The Pygmy Dipole Resonance in atomic nuclei

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EMMI Physics Days
- 2010 -

FIAS Frankfurt Institute for Advanced Studies

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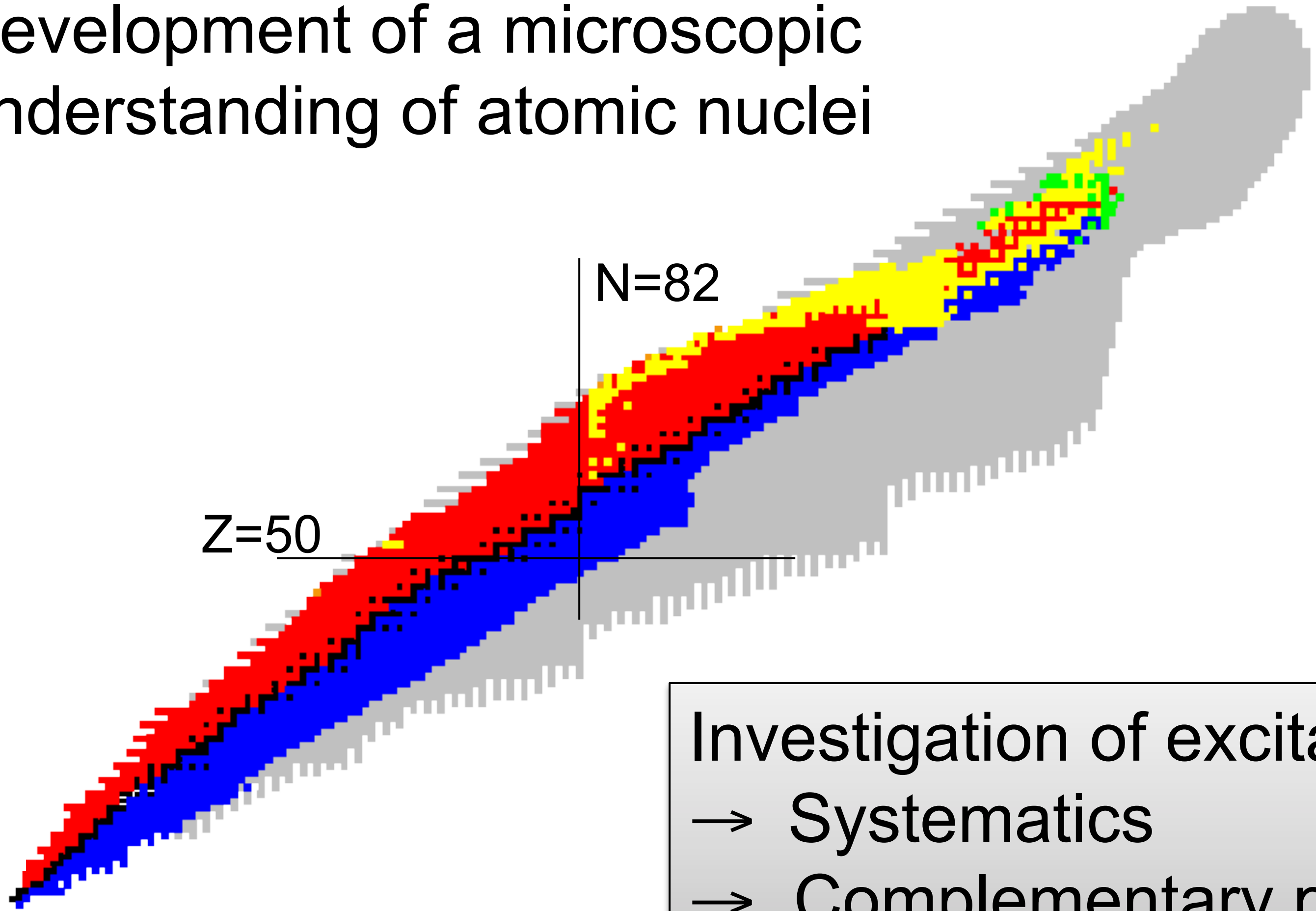
- Experimental approaches
- Real and virtual Photon scattering
- Hadron scattering
- Summary

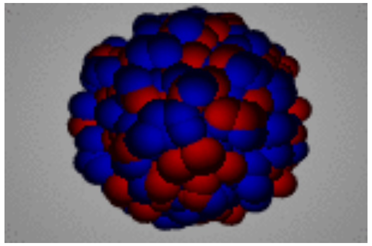
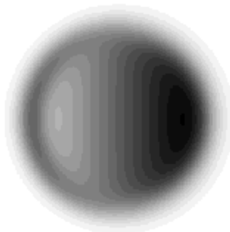
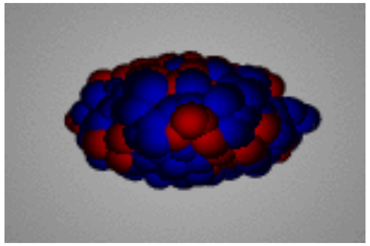
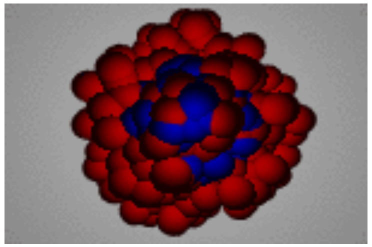
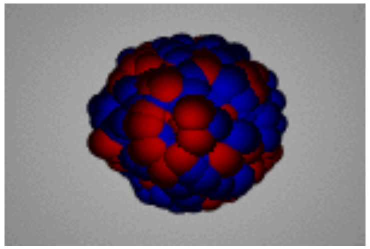
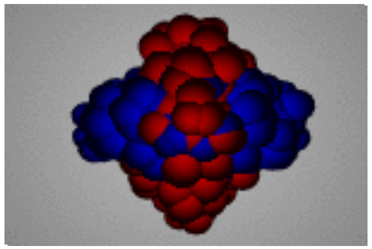
Nuclear Structure

Development of a microscopic understanding of atomic nuclei

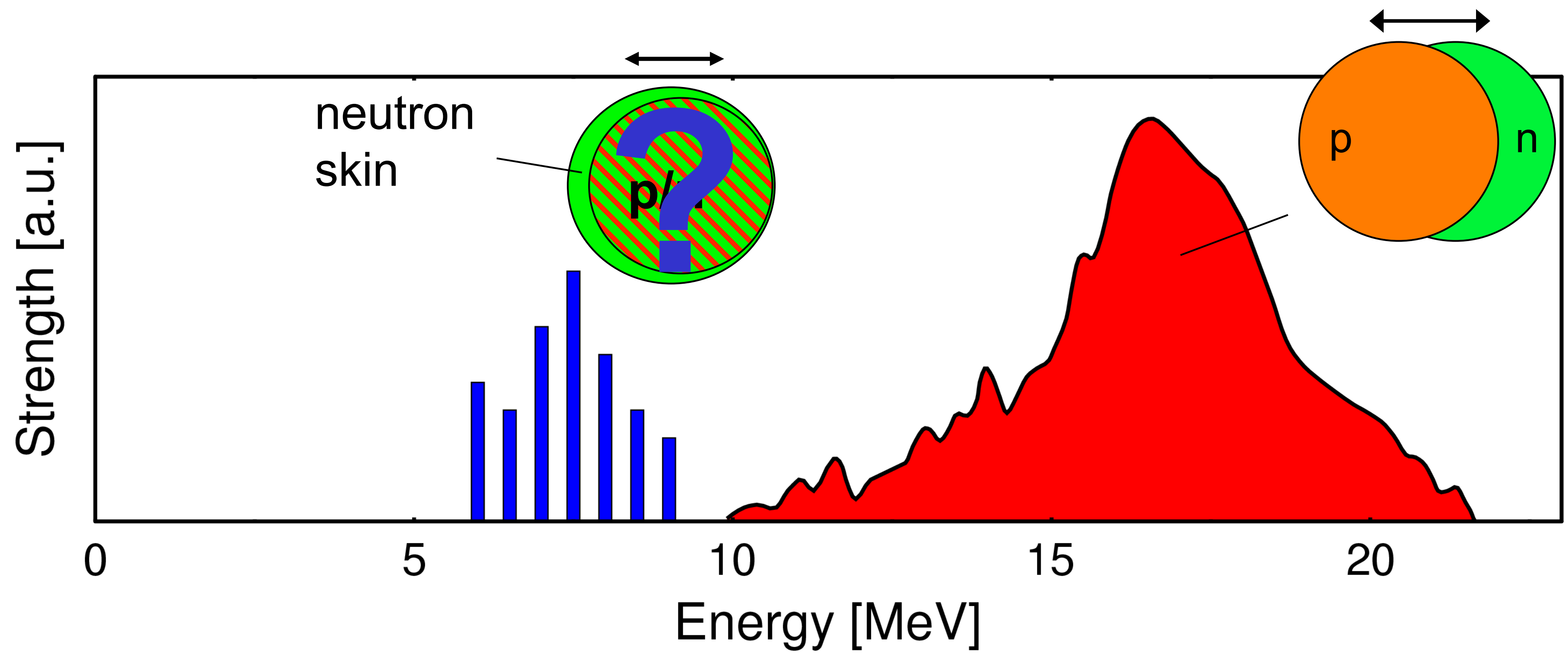


Investigation of excitation modes
→ Systematics
→ Complementary probes

Collective excitations – Giant resonances

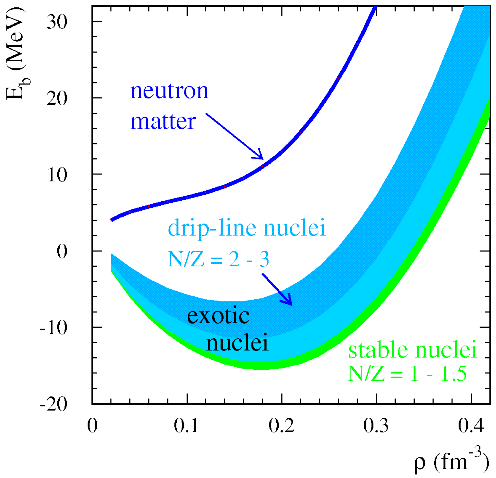
	Monopole (GMR)	Dipole (GDR)	Quadrupole (GQR)
Isoscalar			
Isovector			

E1 strength in (spherical) atomic nuclei



- Giant Dipole Resonance (GDR)
- Pygmy Dipole Resonance (PDR)

Neutron matter and neutron skin

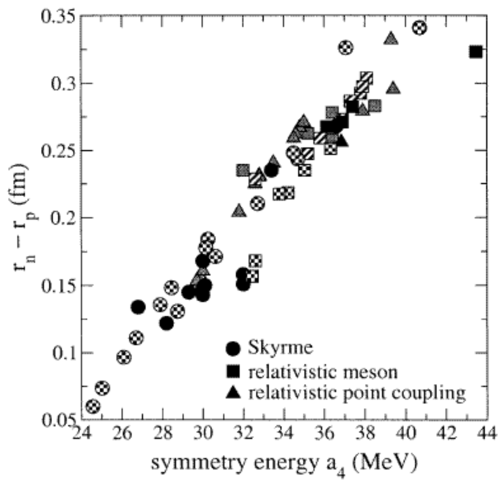


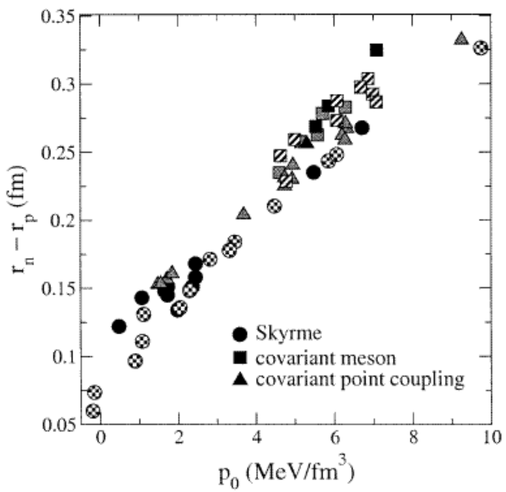
$$E(\rho,\alpha) = E(\rho,0) + S_2(\rho)\alpha^2 + O(\alpha^4)\,,\ \alpha = \frac{N-Z}{A}$$

$$S_2(\rho) = \frac{1}{2}\frac{\partial^2 E(\rho,\alpha)}{\partial\alpha^2}\bigg|_{\alpha=0} =$$

$$= a_4 + \frac{p_0}{\rho_0^2}(\rho-\rho_0) + \frac{\Delta K_0}{18\rho_0^2}(\rho-\rho_0)^2 + \ldots$$

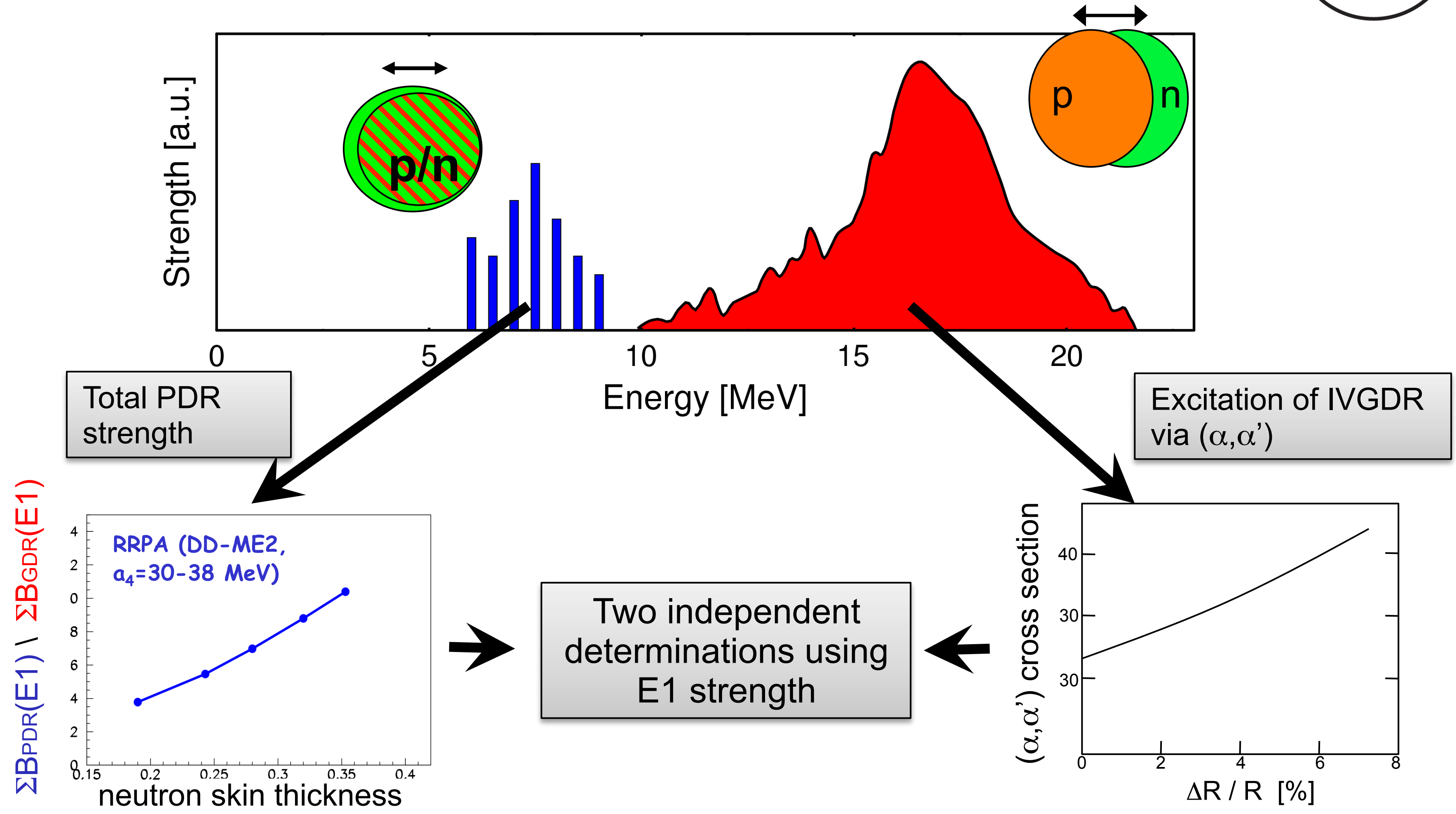
Determination of neutron skin thickness allows to access parameters





