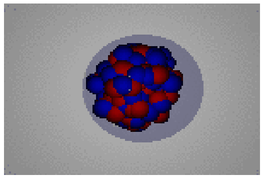
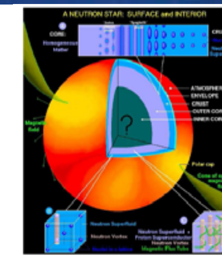
Dipole response of exotic nuclei and the EOS



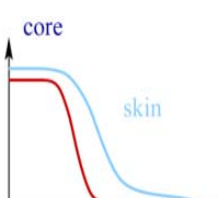


Konstanze Boretzky, GSI

for the

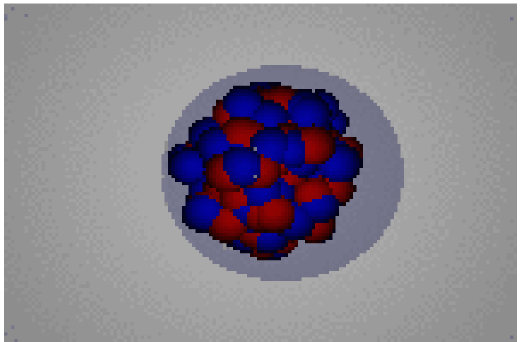
LAND-R^{3}B Collaboration

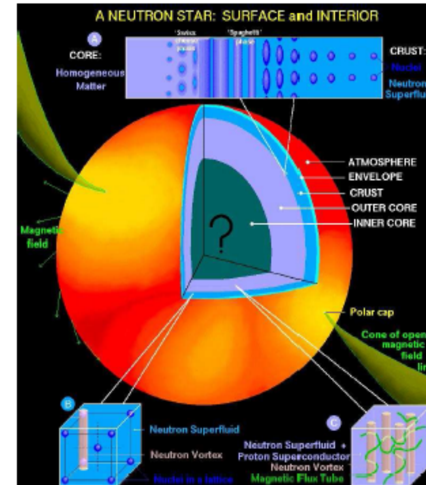
- **low-lying dipole strength ←→ nuclear matter properties**
  - predictions for relation to symmetry energy parameters
- **dipole strength in Tin isotopes:**
  - Coulomb excitation in inverse kinematics using LAND-R^{3}B
  - $^{129-132}Sn$
  - interpretation in terms of symmetry energy for ^{130}, ^{132}Sn, ^{208}Pb
- **experimental outlook:**
  - decay studies: ^{68}Ni
  - dipole strength evolution in proton-rich nuclei
  - new systematic investigations



