Summed E1 strength derived from (α, α')



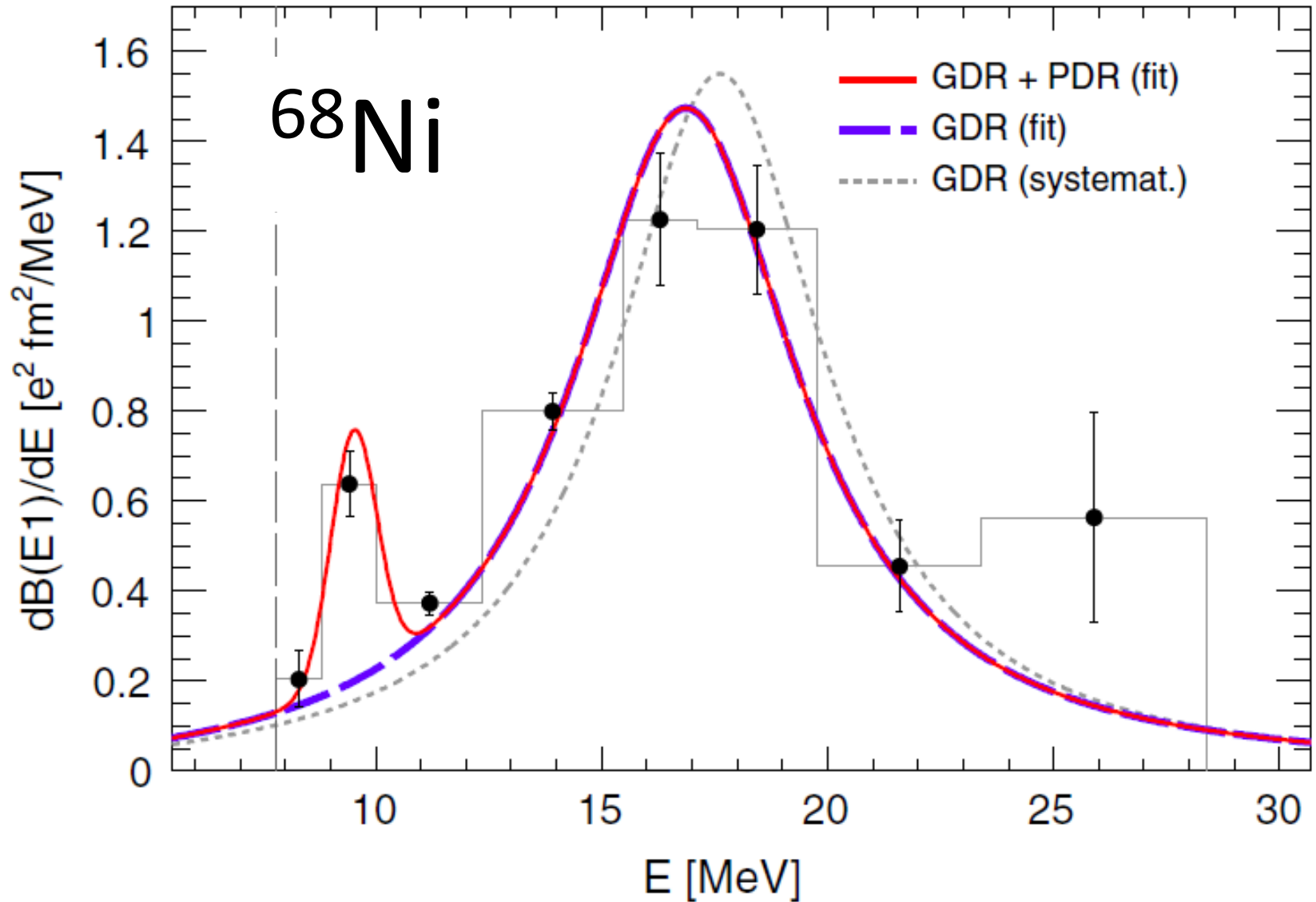
From presence to future: Open questions

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

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



E1 strength in ^{68}Ni measured @ R³B-LAND

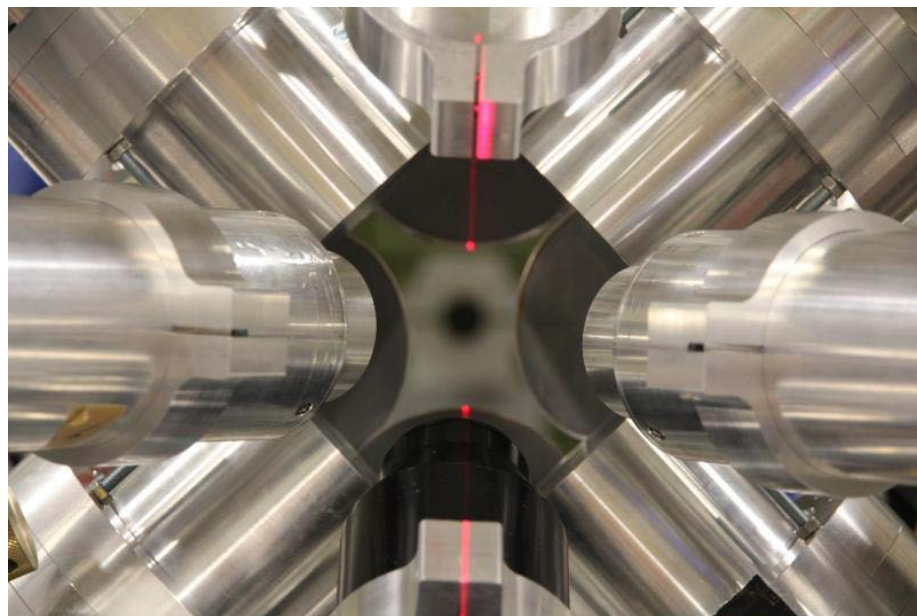


From presence to future: Open questions

- **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*

A new photon facility in Europe: ELI-NP @ Bucharest

A photon beam from laser Compton backscattering with:

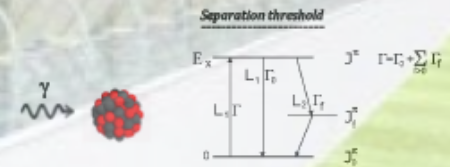
- very high intensity (10^4 photons/(s·eV))
- narrow bandwidth (down to 0.5%)
- high degree of polarization (> 99%)
- small beam diameter (mm range)



Nuclear Resonance Fluorescence
Experiments
at ELI-NP

Technical Design Report

START in 2017!



