Pygmy dipole excitations in neutron-rich nuclei

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2nd EMMI Workshop on Neutron-Rich Exotic Nuclei

- Neutron-Rich Nuclear Matter, Nuclear Structure, and Nuclear Astrophysics -

RIKEN

16th – 18th June 2010

Dipole excitations of n-rich nuclei –experimental results

Relation to the density-dependence of the symmetry-energy

Open questions and next experimental steps

Dipole excitations of neutron-proton asymmetric nuclei

Nuclear Structure of exotic nuclei

Neutron-Proton asymmetric matter

Nuclear Astrophysics

Proton number, Z

Neutron number, N

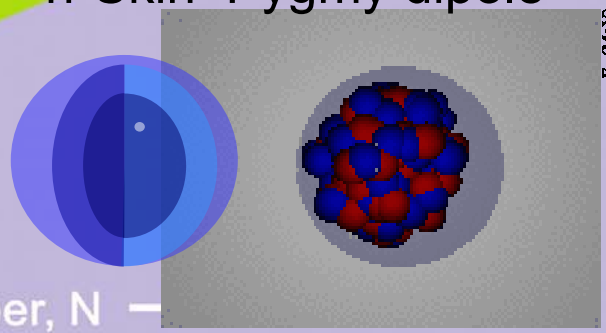
2 8 20 28 50 82 126 184 114

N=Z

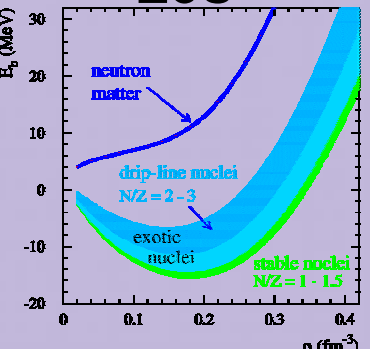
UNKNOWN NUCLEI

Neutron-rich nuclei – Neutron-rich Matter

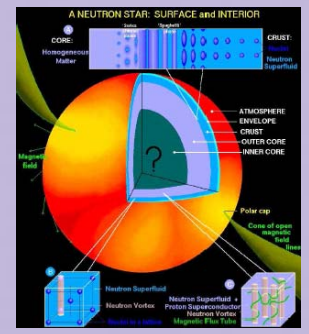
n-Skin Pygmy dipole



EoS

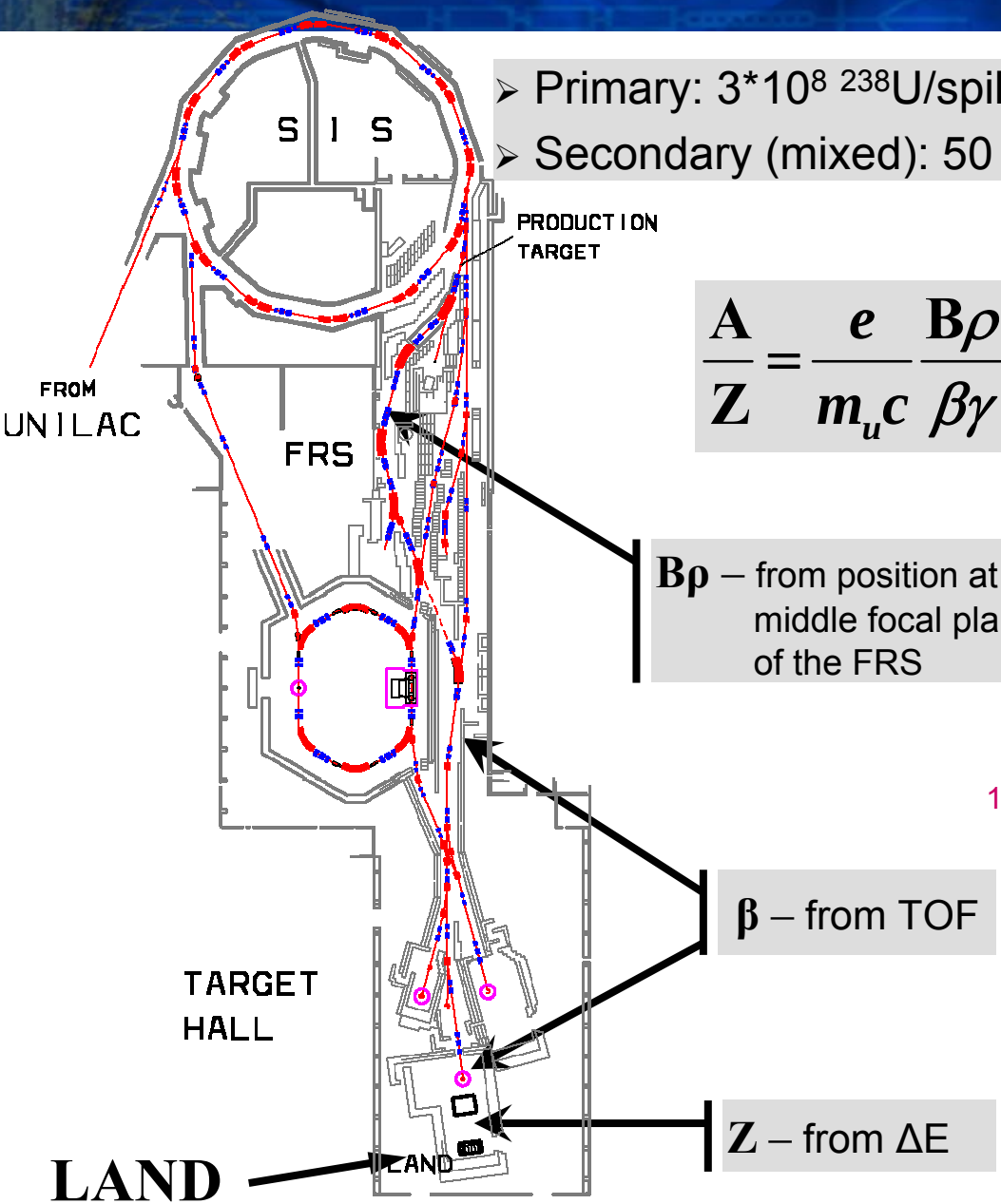


Neutron Star



Experimental Approach I: Production of (fission-)fragment beams

- Primary: 3*10^{8} ^{238}U/spill @550MeV/u
- Secondary (mixed): 50 ions ^{132}Sn/spill (~10/sec @500 MeV/u)

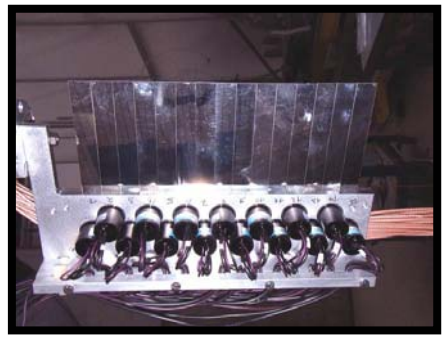


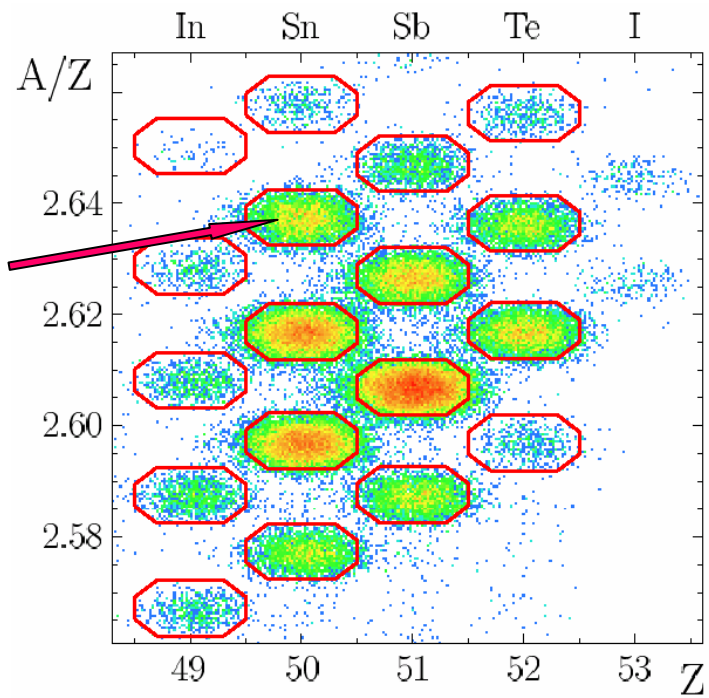
$$\frac{A}{Z} = \frac{e}{m_u c}\frac{B\rho}{\beta\gamma}$$