R.J.Furnstahl NPA 706 (2002) 85-110

E1 strength and neutron skin thickness

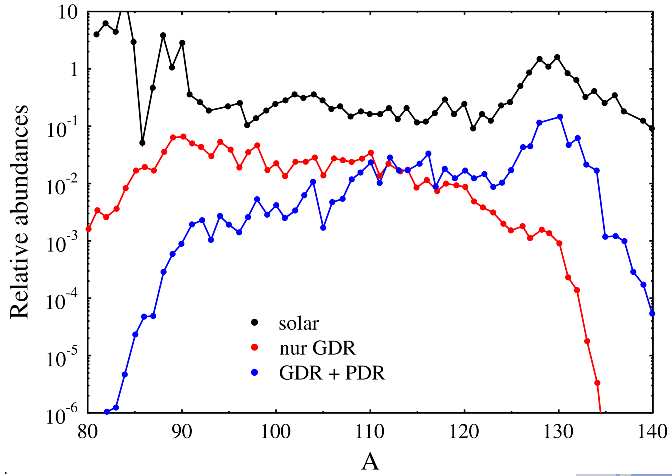


N. Paar et al.

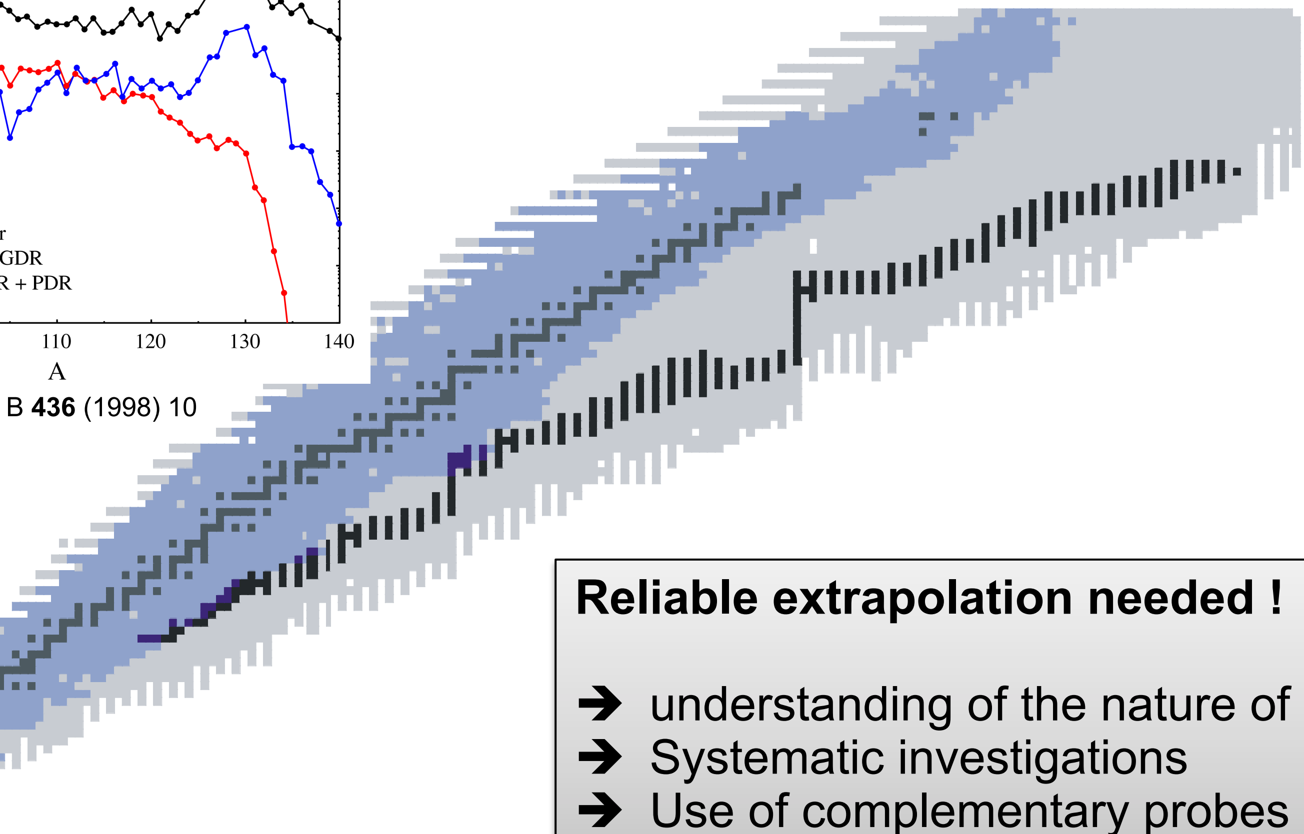
A. Krasznahorkay et al., PRL 66 (1991) 1287

PDR and nuclear astrophysics

Possible influence on (γ,n) und (n,γ) reaction rates in astrophysical scenarios



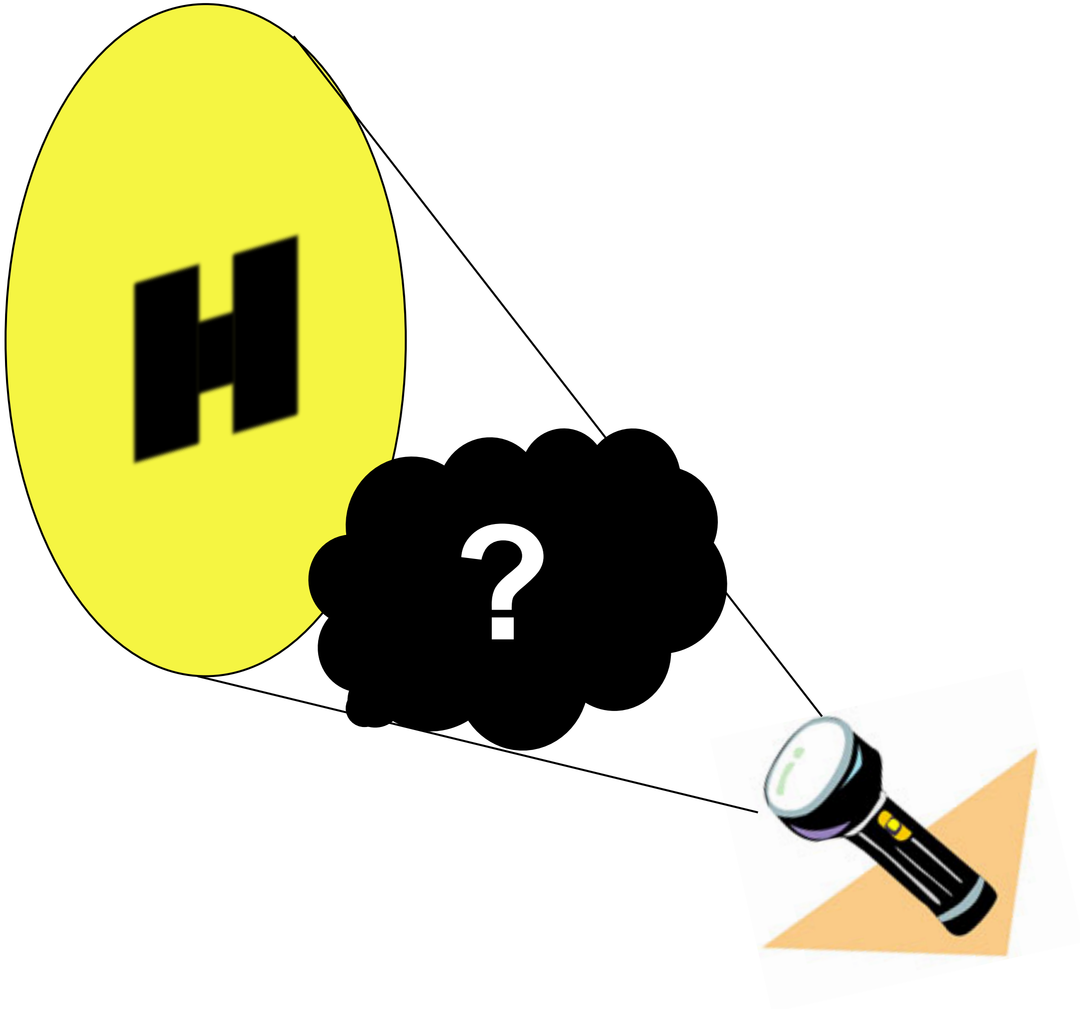
S. Goriely, Phys. Lett. B **436** (1998) 10



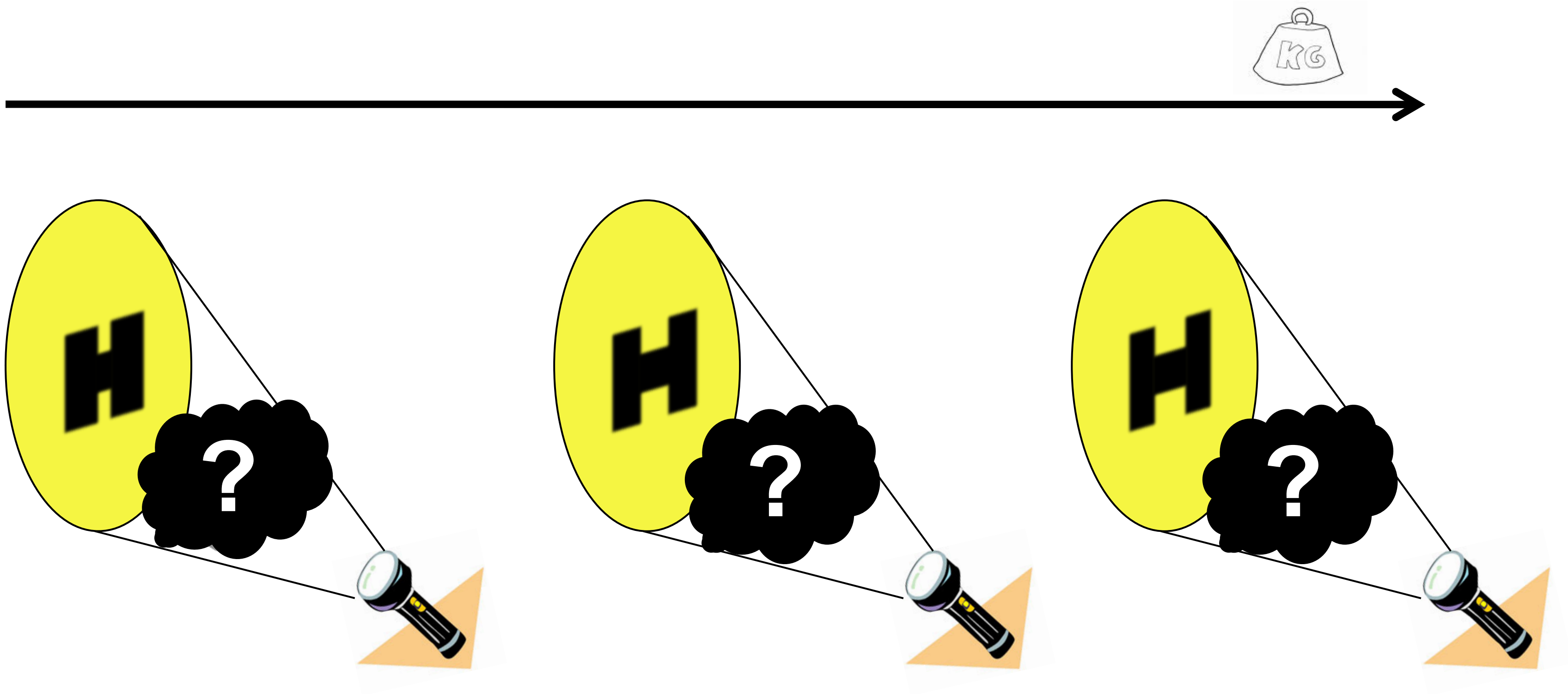
Reliable extrapolation needed !

➔ understanding of the nature of the PDR
➔ Systematic investigations
➔ Use of complementary probes