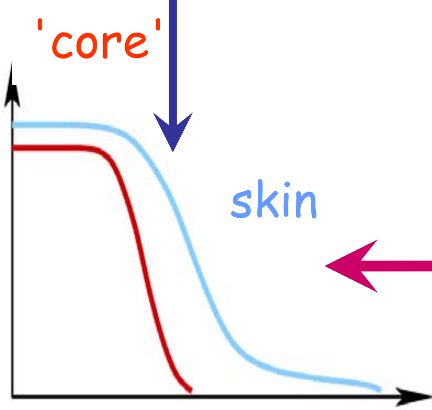
EQUATION OF STATE

Dipole response of exotic nuclei and the EOS



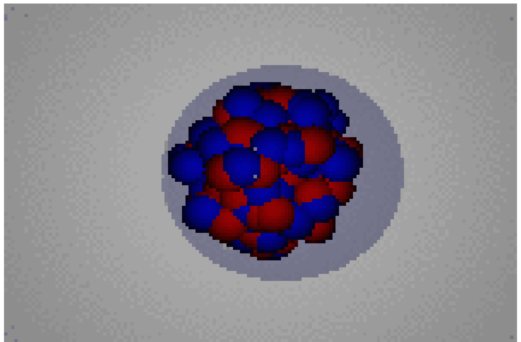


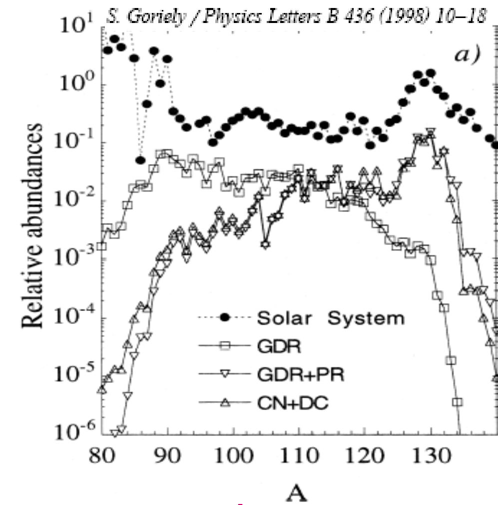
symmetry energy (ρ)



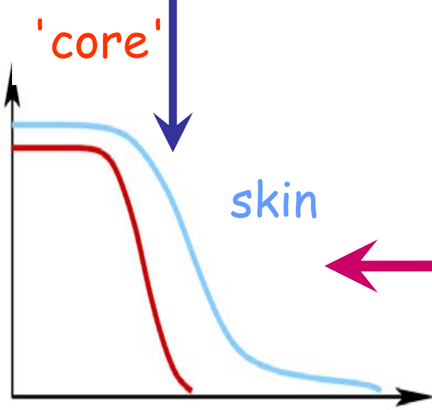
EQUATION OF STATE

Dipole response of exotic nuclei and the EOS





symmetry energy (ρ)



EQUATION OF STATE

symmetry energy of nuclear matter

Taylor expansion per nucleon in nuclear matter :