Bρ – from position at middle focal plane of the FRS

β – from TOF

Z – from ΔE

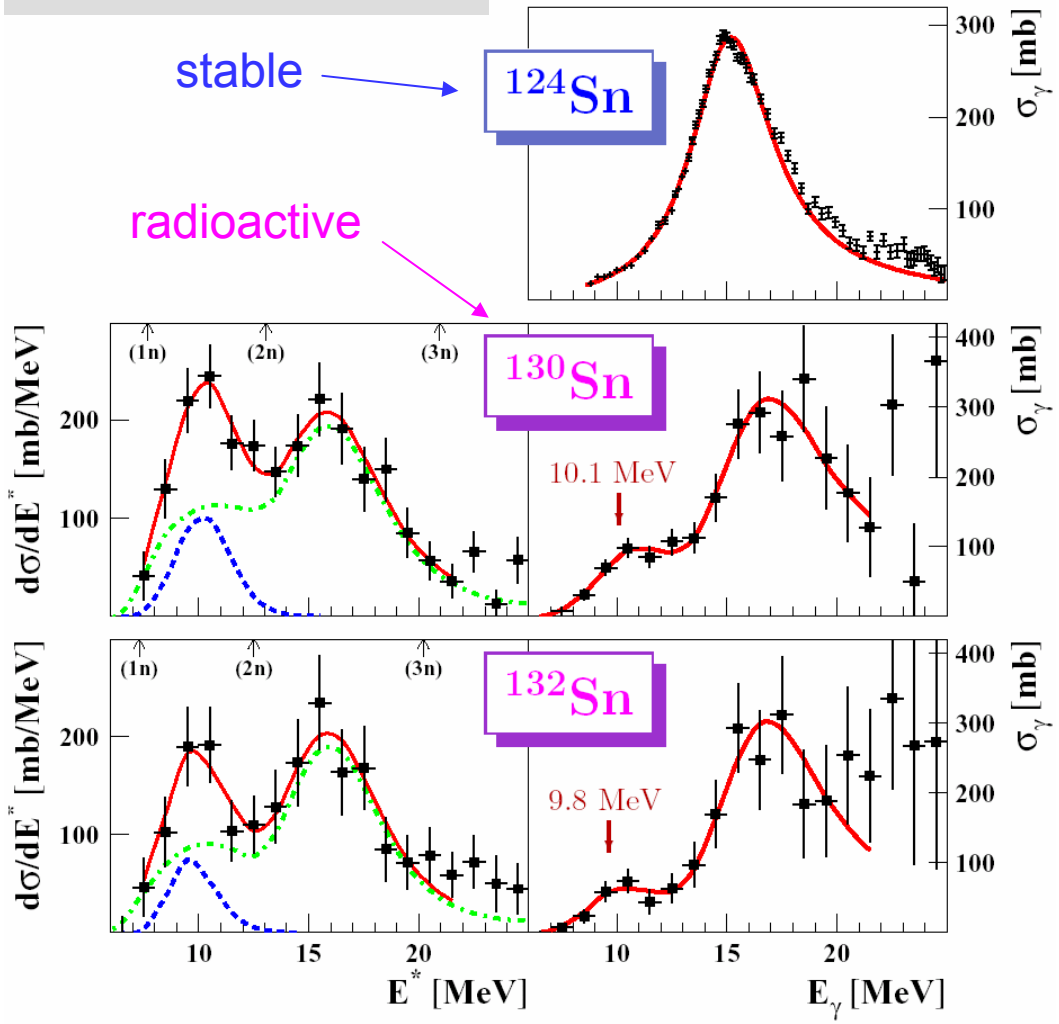




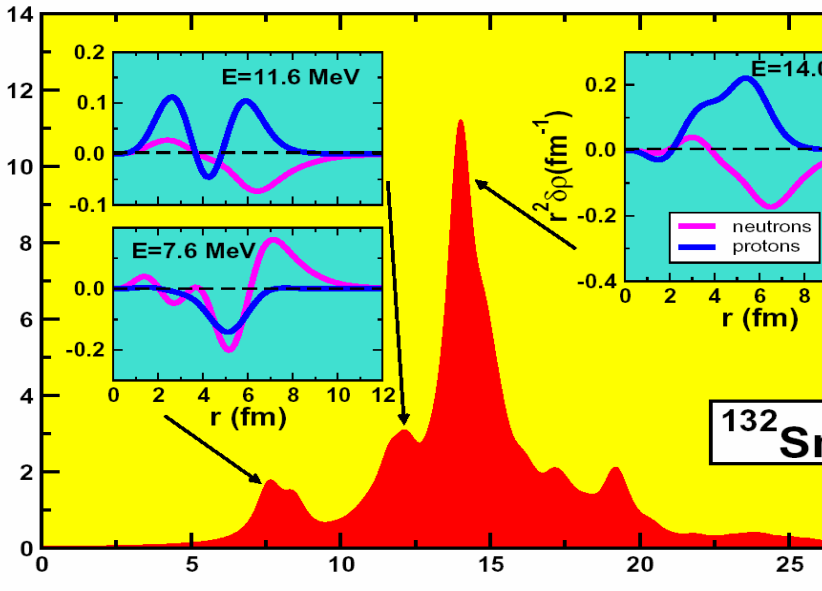
Dipole-strength distributions in neutron-rich Sn isotopes