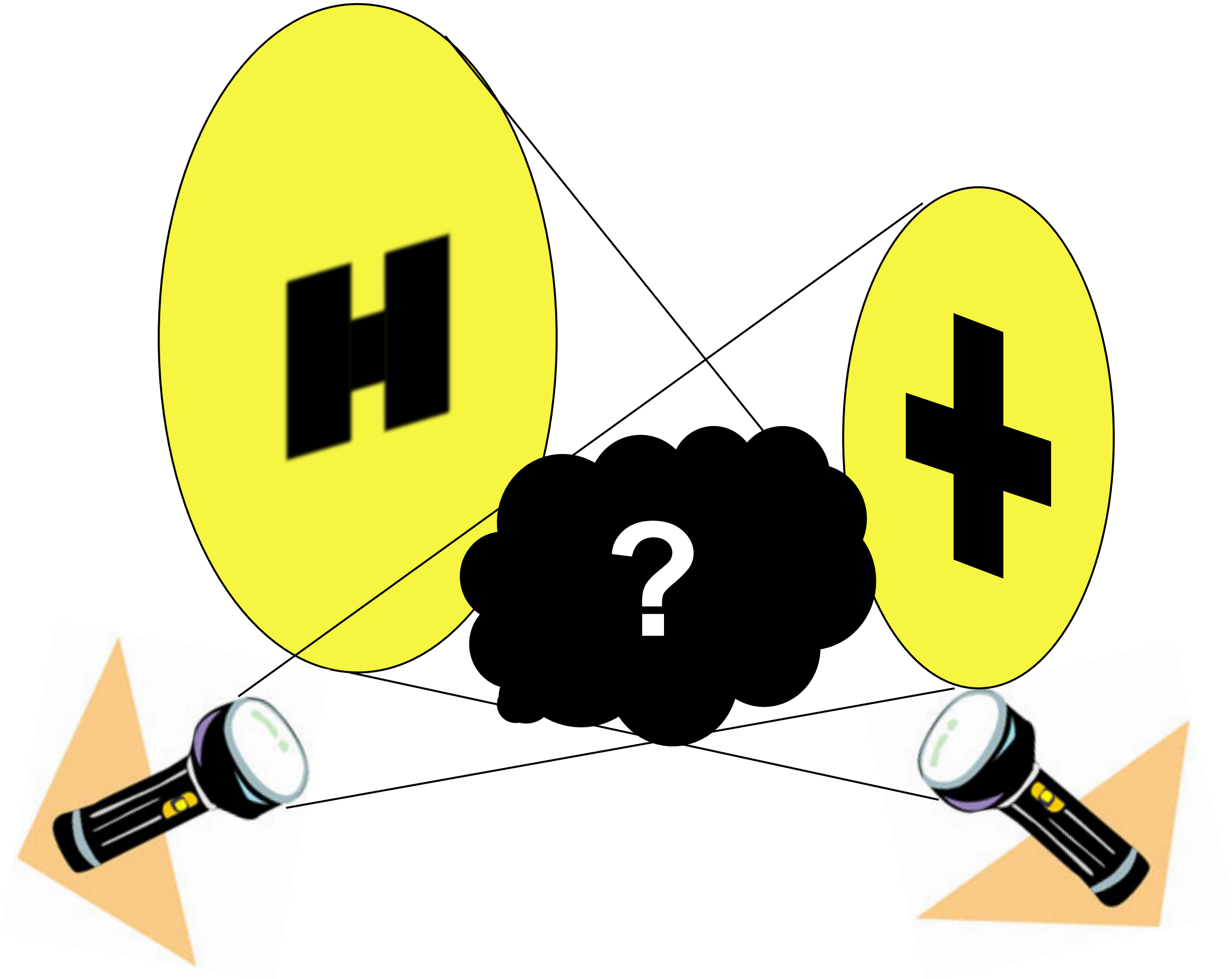
Experimental approaches



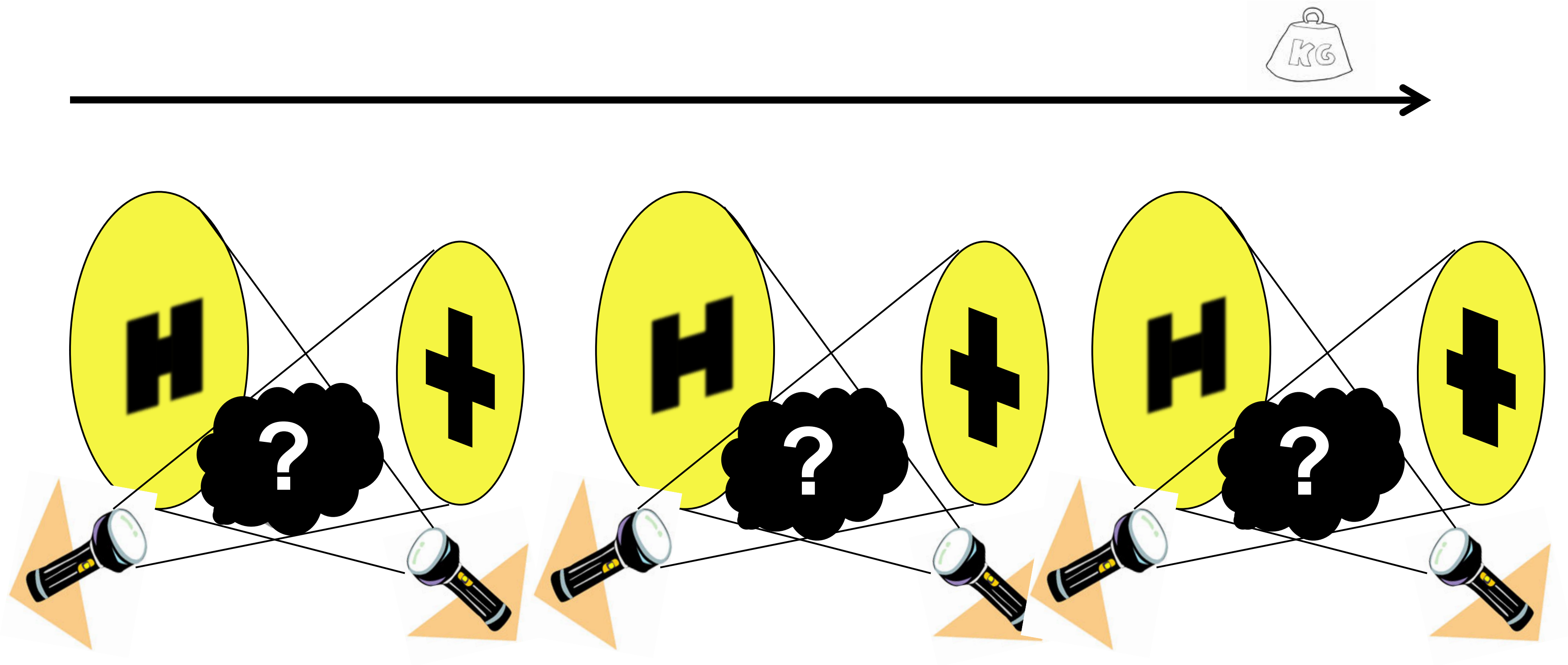
Experimental approaches - Systematics



Experimental approaches –complementary probes

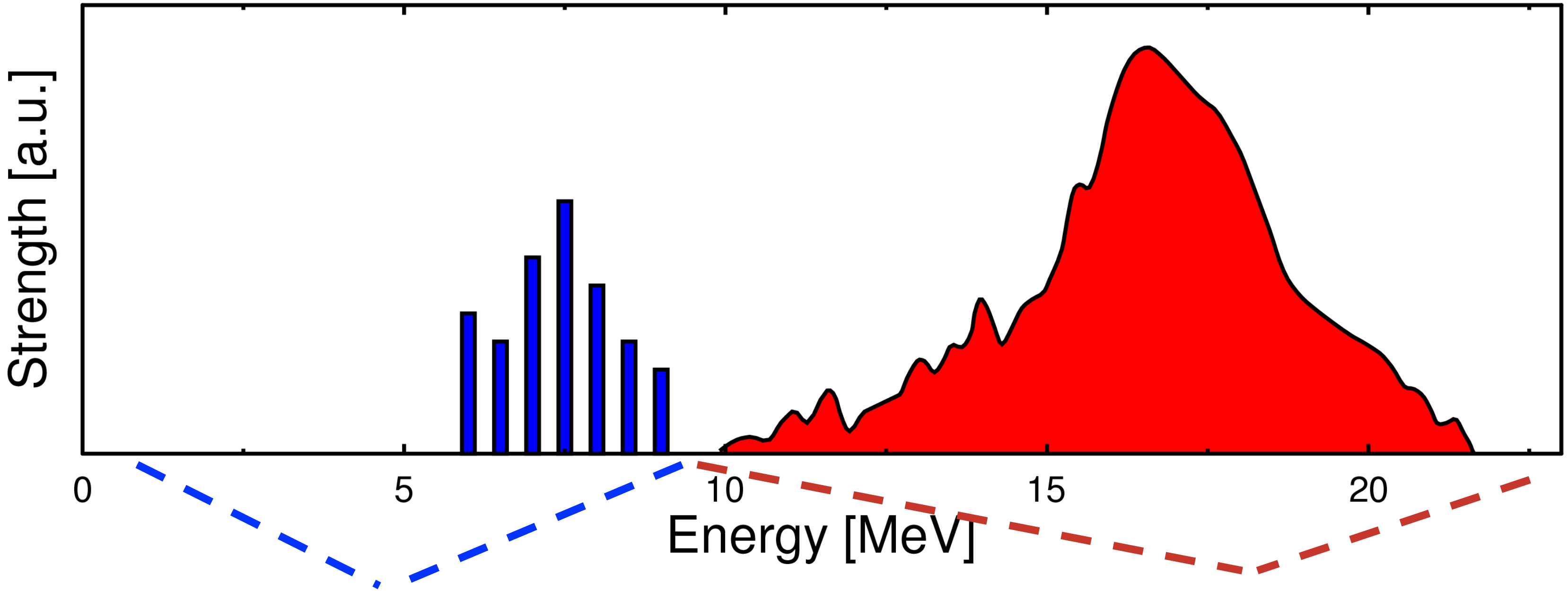


Experimental approaches –complementary probes



Experiments with real photons

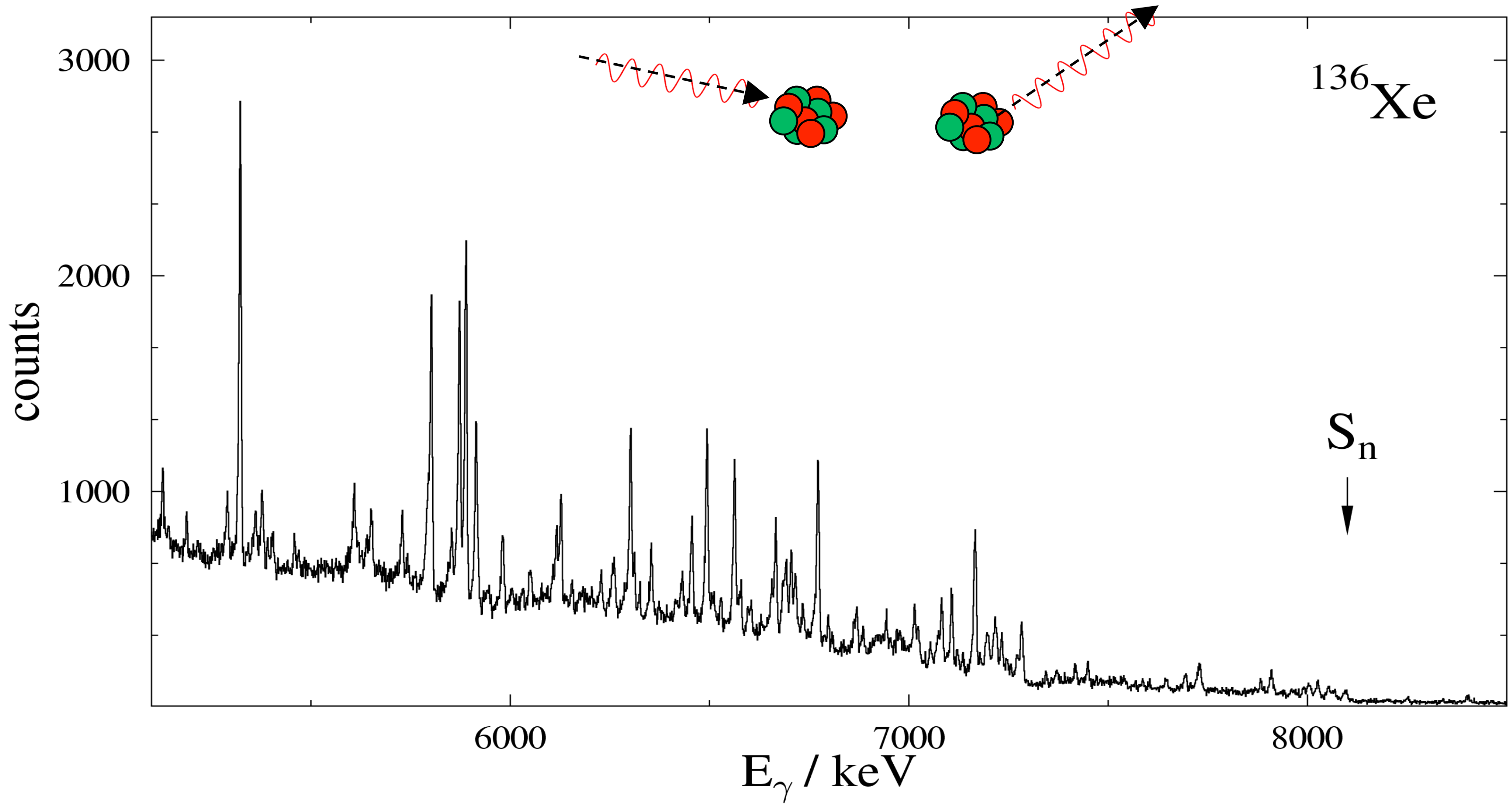
- High selectivity to dipole excitations
- Well-known excitation mechanism



Photon scattering (γ,γ‘)

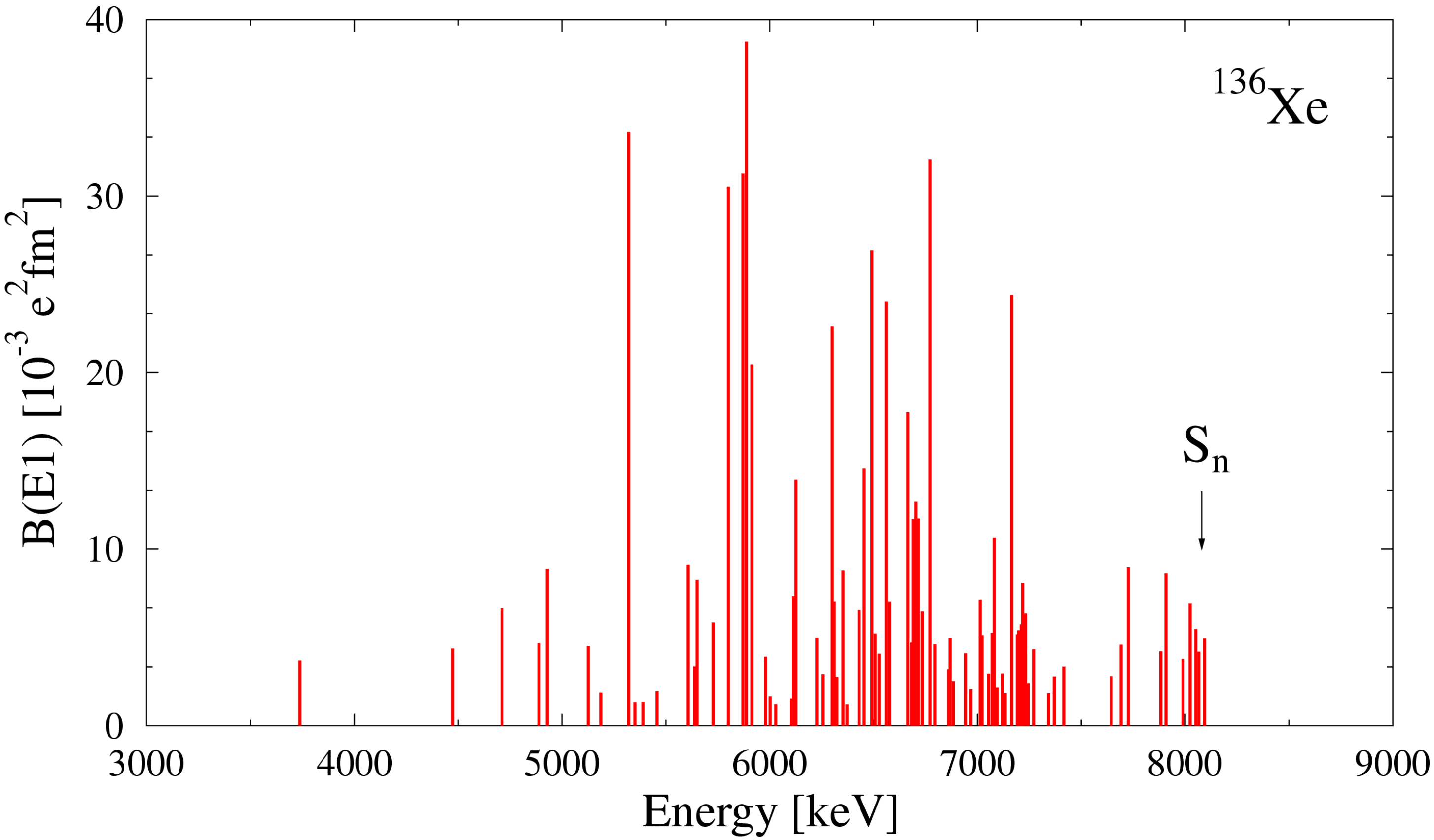
Photodissociation (γ,n), (γ,p), …

Example: $^{136}Xe(\gamma,\gamma')$



High energy resolution allows investigation of fine structure (fragmentation)