Edited by

Andreas Zilges
Calin Alexandru Ur

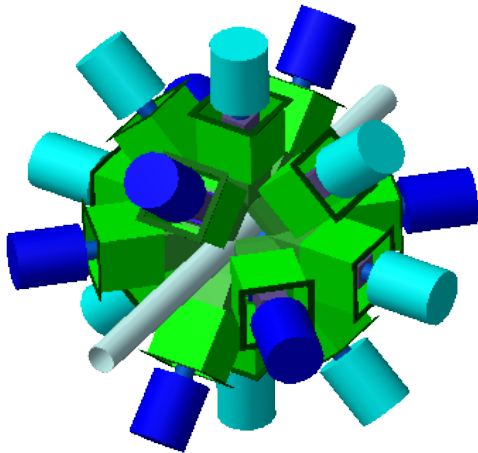
From presence to future: Open questions

- 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

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

CAGRA



GRAND RAIDEN

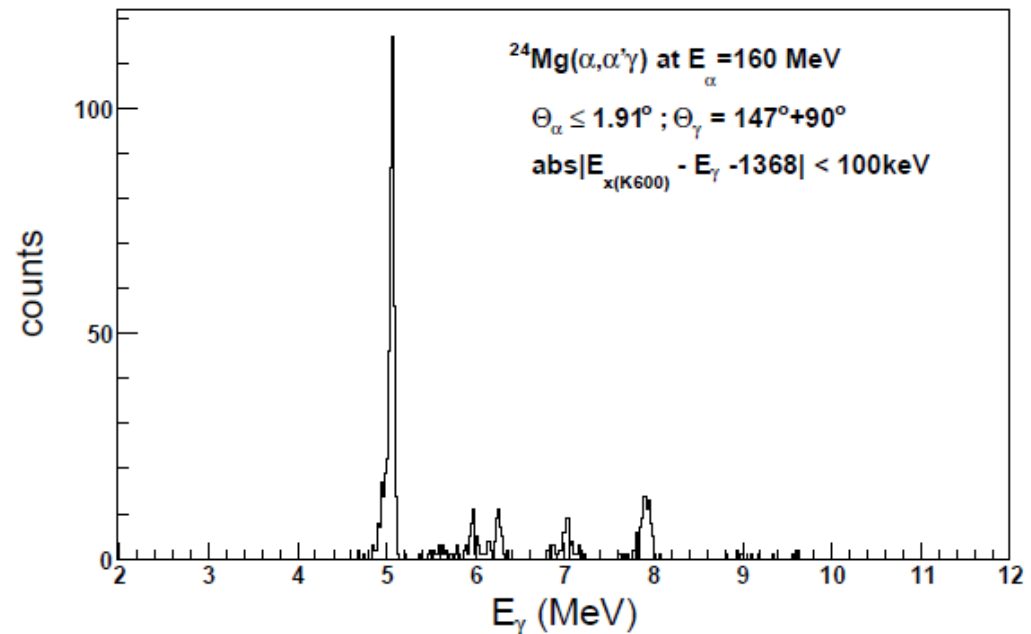


Collaboration: Osaka – Cologne - Darmstadt - Milano

Isospin structure of the PDR in stable nuclei: The K600 collaboration @ iThemba LABS



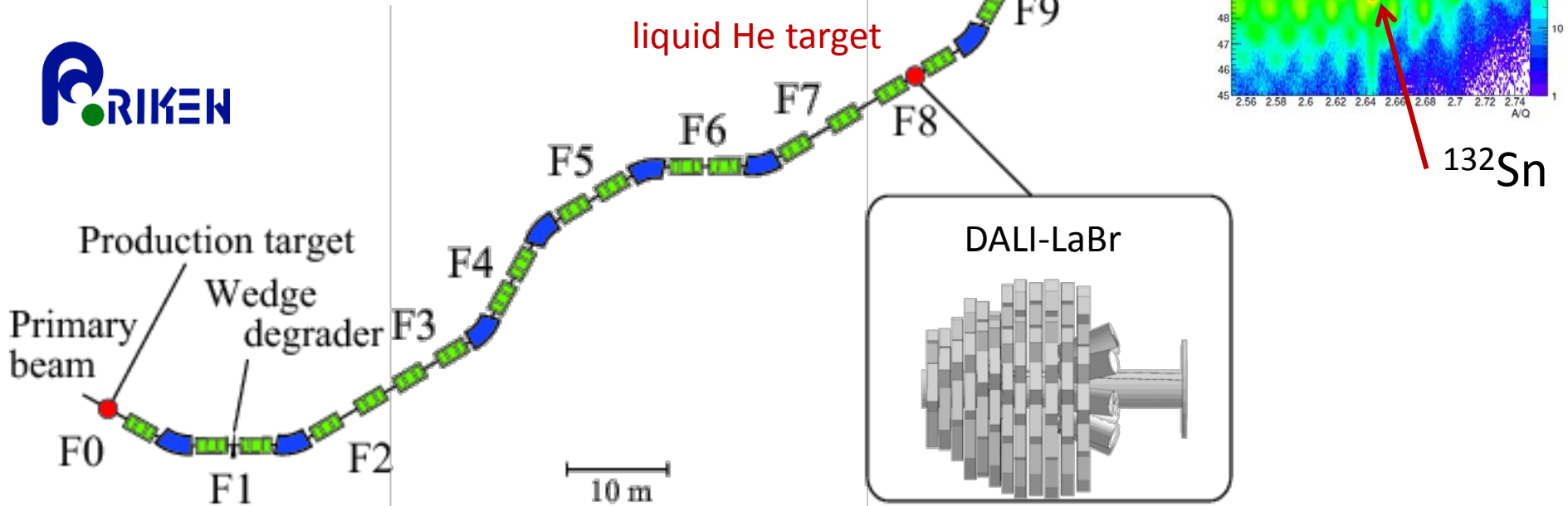
$(\alpha, \alpha'\gamma)$ @ $E_\alpha = 120$ MeV
combining K600 with eight
Ge(HP) from AFRODITE array