Electromagnetic-excitation cross section

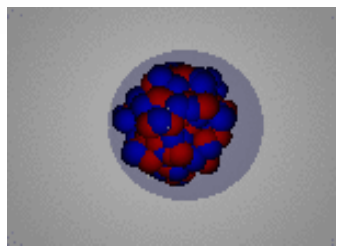
Photo-neutron cross section



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



P. Ring et al.



PDR

- located at 10 MeV
- exhausts a few % TRK sum rule
- in agreement with theory

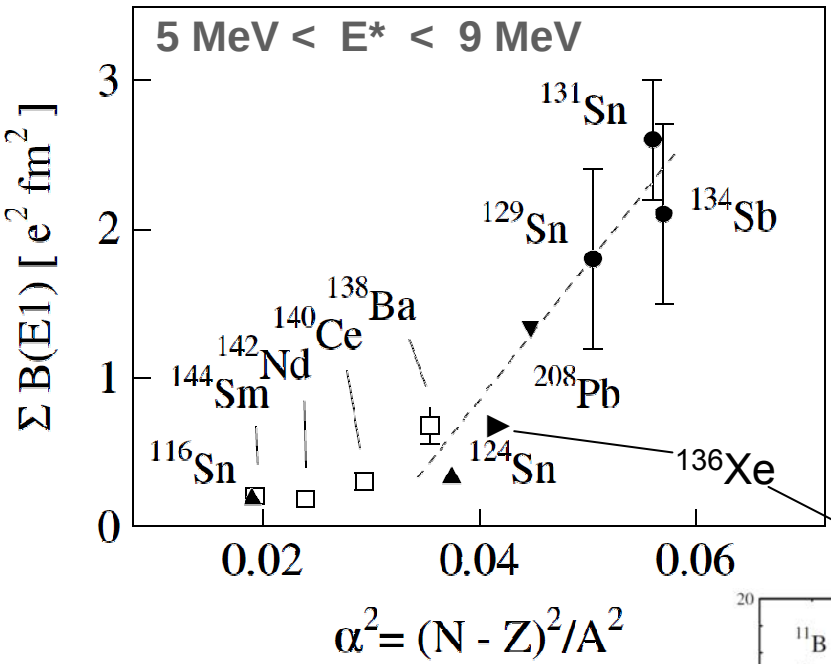
GDR

- no deviation from systematics

Low-lying dipole strength in the ^{132}Sn mass neighborhood

odd nuclei allow extending (γ,n) measurements to lower excitation energies

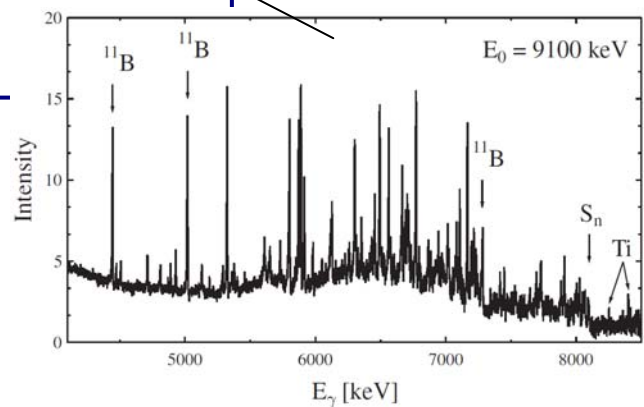
→ comparison to (γ,γ') data for stable isotopes



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

S-DALINAC data

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



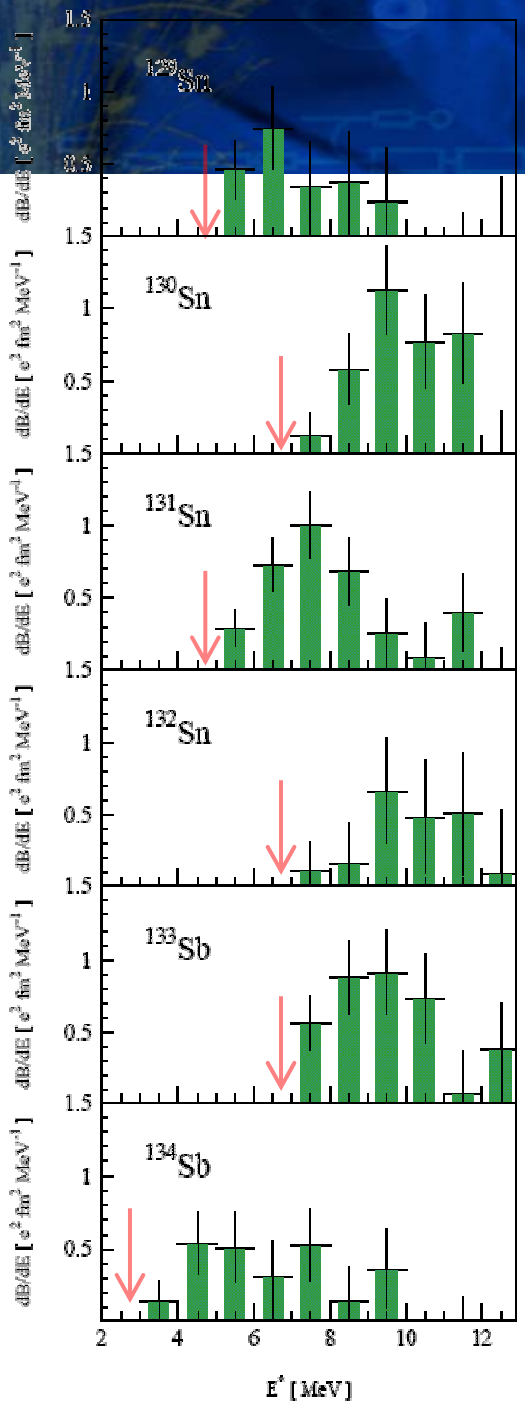
Data for stable nuclei from:

A.Zilges et al., PLB 542,43 (2003)

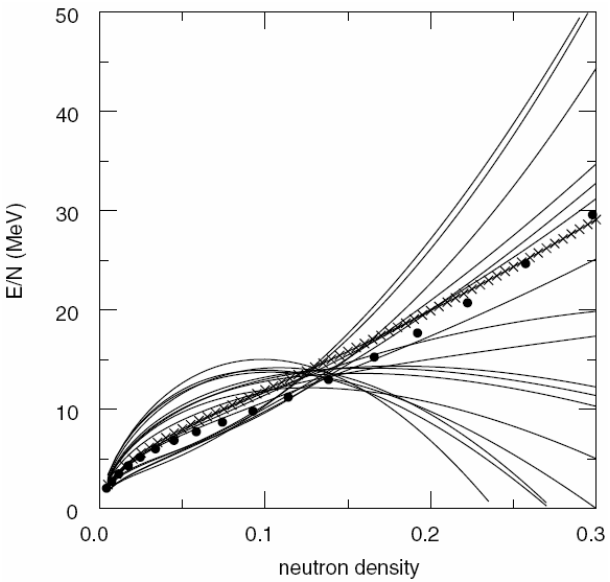
S.Volz et al., NPA 779, 1 (2006)