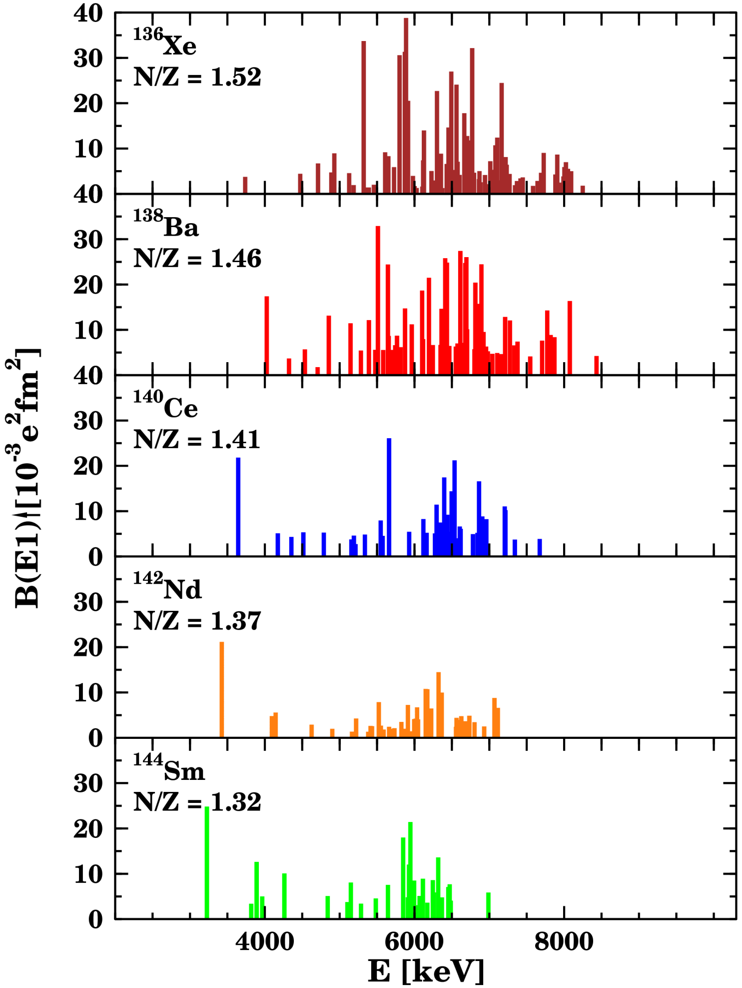
B(E1) strength distribution in ^{136}Xe



High energy resolution allows investigation of fine structure (fragmentation)

Systematics in stable N=82 isotones

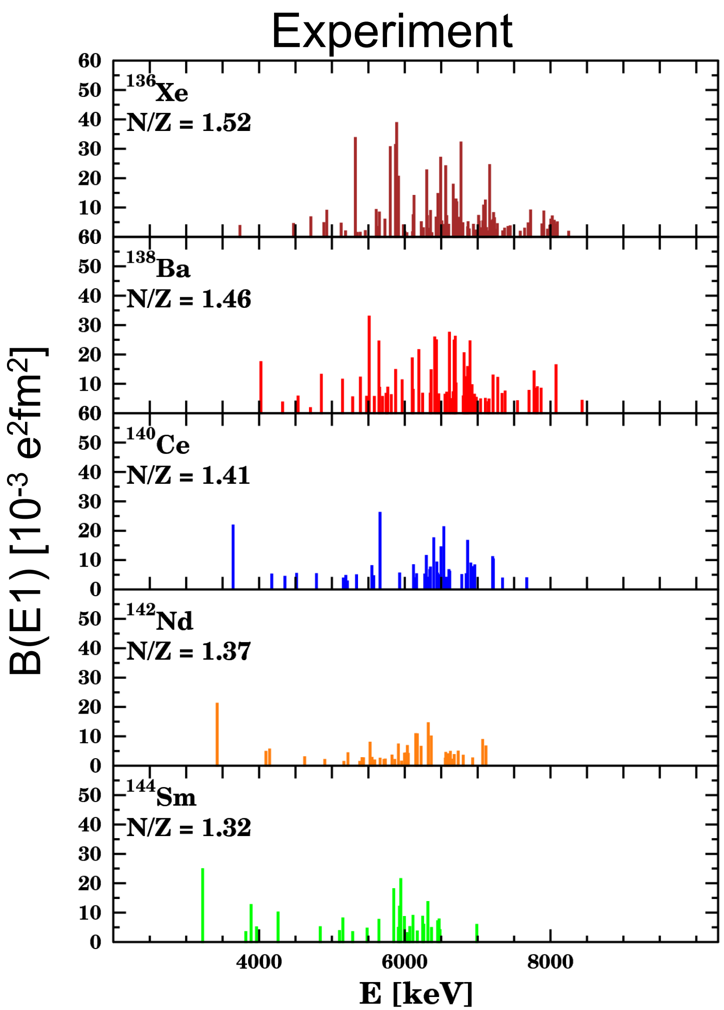
(γ,γ') @ S-DALINAC

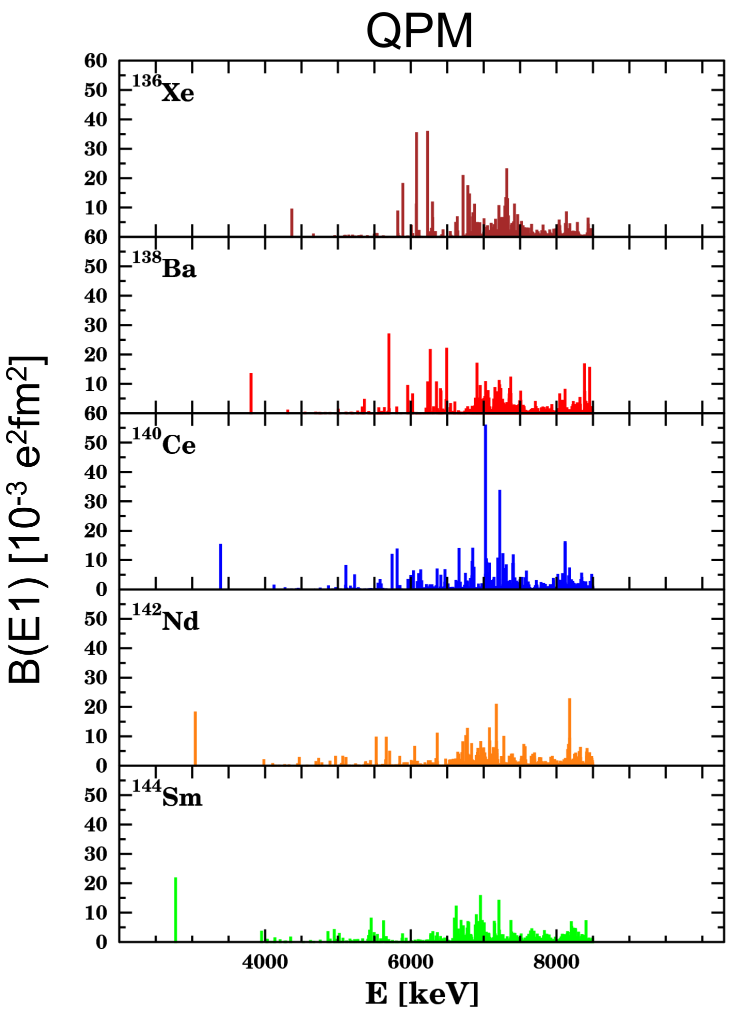


Compare to theory in
- fragmentation
- Integrated strength

A. Zilges et al., Phys. Lett. B **542** (2002) 43
S. Volz et al., Nucl. Phys. **A779** (2006) 1
D. Savran et al., PRL **100** (2008) 232501