Collaboration: Cape Town – Cologne - Darmstadt – Milano – Osaka – Notre Dame

Isospin structure of the PDR in unstable nuclei: The DALI-LaBr-RIBF campaign @RIKEN

Shoot radioactive (or stable)
ion beam on liquid Helium target
→ detect scattered beam and γ rays



Collaboration: RIKEN – Cologne – Darmstadt – Huelva – Milano – Tokyo

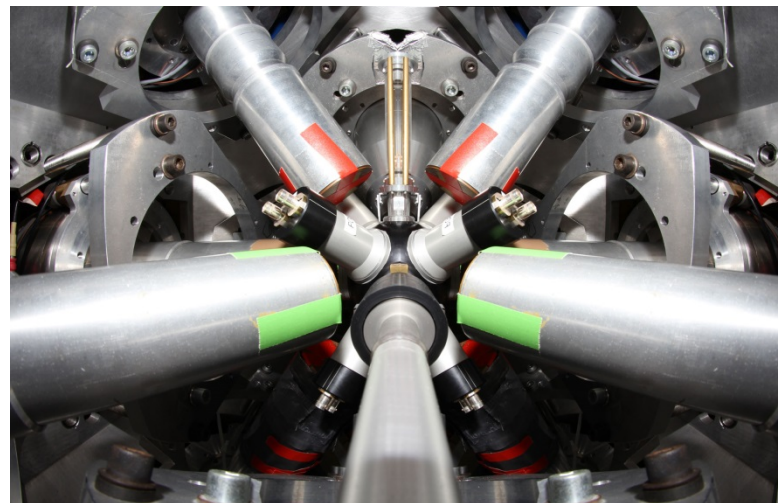
From presence to future: Open questions

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

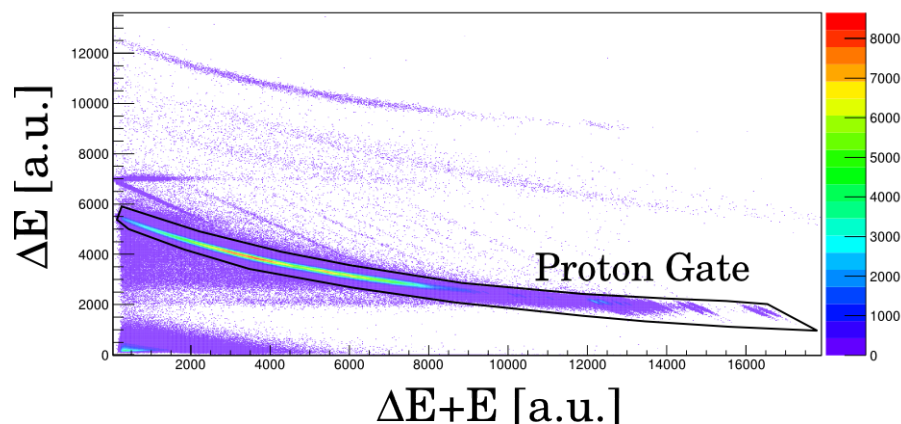
Single-particle structure of the PDR

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

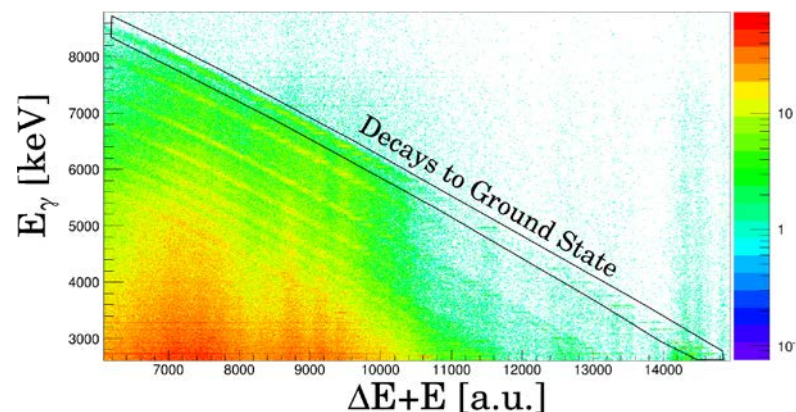
- Selective to neutron particle-hole configurations, e.g., $(p_{3/2})(s_{1/2})^{-1}$
- Clean selection of reaction channel
- Choose certain decays by p- γ coincidence