N. Ryezayeva et al., PRL 89 (2002)

K. Govaert et al., PRC 57,2229 (1998)



Symmetry energy $S_2(\rho)$ and the neutron skin in ^{208}Pb

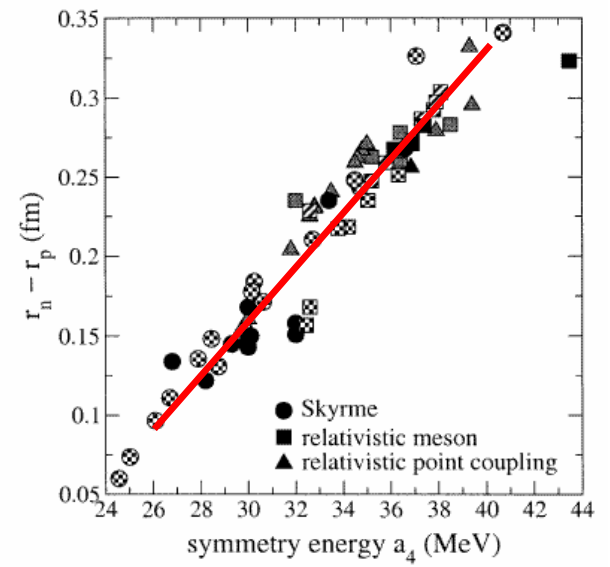


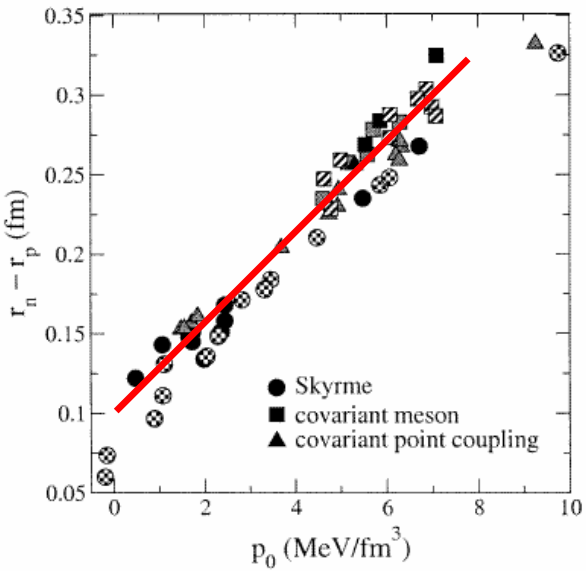
$$E(\rho,\alpha) = E(\rho,0) + S_2(\rho)\alpha^2 + O(\alpha^4),\ \alpha = \frac{N-Z}{A}$$

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

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

Alex Brown,
PRL 85 (2000) 5296
S. Typel, B.A. Brown, PRC 64 (2001) 027302

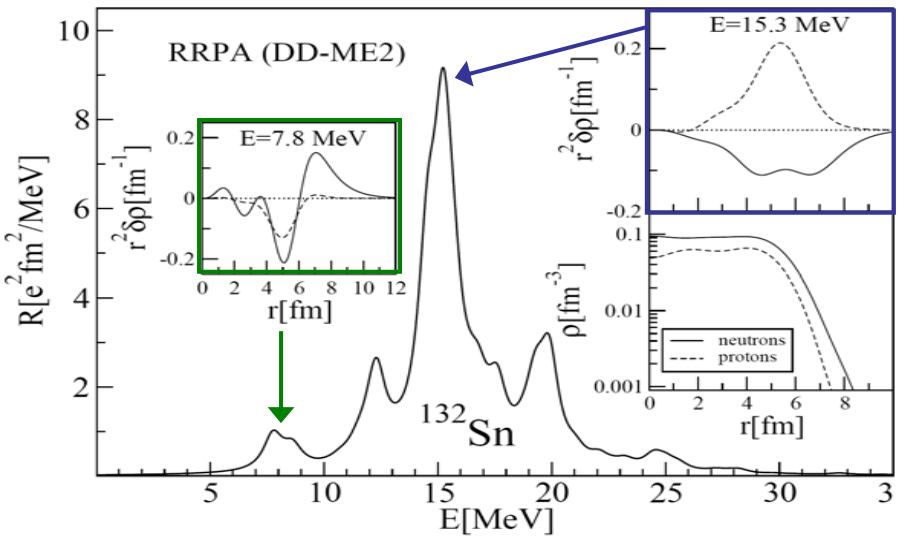


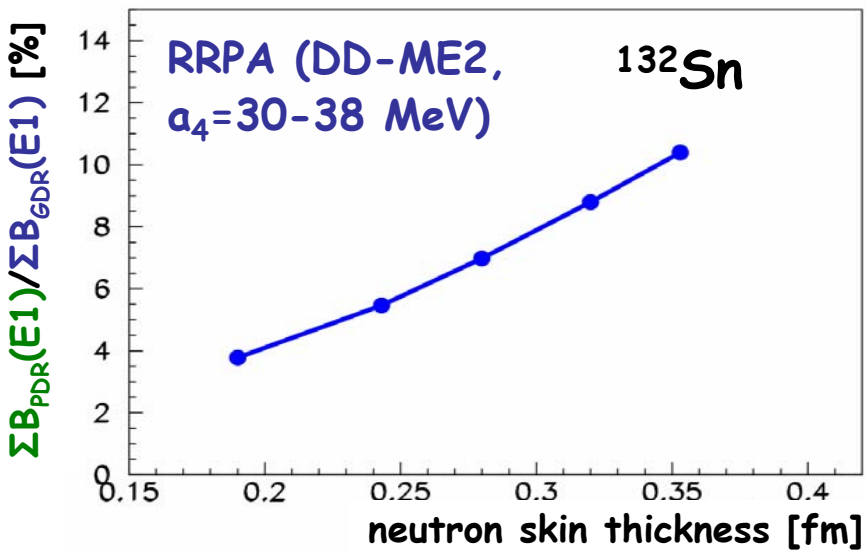


R.J.Furnstahl
NPA 706(2002)85-110

• strong <u>linear</u> correlation between neutron skin thickness and parameters **a_4, p_0**