E1 strength in stable N=82 isotones

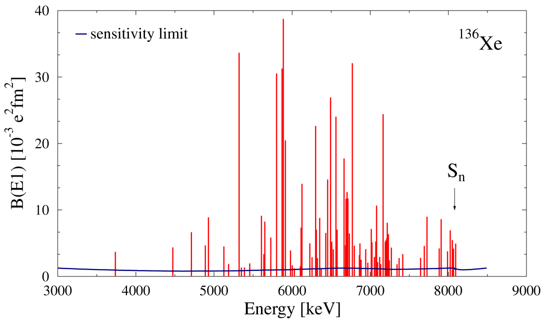


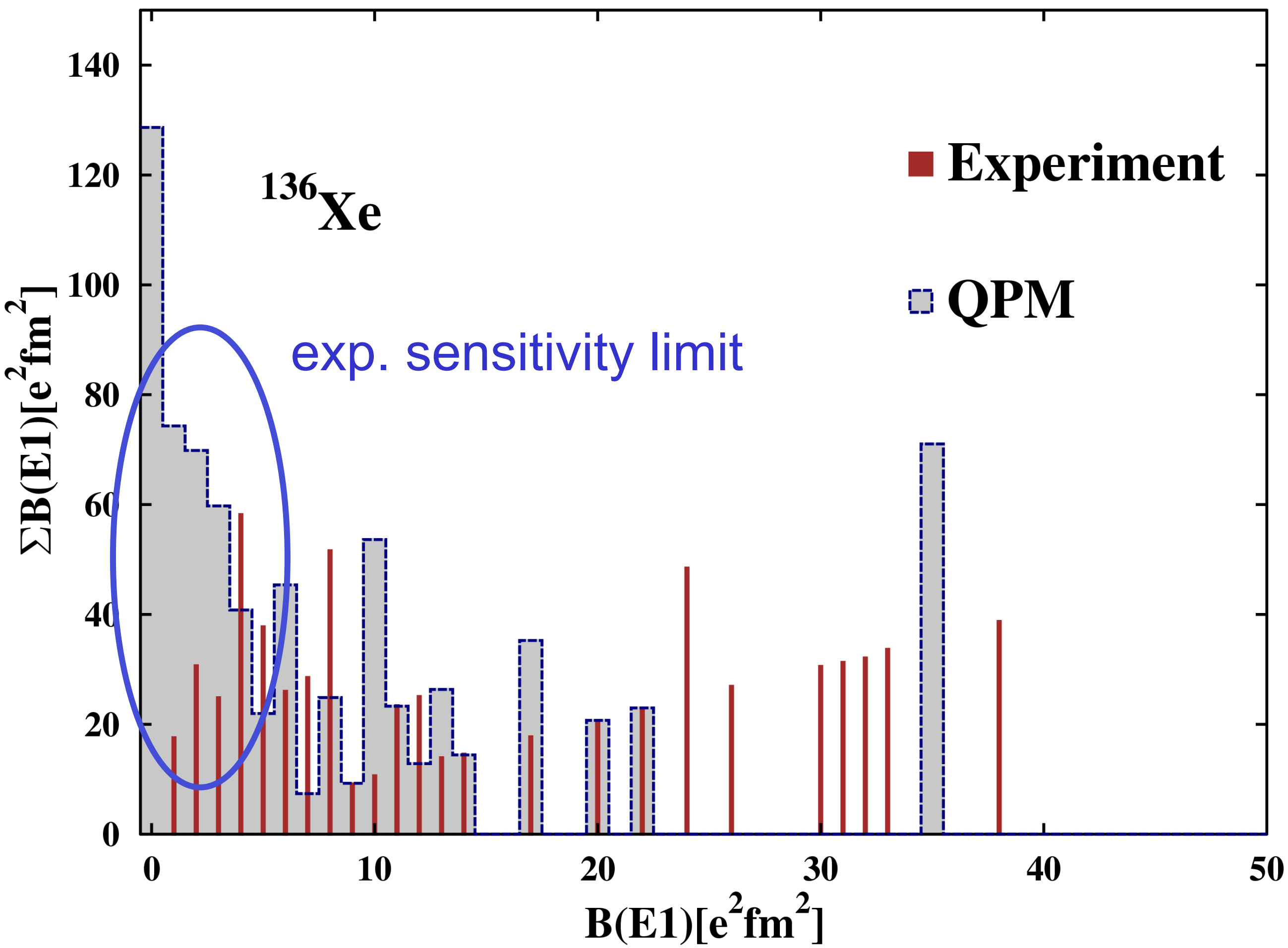


S. Volz et al., Nucl. Phys. **A779** (2006) 1

V. Yu. Ponomarev

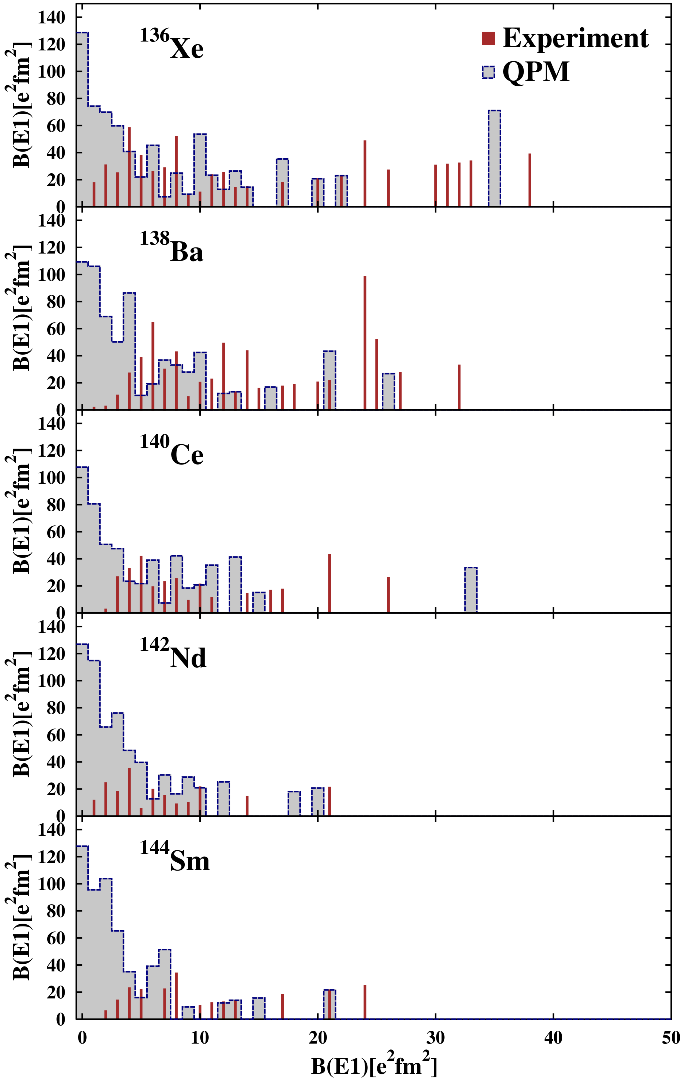
Fragmentation: Experiment vs. QPM





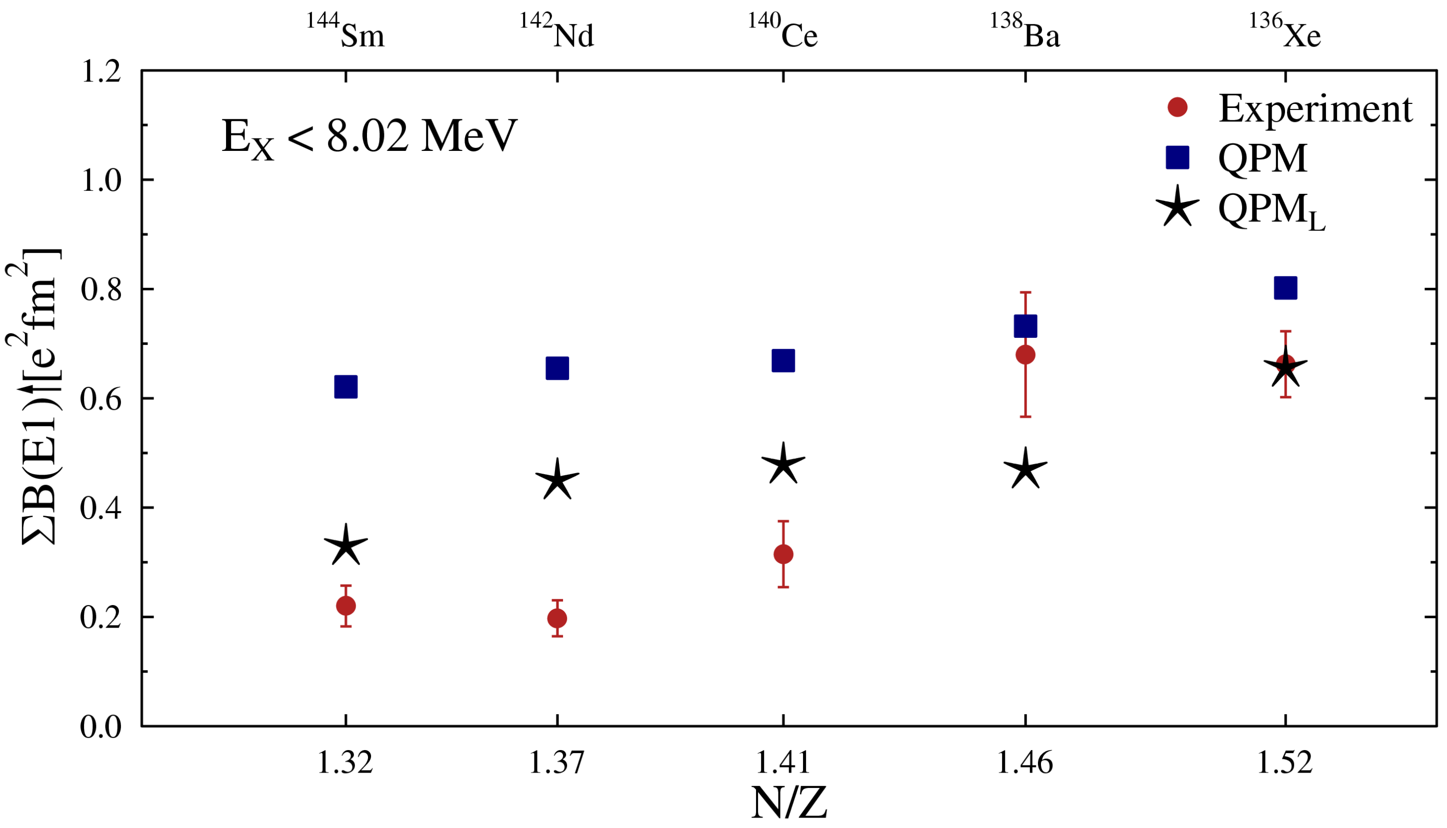
D. Savran et al., PRL **100** (2008) 232501

Fragmentation



- Good agreement of experiment and theory in isotonic chain
- Confidence in correct description of damping within the model

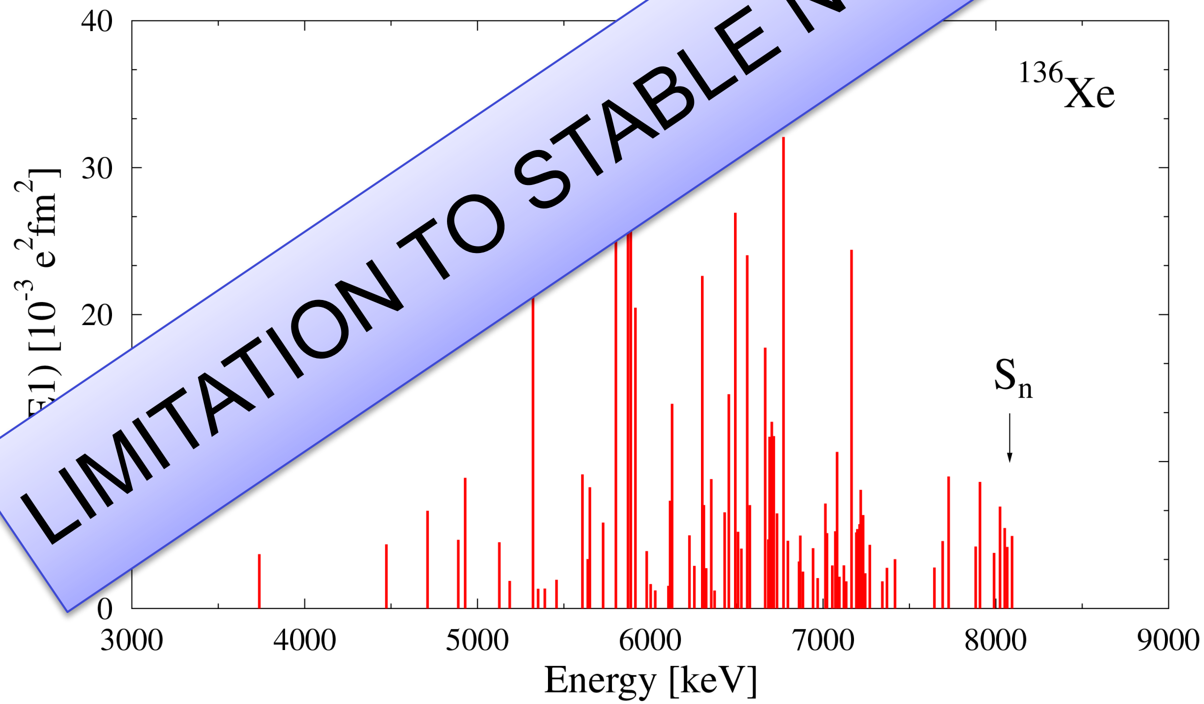
Integrated B(E1) strength



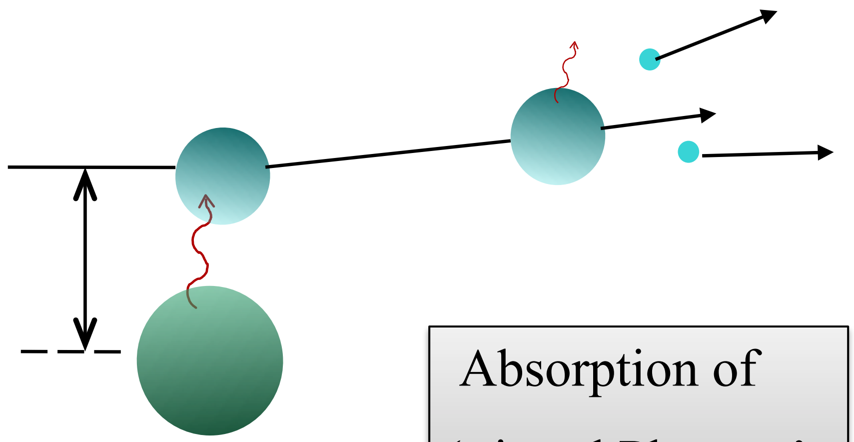
Experiments with ~~real~~ photons

- High selectivity to dipole excitations
- Well-known excitation mech n

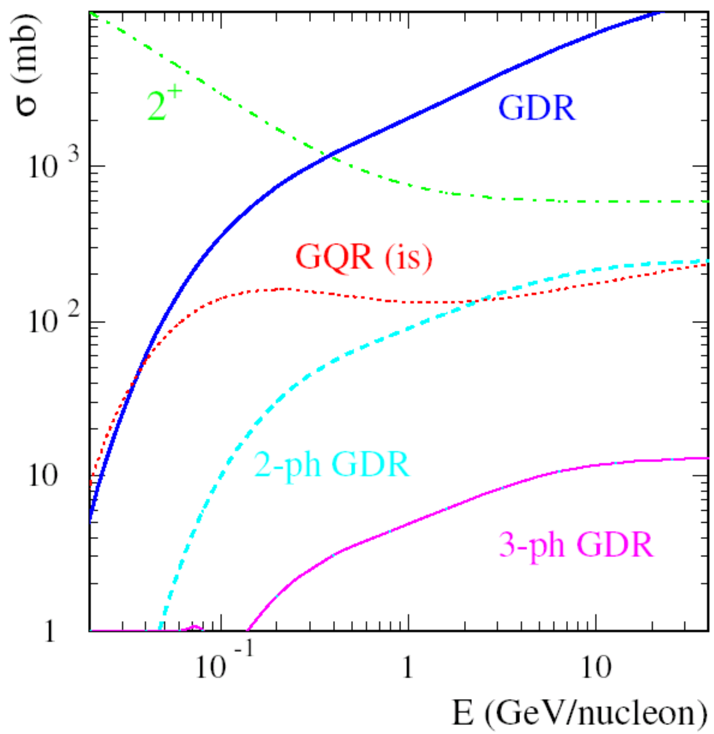
LIMITATION TO STABLE NUCLEI



Coulomb excitation in inverse kinematics

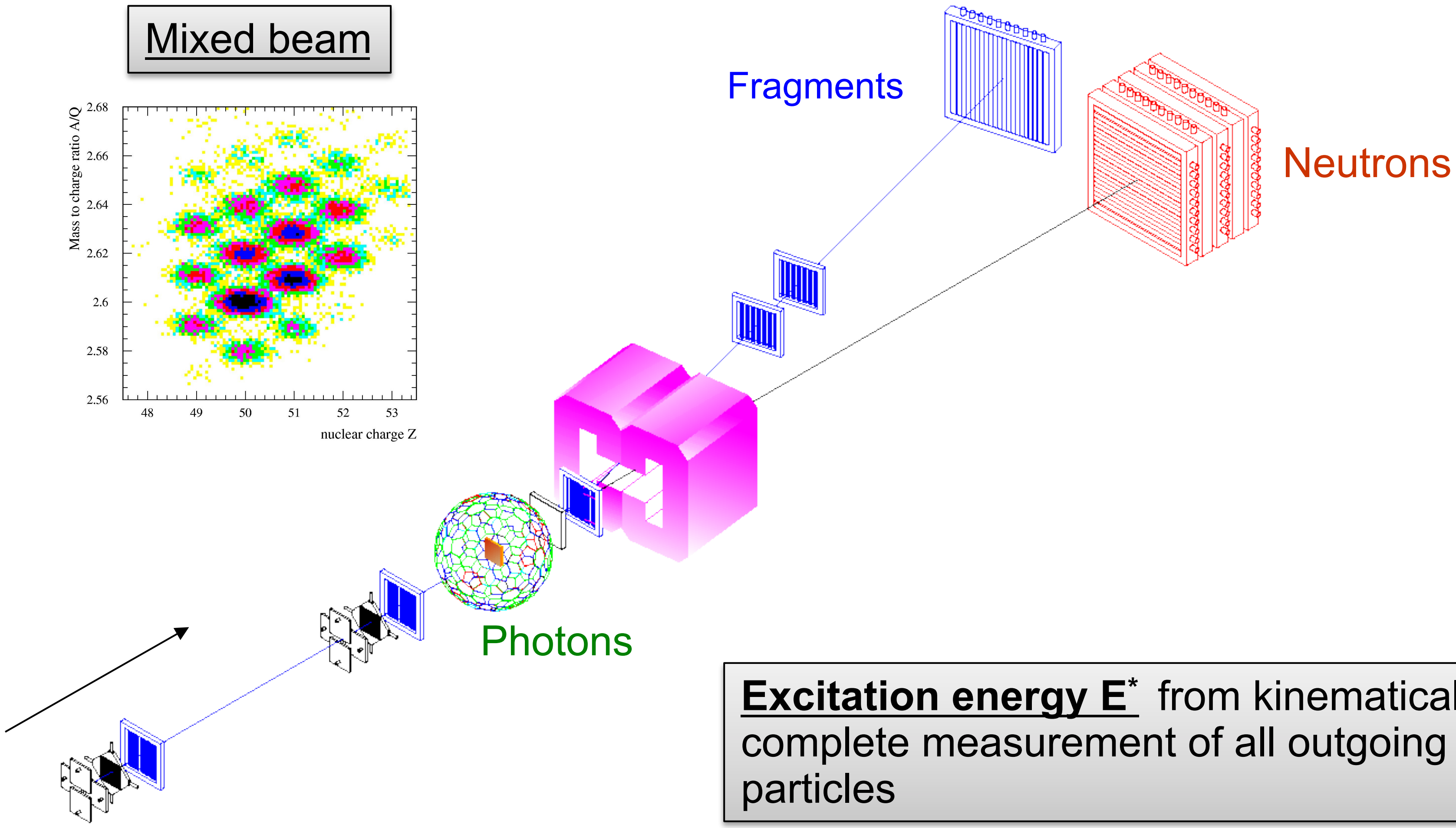


Absorption of 'virtual Photons'



<u>Excitation energy E*</u> from kinematically complete measurement of all outgoing particles

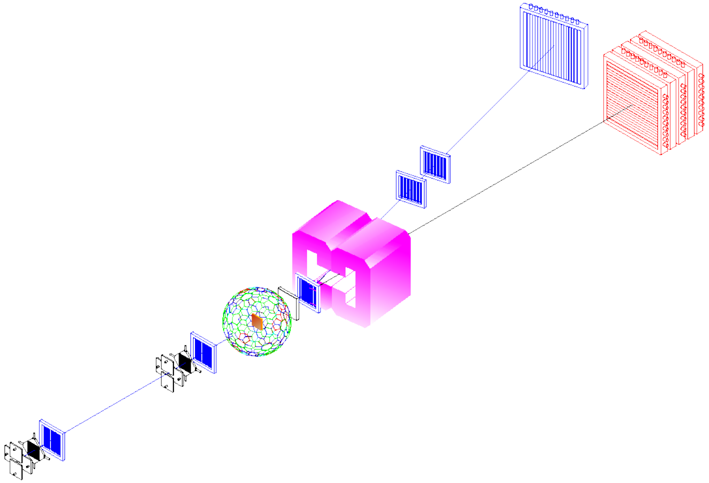
LAND reaction setup @GSI

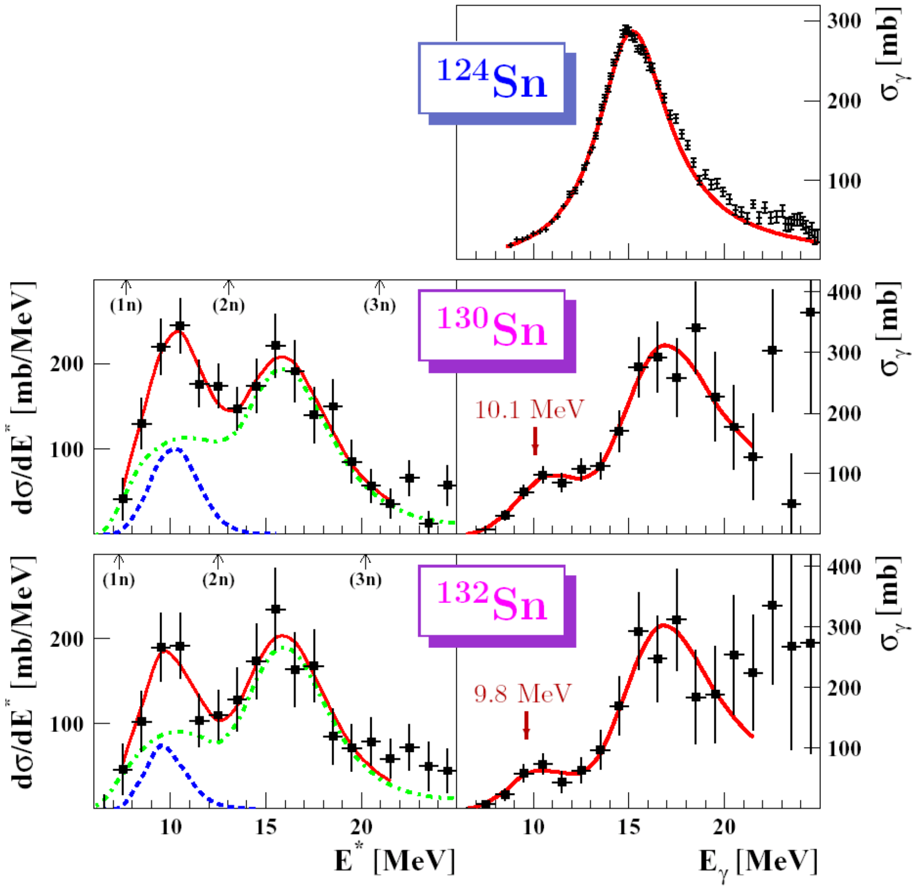


<u>Excitation energy E*</u> from kinematically complete measurement of all outgoing particles