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

$$E(\rho,0) = -a_V + \frac{K_0}{18\rho_0^2}(\rho-\rho_0)^2 + \ldots$$

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

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

J = a_4: Symmetry energy per nucleon in pure neutron matter

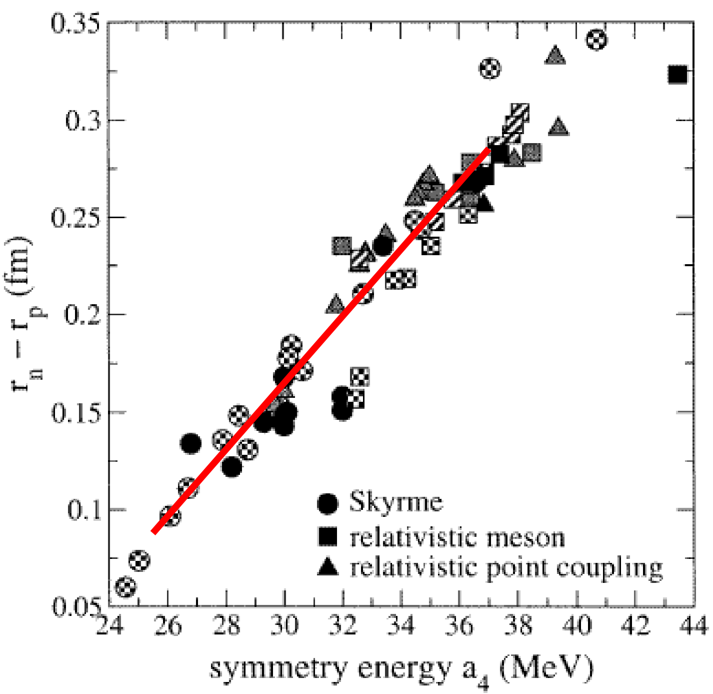
L ~ p_0: symmetry energy pressure

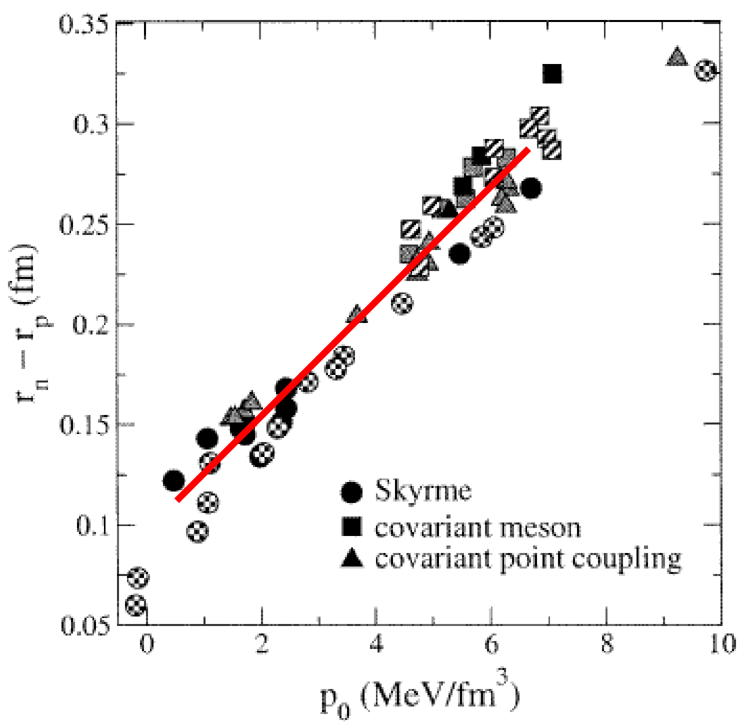
ΔK_0: correction to incompressibility

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

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

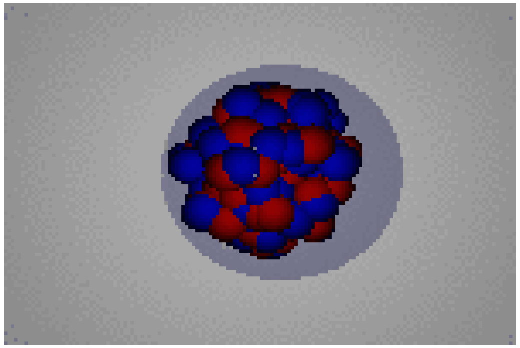
- strong **linear** correlation between neutron skin and **a_4, p_0**
- no distinct correlation to other quantities