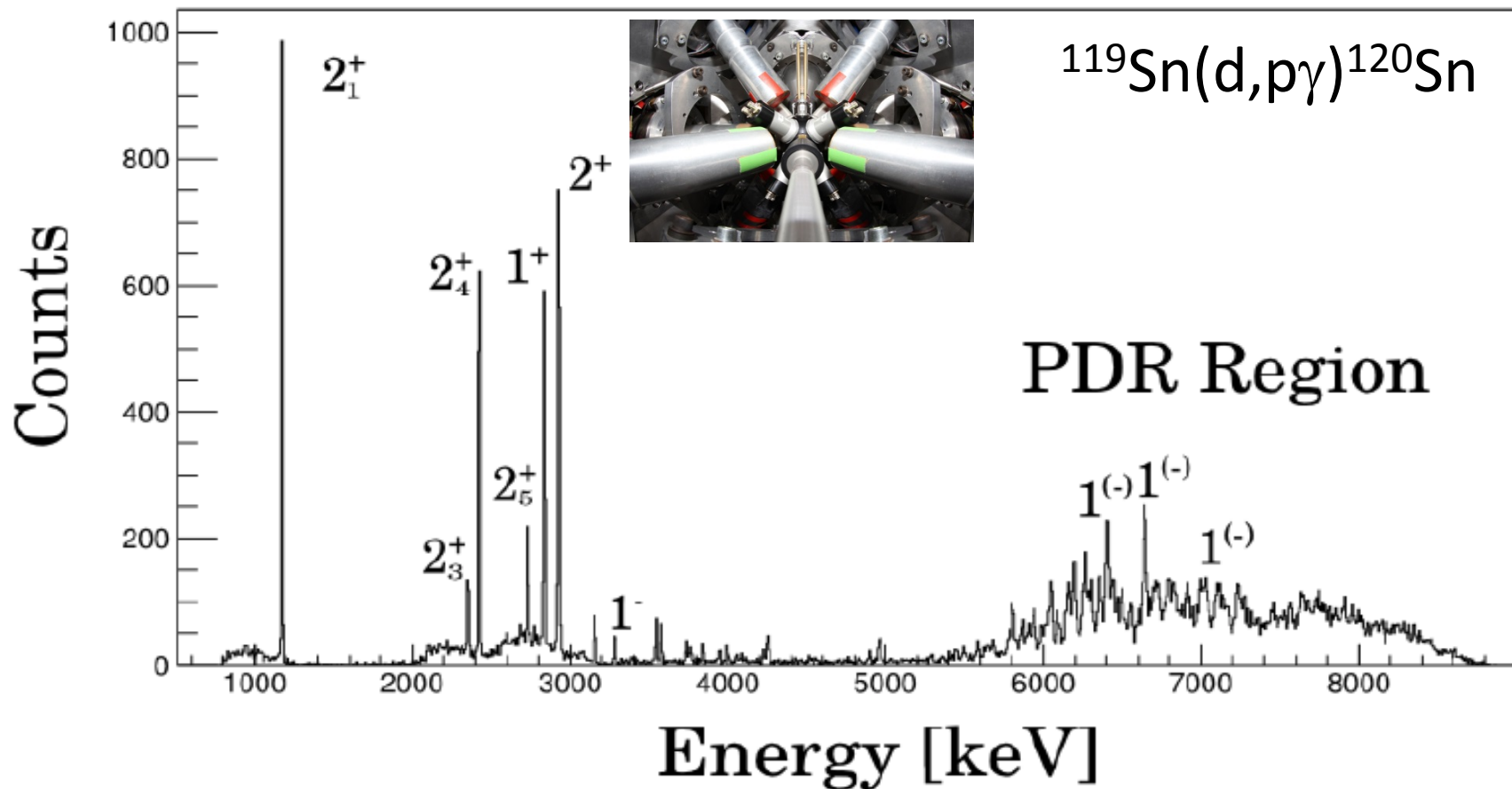
Particle Identification



Decay-Channel Selection



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



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

→ talk by Simon Pickstone

Electric Dipole Strength below the Particle Threshold – Status and Perspectives



V. Derya, A. Hennig, J. Mayer, L. Netterdon,
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

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