T. Aumann, Eur. Phys. Journal A **26** (2005) 441

PDR in ^{130}Sn and ^{132}Sn

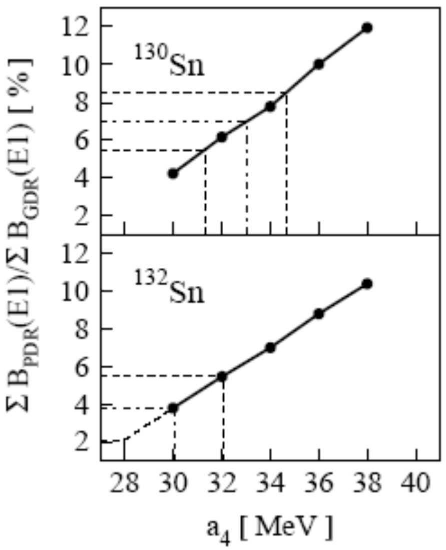


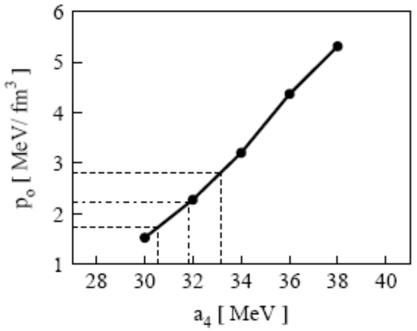


Observation of low-lying E1 strength in (unstable) neutron rich Sn nuclei

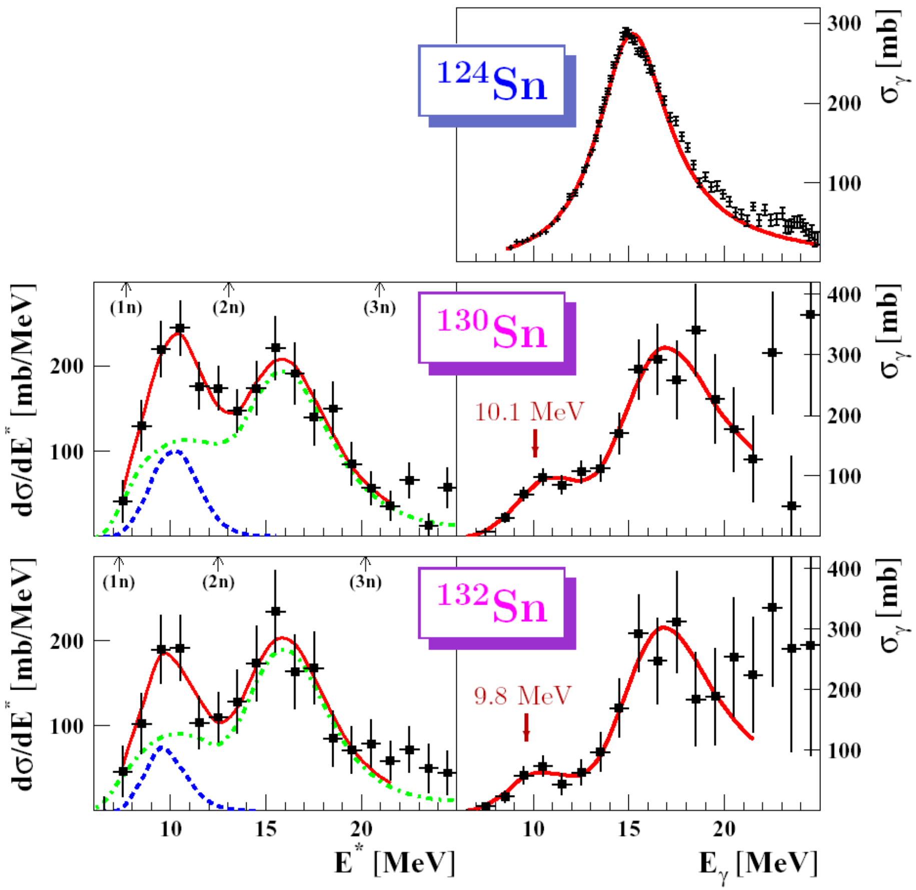
P. Adrich et al., PRL 95 (2005) 132501

PDR in ^{130}Sn and ^{132}Sn



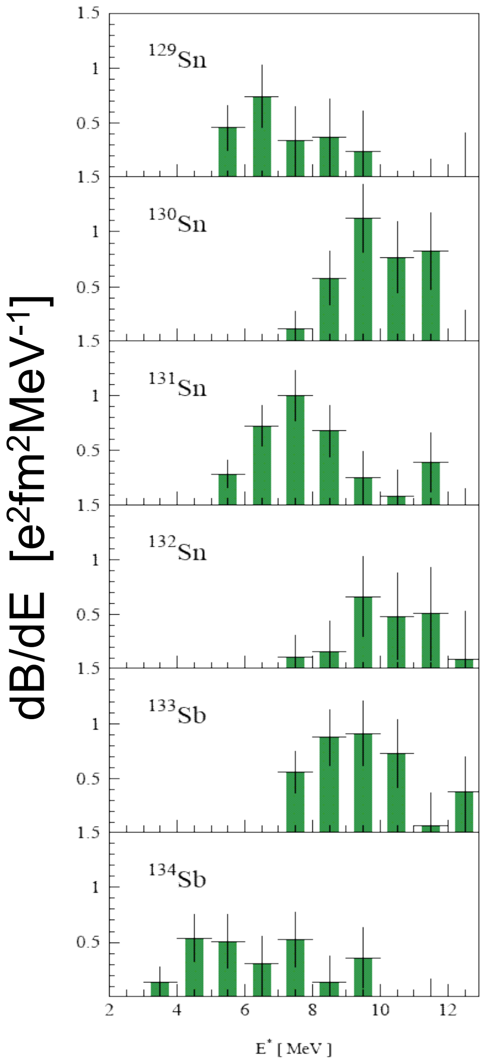


A. Klimkiewicz, N. Paar et al.,
PRC 76 (2007) 051603(R)

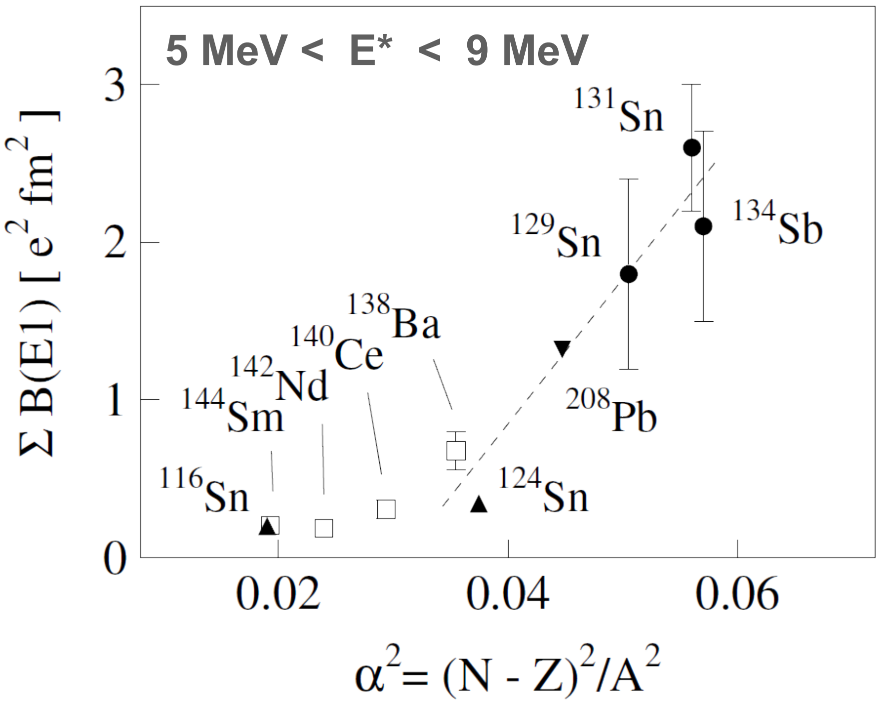


P. Adrich et al., PRL 95 (2005) 132501

Systematics of the PDR



A. Klimkiewicz et al., PRC 76 (2007) 051603(R)

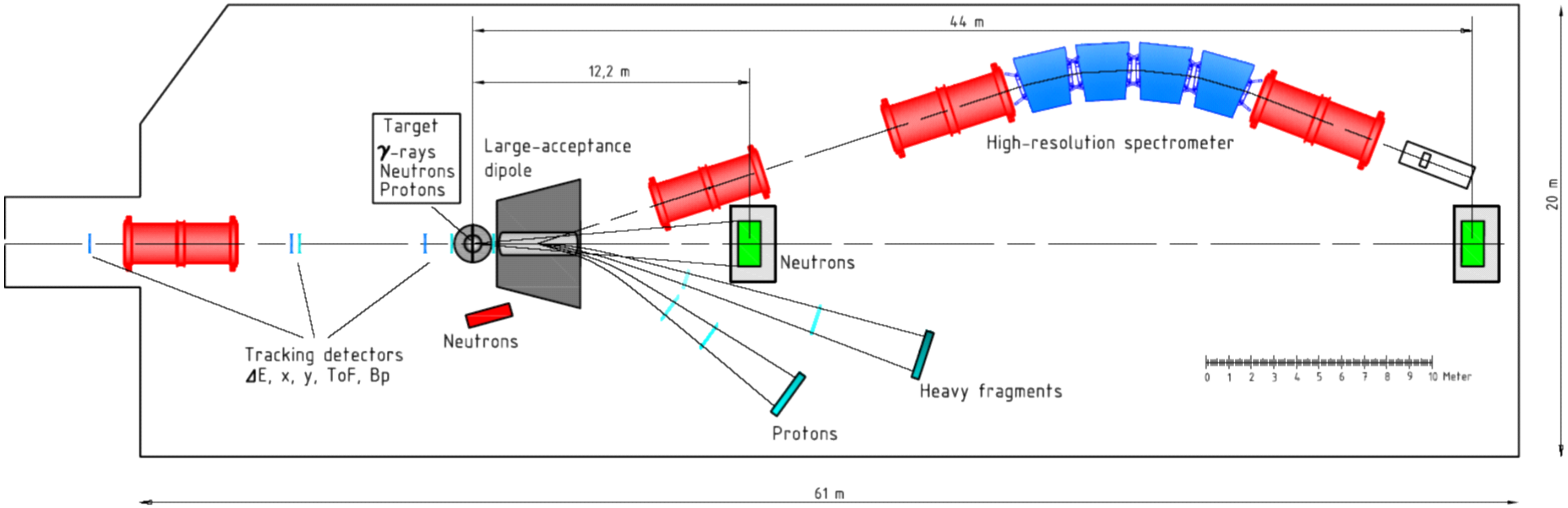


Different experimental limitations

⇒ <u>consistent sets of data important</u>

R^{3}B setup at FAIR

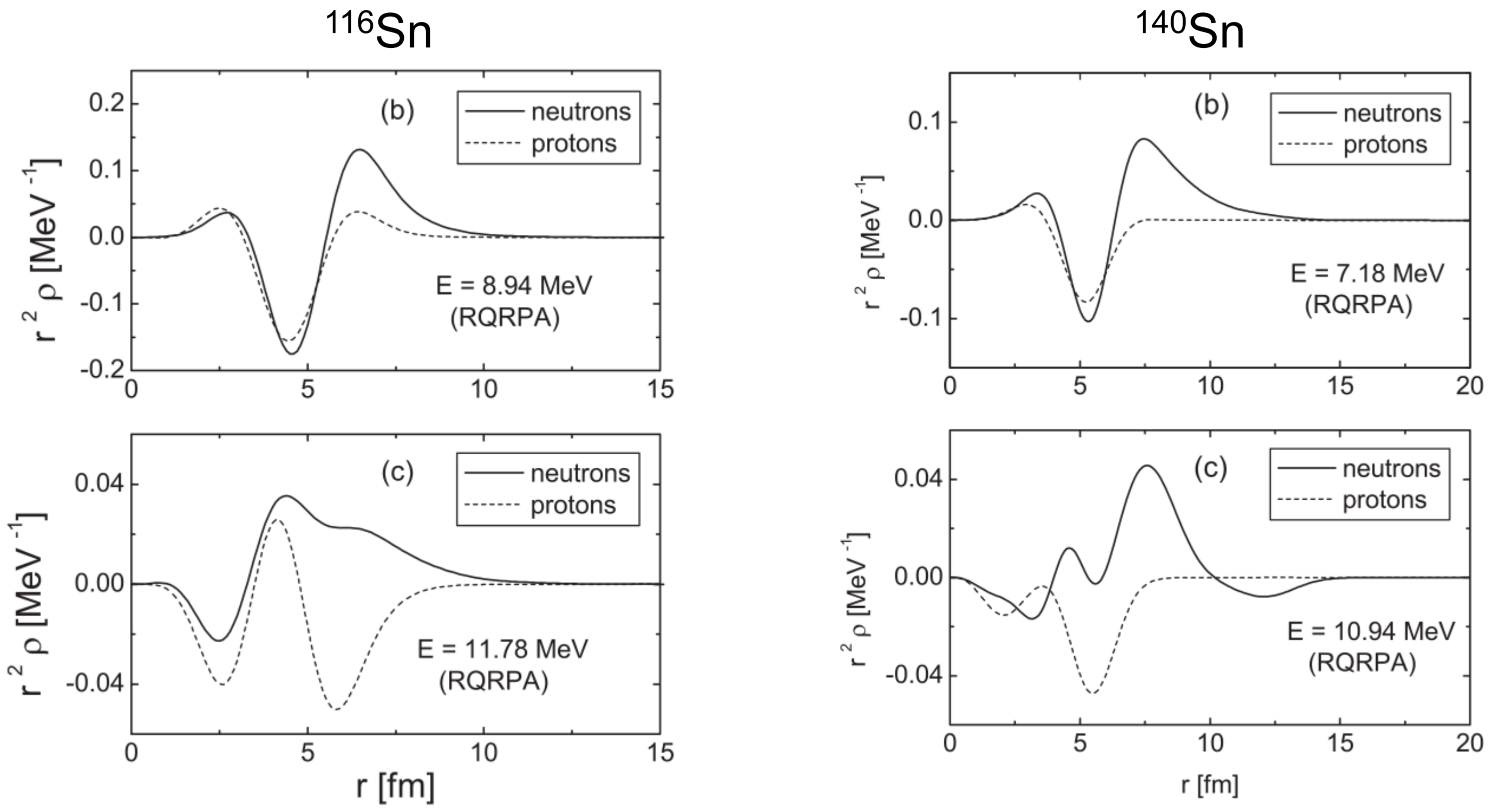
(Reactions with Relativistic Radioactive Beams)