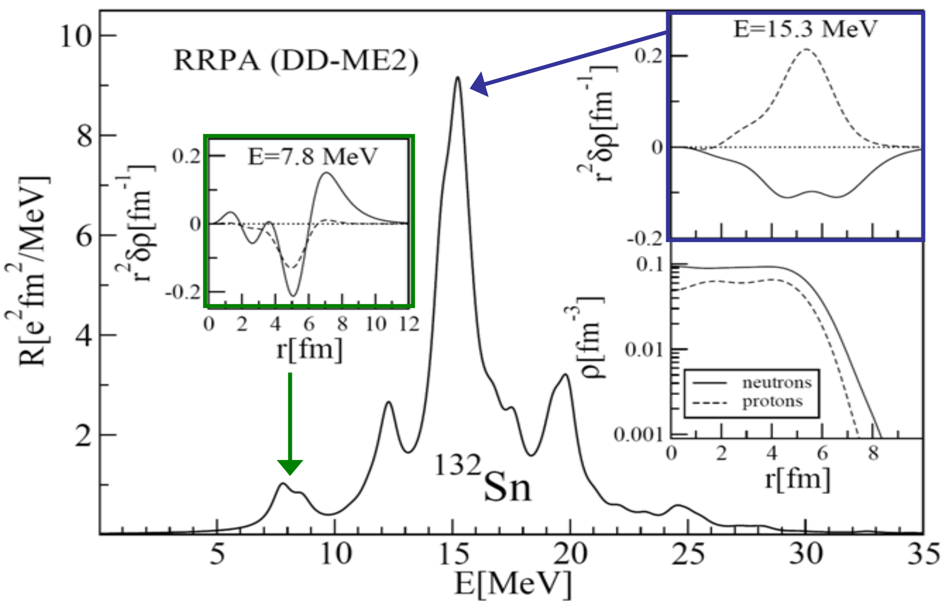
R.J.Furnstahl NPA 706(2002)85-110

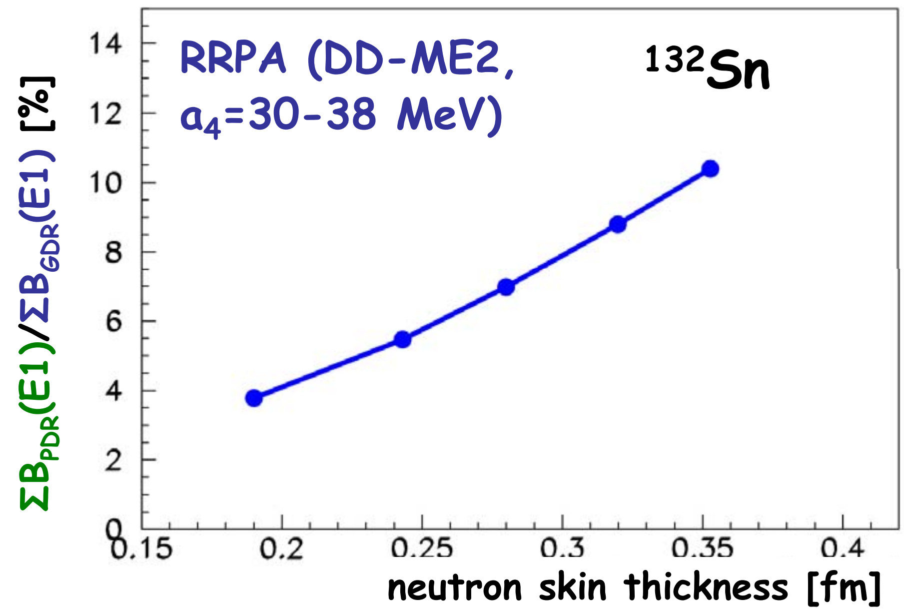
pygmy dipole resonance and neutron skin



"...,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



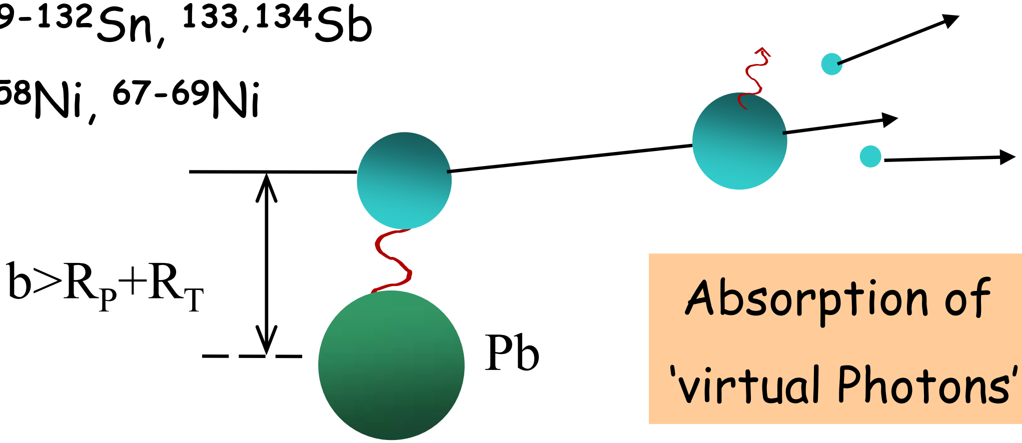


RQRPA N.Paar

Experimental Approach: Electromagnetic excitation at high energies