Pygmy dipole resonance and neutron skin



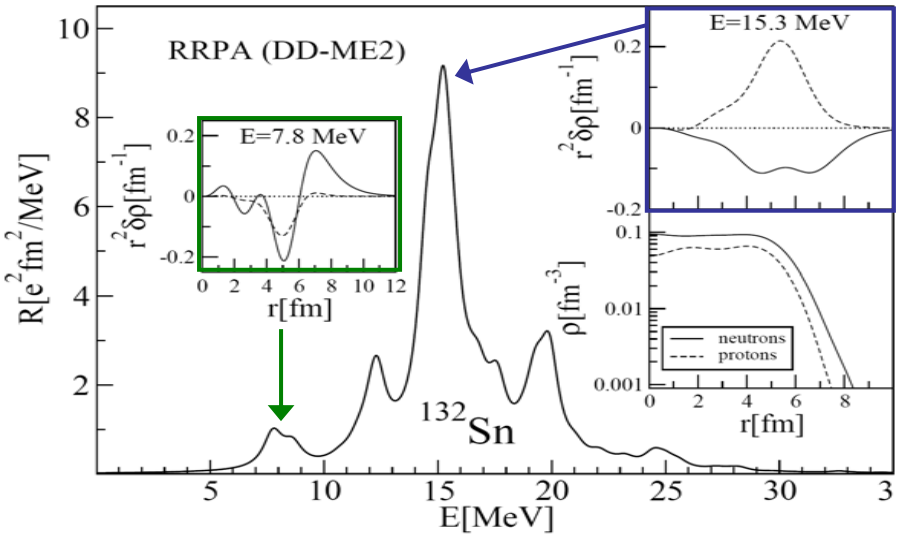


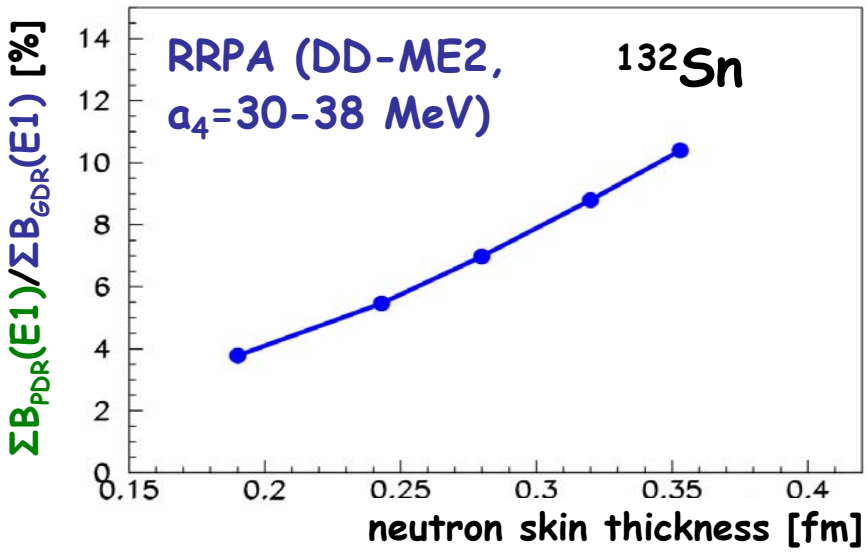
RQRPA N.Paar

"...,the pygmy dipole resonance may place important constraints on the neutron skin of heavy nuclei and, as a result, on the equation of state of neutron-rich matter."

J. Piekarewicz, PRC 73 (2006) 044325

Pygmy dipole resonance and neutron skin





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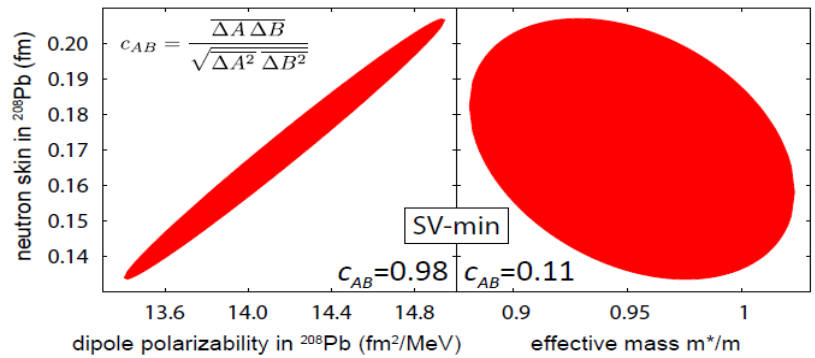
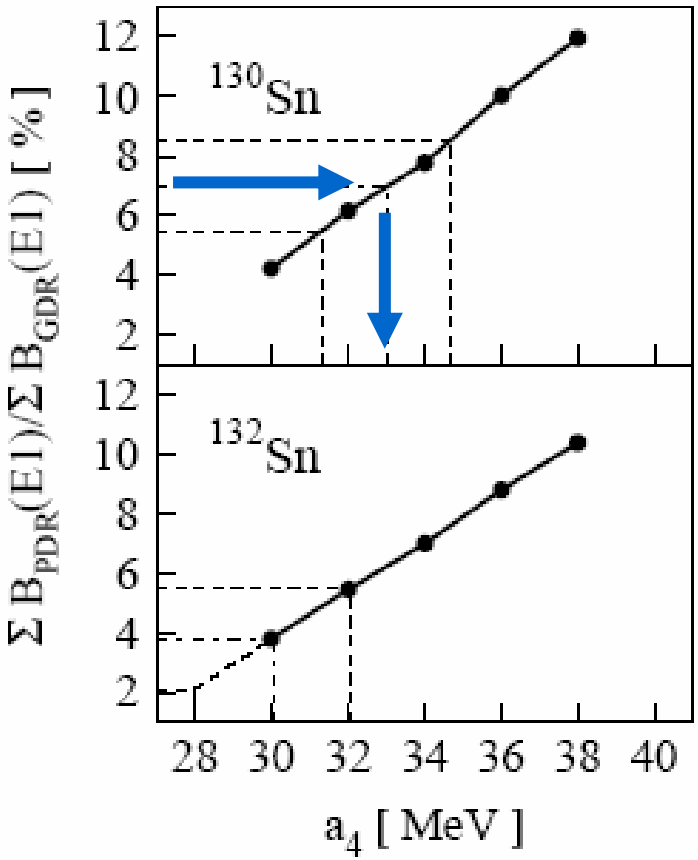
The information content of the nuclear neutron skin