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

- Detection of all decay channels

Structure of low-lying E1 strength



E. Litvinova et al., Phys. Rev. C **79** (2009) 054312

Use of complementary probe sensitive to different combination of transition densities to investigate (sub)structures

Structure of low-lying E1 strength

Use of complementary probe sensitive to different combination of transition densities to investigate (sub)structures

Photon scattering:
- dominant isovector excitation (for E1)
- interaction with whole nucleus (kR << 1)

α scattering:
(hadronic interaction)
- dominant isoscalar excitation
- interaction surface peaked

⇒ Investigation of E1 strength in α scattering experiments

PDR in (α,α'γ) coincidence experiments

Coincident γ-decay detection:

- Selection of decays to the ground state

$\Rightarrow$ Selectivity to E1

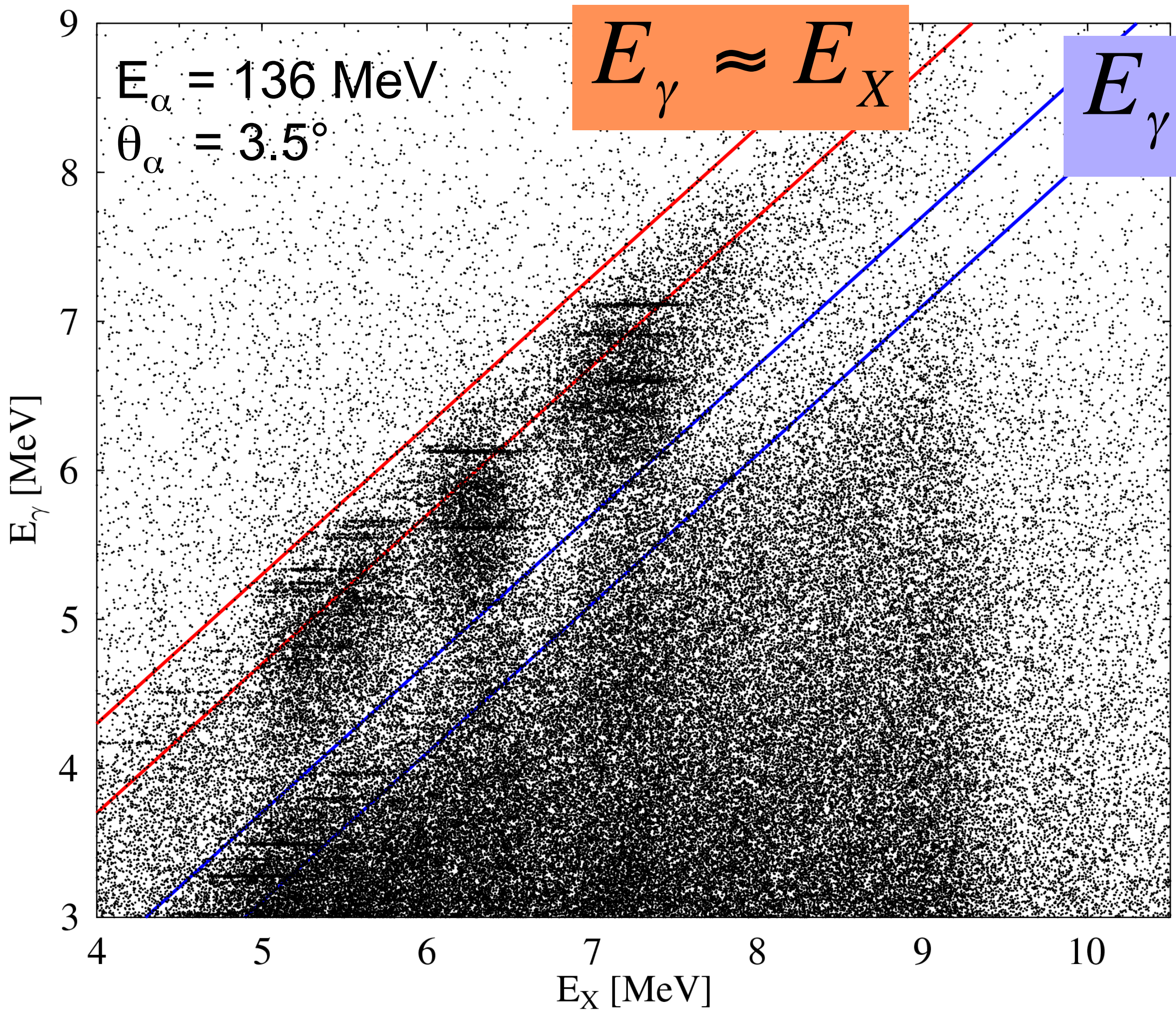
T.D. Poelhekken et al., Phys. Lett. B **278** (1992) 423

- HPGe detectors

$\Rightarrow$ Very high energy resolution

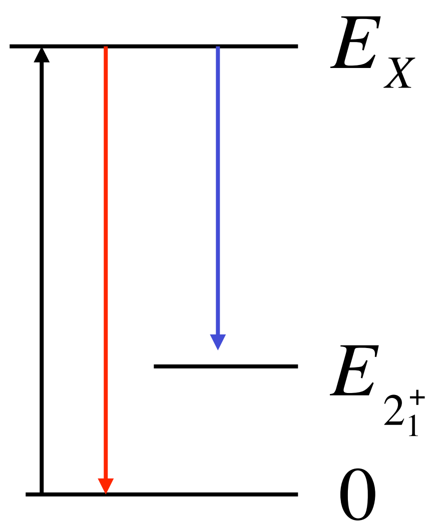
D. Savran et al., Nucl. Instr. and Meth. A **564** (2006) 267

^{140}Ce(α,α'γ) - coincidence matrix

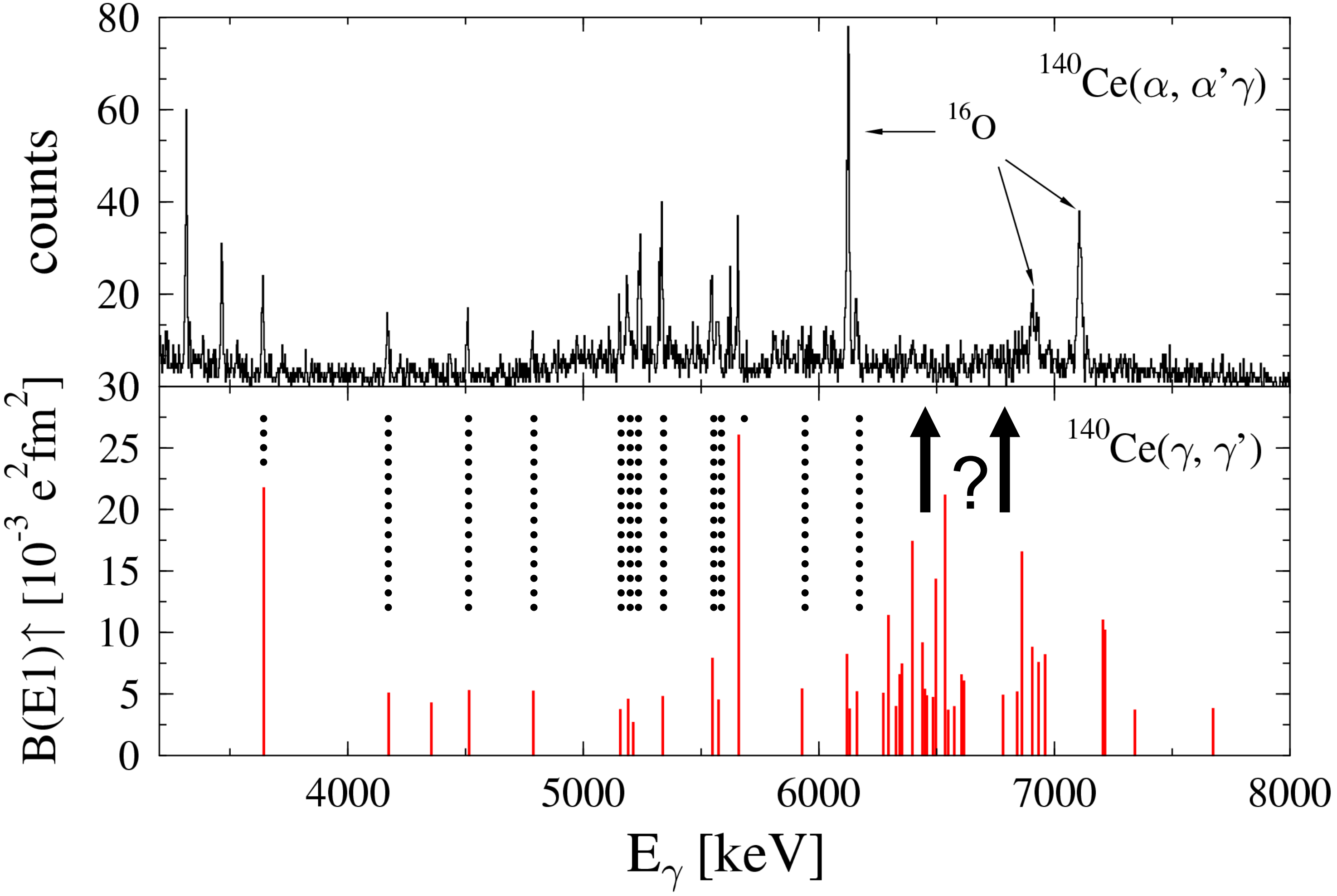


$$E_\gamma \approx E_X$$

$$E_\gamma \approx E_X - E_{2_1^+}$$

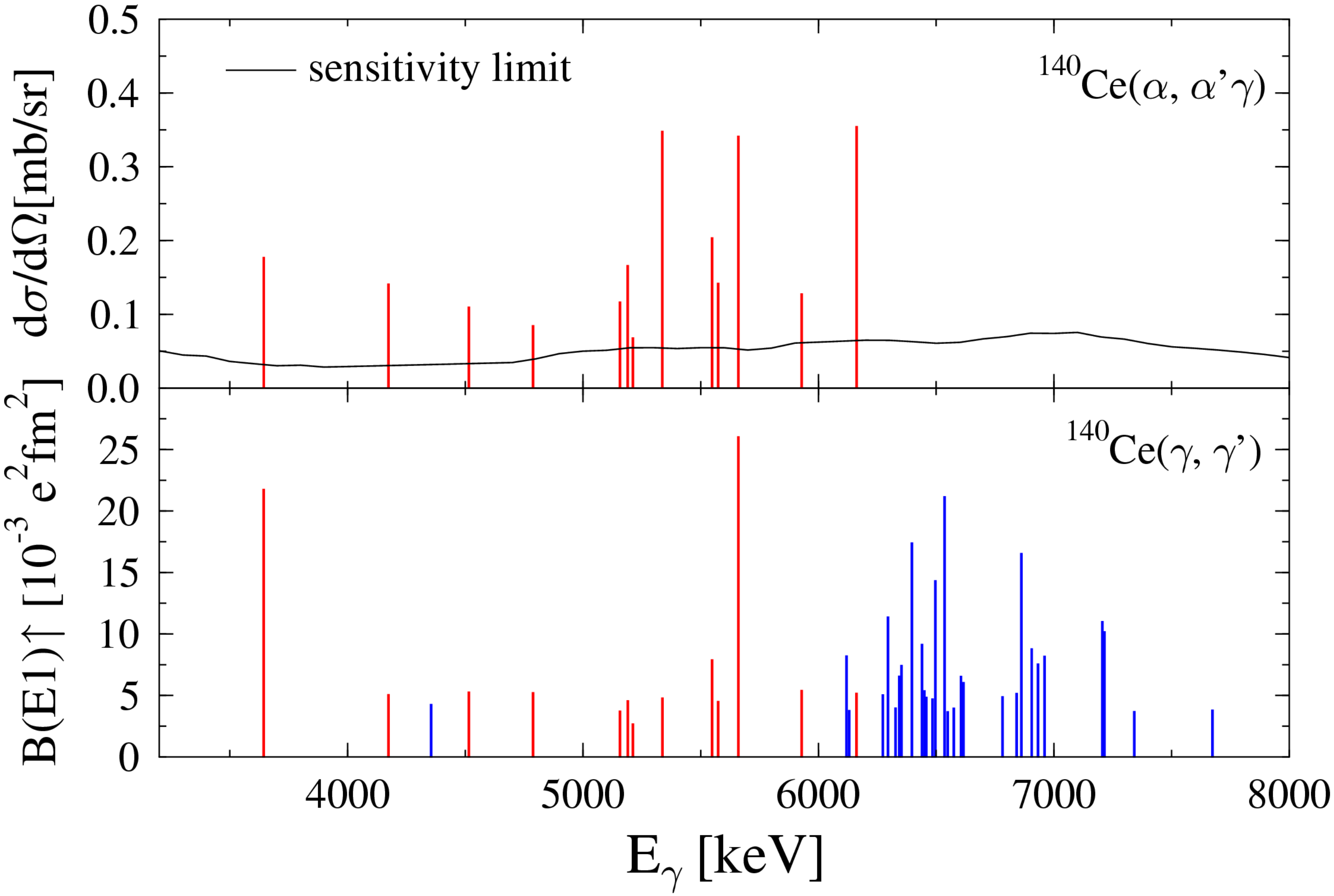


$^{140}Ce(\alpha,\alpha'\gamma)$ vs. $^{140}Ce(\gamma,\gamma')$



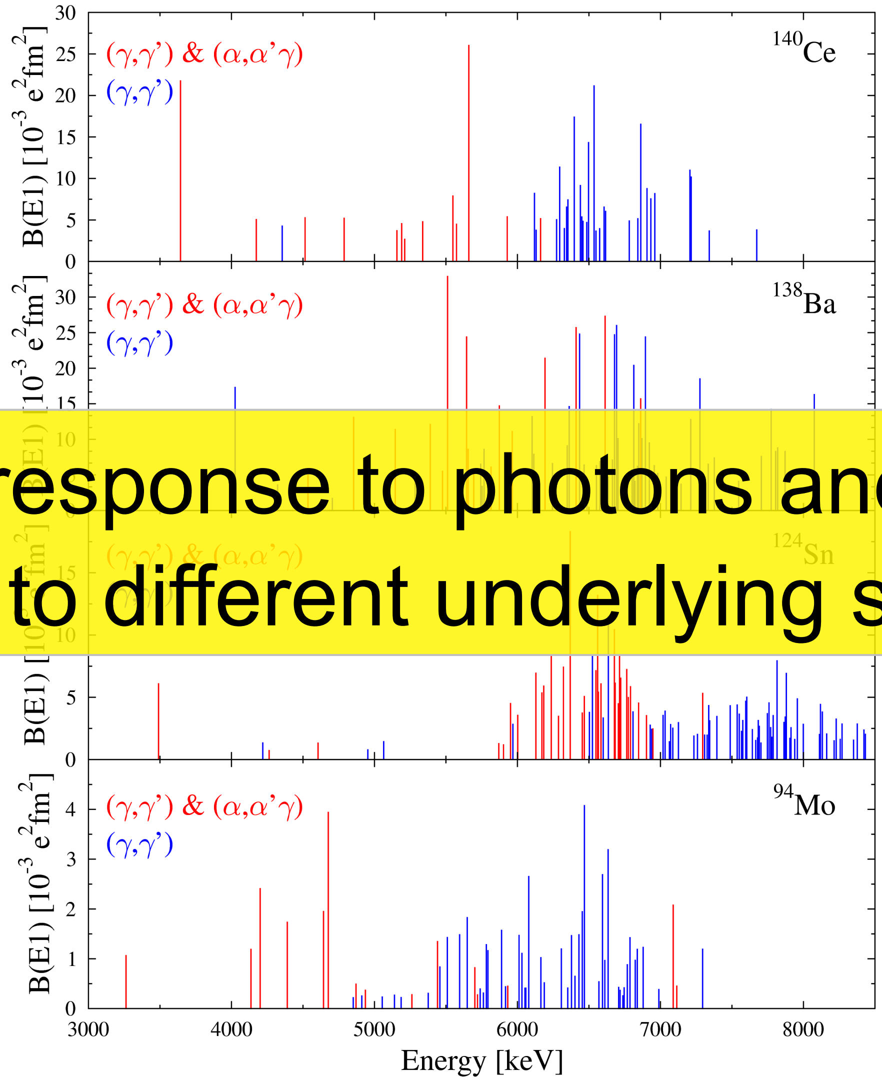
D.Savran et al., Phys. Rev. Lett. **97** (2006) 172502