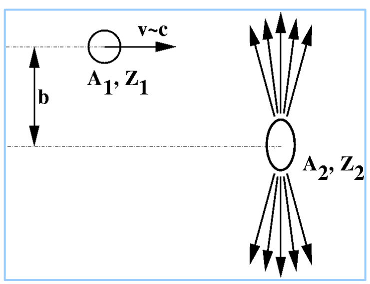
$^{129-132}$Sn, ^{133,134}Sb

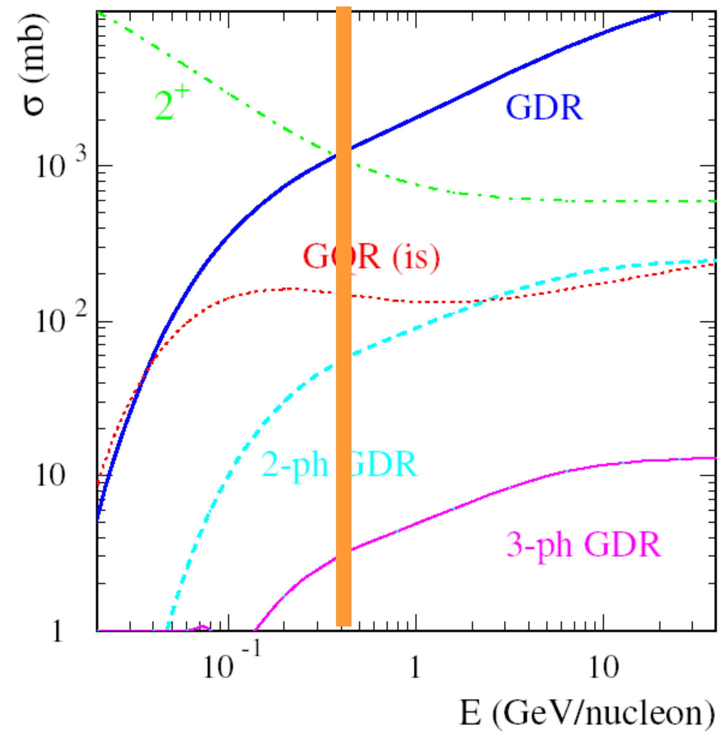
^{58}Ni, $^{67-69}$Ni



Absorption of 'virtual Photons'

$\sigma_{elm} \sim Z^2$





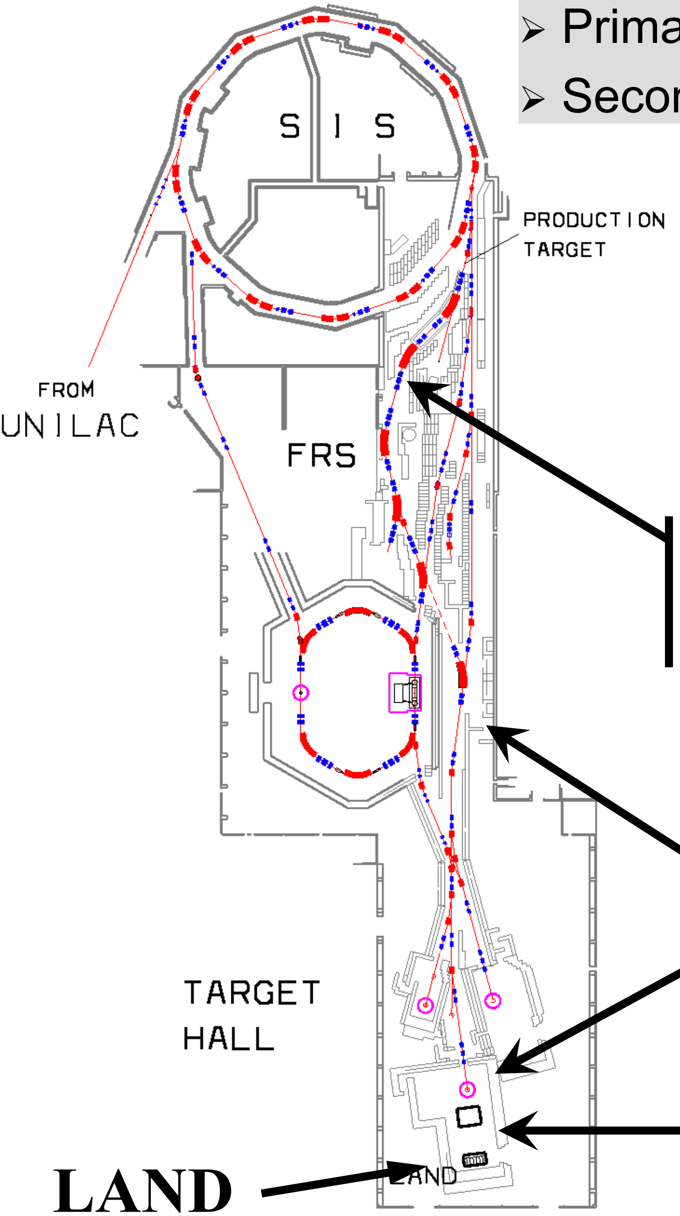
High velocities $\beta \approx 0.6$-0.9
$\Rightarrow$ High-frequency Fourier components
$E_{\gamma,max} \approx 18$ MeV (for $\beta=0.8$)