P.–G. Reinhard[1] and W. Nazarewicz[2, 3, 4]



PDR strength versus a_4, p_o

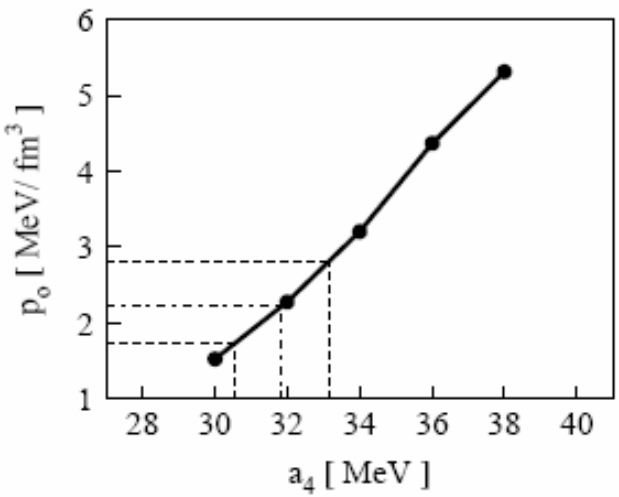


RQRPA – DD-ME

N. Paar et al.

Result (*averaged ^{130,132}Sn*) :

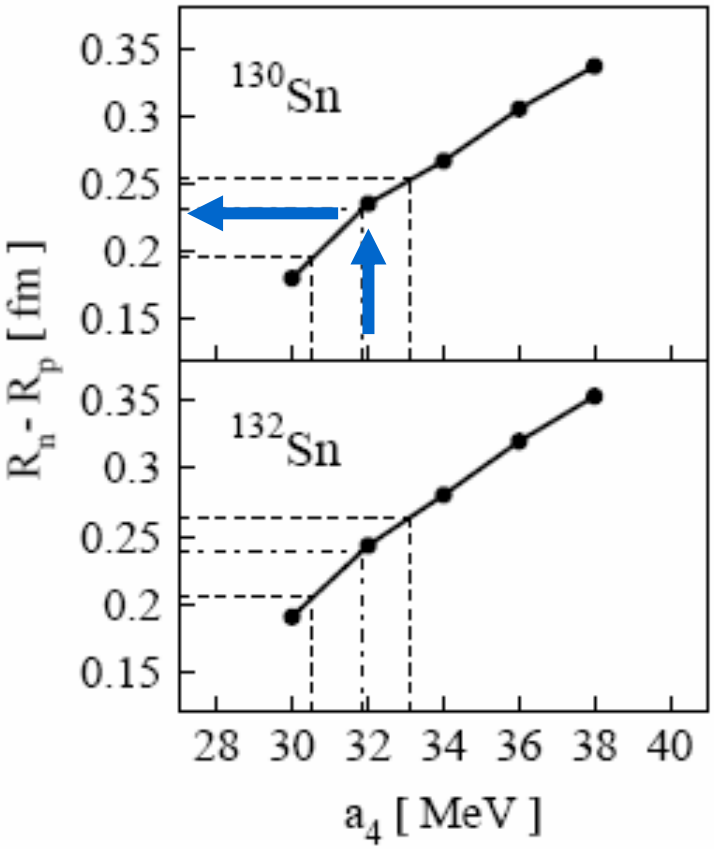
a_4 = 32.0 ± 1.8 MeV



p_o = 2.3 ± 0.8 MeV/fm^3

S(ρ) : moderate stiffness

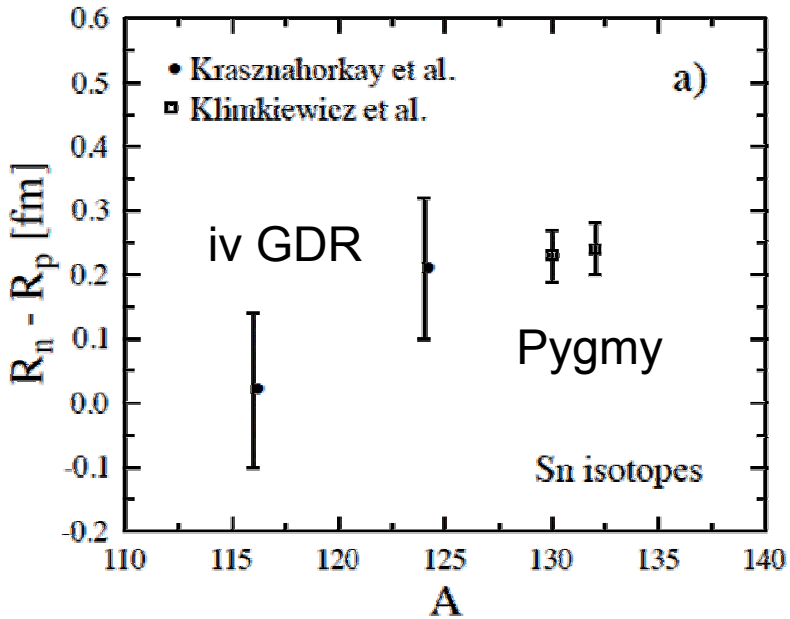
Neutron skin thickness



$R_n - R_p$:

^{130}Sn: 0.23 ± 0.04 fm

^{132}Sn: 0.24 ± 0.04 fm



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

Questions to be answered by experiment

1) How does the dipole strength function depends on mass, binding energy and n-p asymmetry (Pygmy and GDR!!)

→ Systematics, improve quality of data (statistics, resolution, extract E2

2) Collectivity ? → decay modes (direct gamma, particle decay to A-1 states)

3) Low-lying strength partly below threshold ? → meas. below and above threshold

4) Connection to measurements with stable nuclei

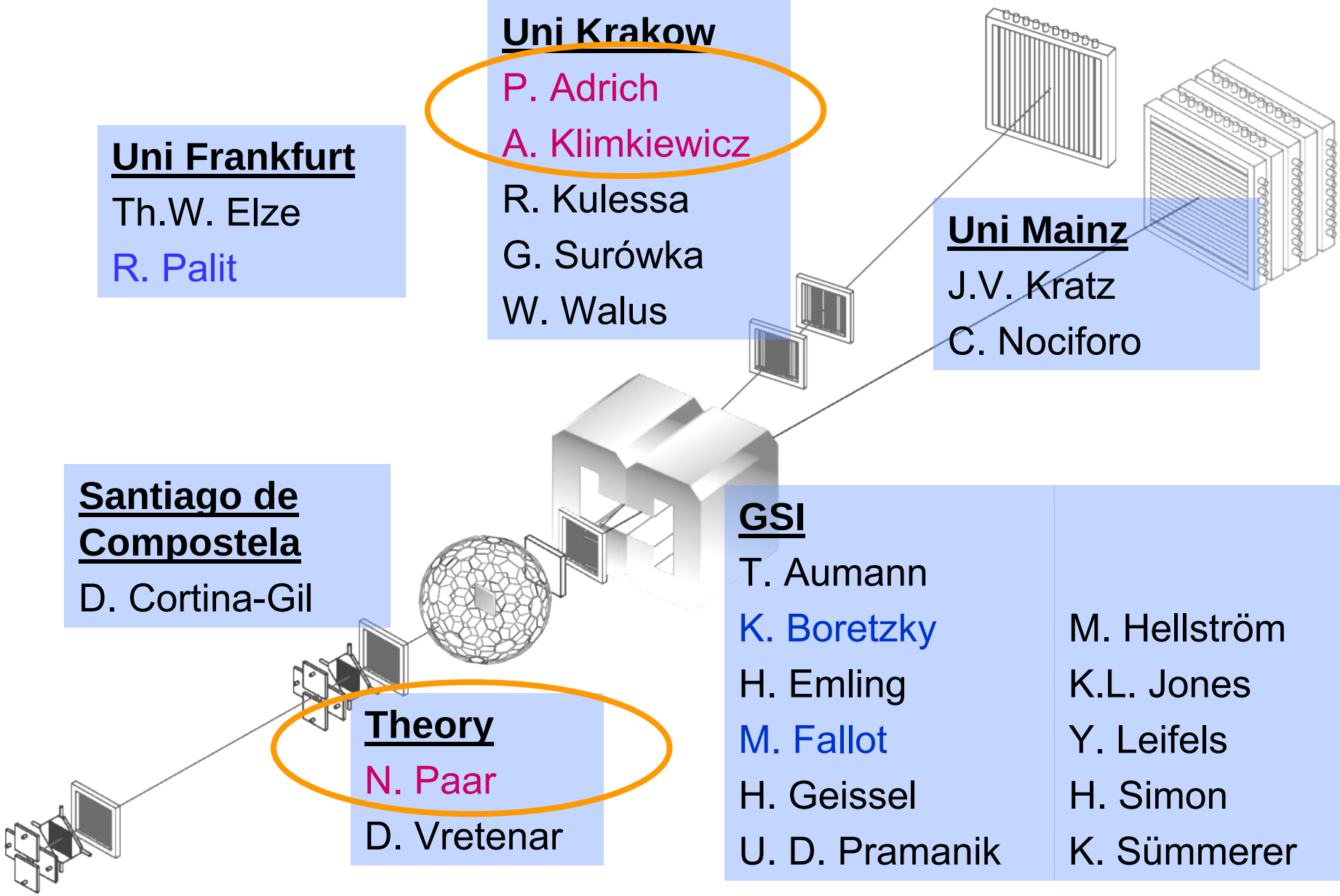
5) Structure of low-lying dipole (use of different probes, e.g., alpha scattering)

6) Relation to EoS and neutron skin: different nuclei and mass regions

7) proton Pygmy? Meas. ^{32,34}Ar (data in analysis)

8) Effect of deformation ?

The LAND/FRS collaboration S221



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