$^{140}Ce(\alpha,\alpha'\gamma)$ vs. $^{140}Ce(\gamma,\gamma')$



D.Savran et al., Phys. Rev. Lett. **97** (2006) 172502

Splitting of the PDR



Different response to photons and α-particles points to different underlying structures

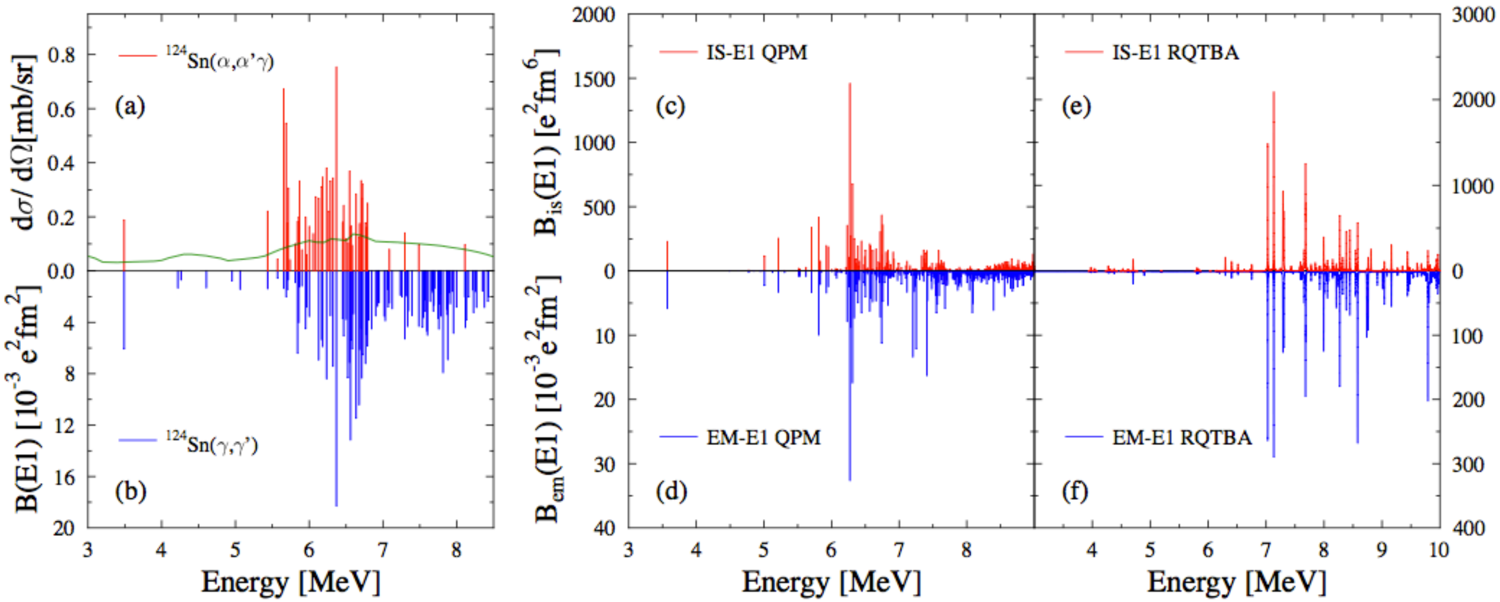
Splitting of the PDR – Theory vs. Exp.

Calculate response to isovector (EM) and isoscalar E1 Operator

$$Q_{1M}^{IS} = \sum_{i=1}^{A} (r_i^3 - \eta r_i) Y_{1M}(\Omega_i)$$

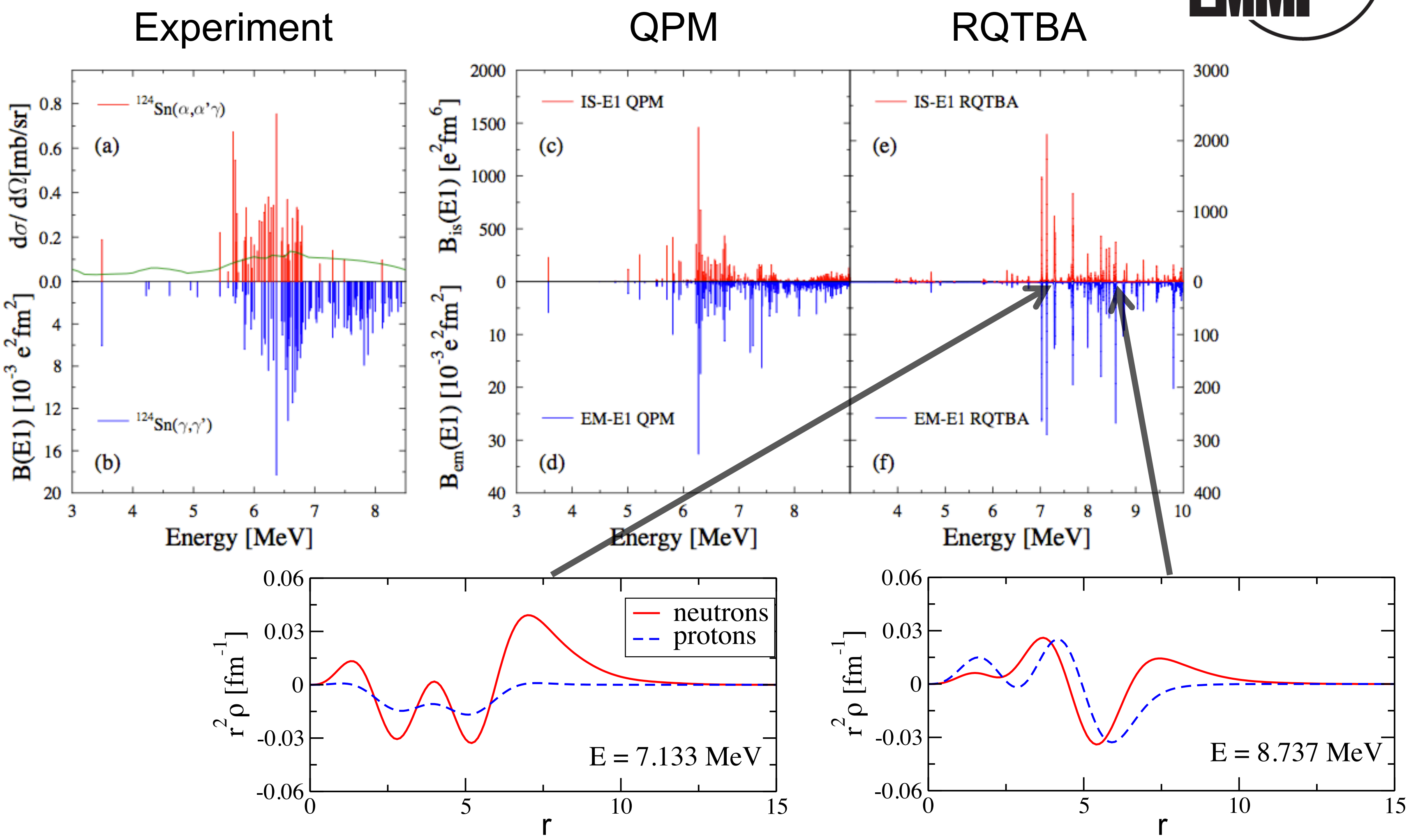
$$Q_{1M}^{EM} = \frac{N}{A} \sum_{p=1}^{Z} r_p Y_{1M}(\Omega_p) - \frac{Z}{A} \sum_{n=1}^{N} r_n Y_{1M}(\Omega_n)$$

Experiment QPM RQTBA



J. Endres, E. Litvinova, V. Ponomarev et al., Phys. Rev. Lett., in press

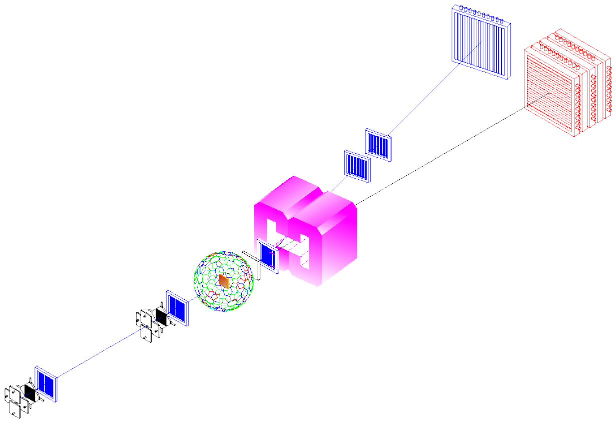
Splitting of the PDR – Theory vs. Exp.



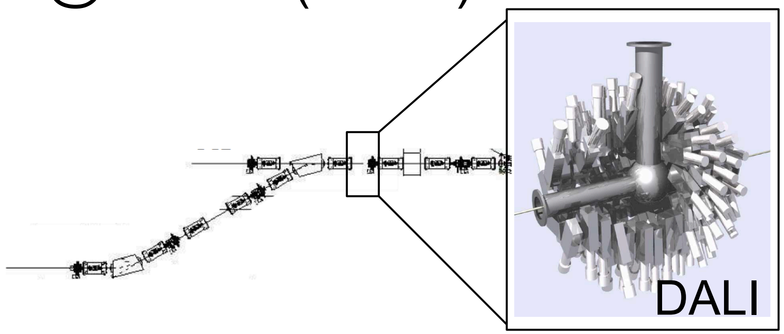
J. Endres, E. Litvinova, V. Ponomarev et al., Phys. Rev. Lett., in press

Experiments on unstable nuclei

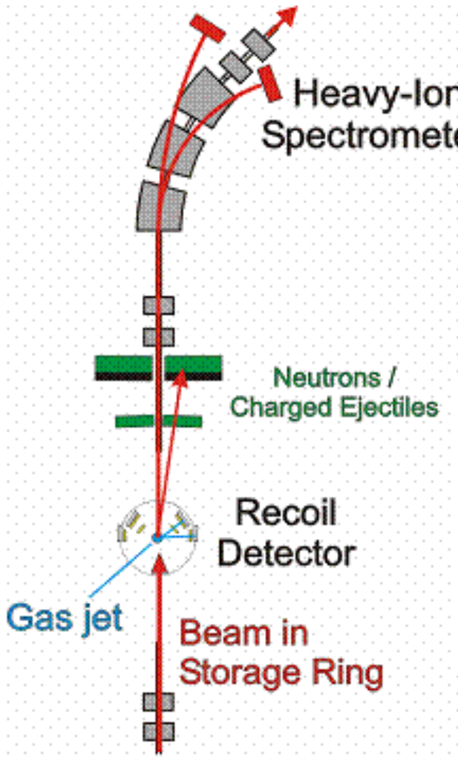
LAND @ GSI (2011)

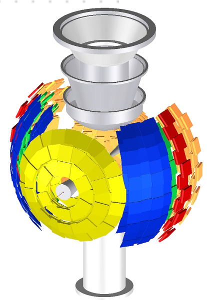


ZeroDegree Spectrometer
@ RIKEN (2011?)



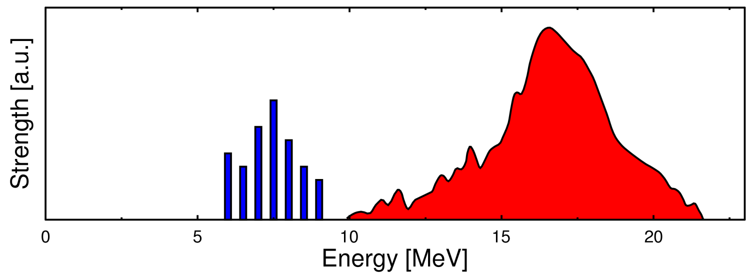
EXL @ FAIR



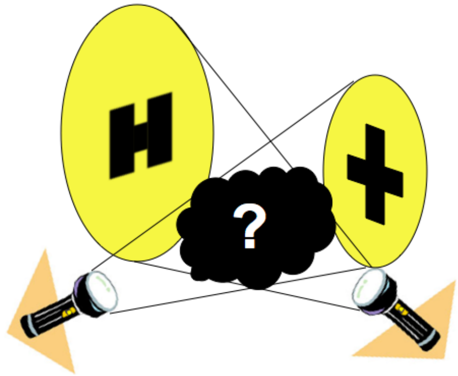


Summary

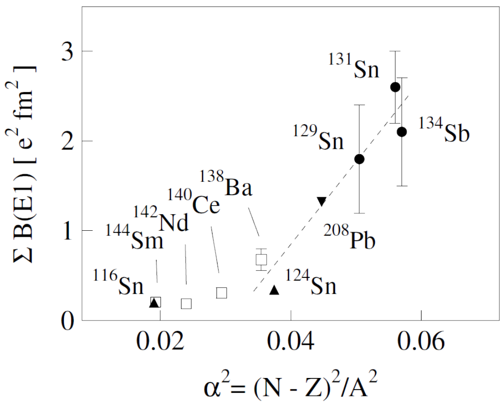
E1 strength as a key to nuclear properties



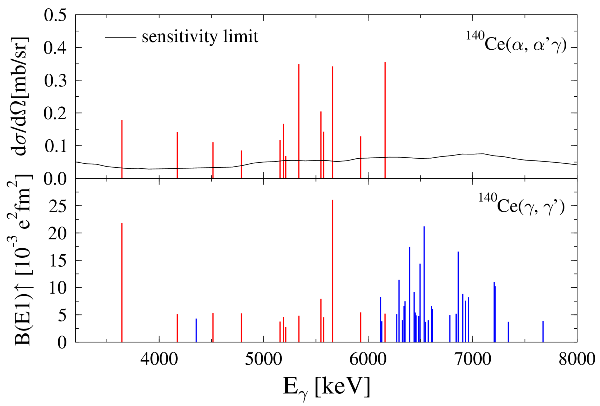
Experimental approaches



Systematics of E1 strength



Structure of E1 strength



Collaboration

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V. Simon, K. Sonnabend, C. Waelzlein, M. Zweidinger**

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**M. Elvers, J. Endres, J. Hasper, , A. Sauerwein
A. Zilges**

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