1st order pertubation theory:

$$d\sigma_{elm} / dE = N_\gamma(E)\, \sigma_\gamma(E)$$

Exp. Approach: 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)

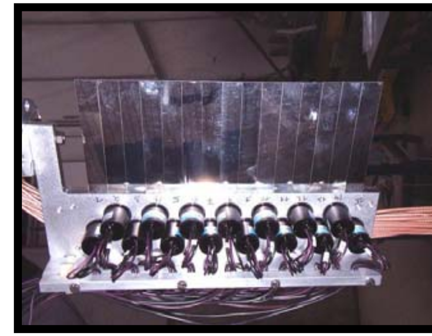


$$\frac{A}{Z} = \frac{e}{m_u c}\,\frac{B\rho}{\beta\gamma}$$

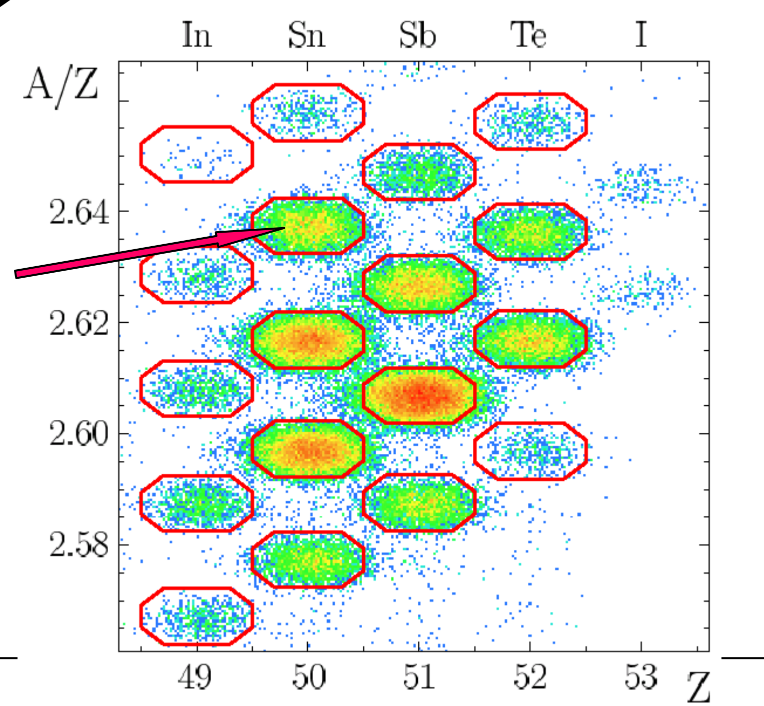
Bρ – from position at middle focal plane of the FRS

β – from TOF

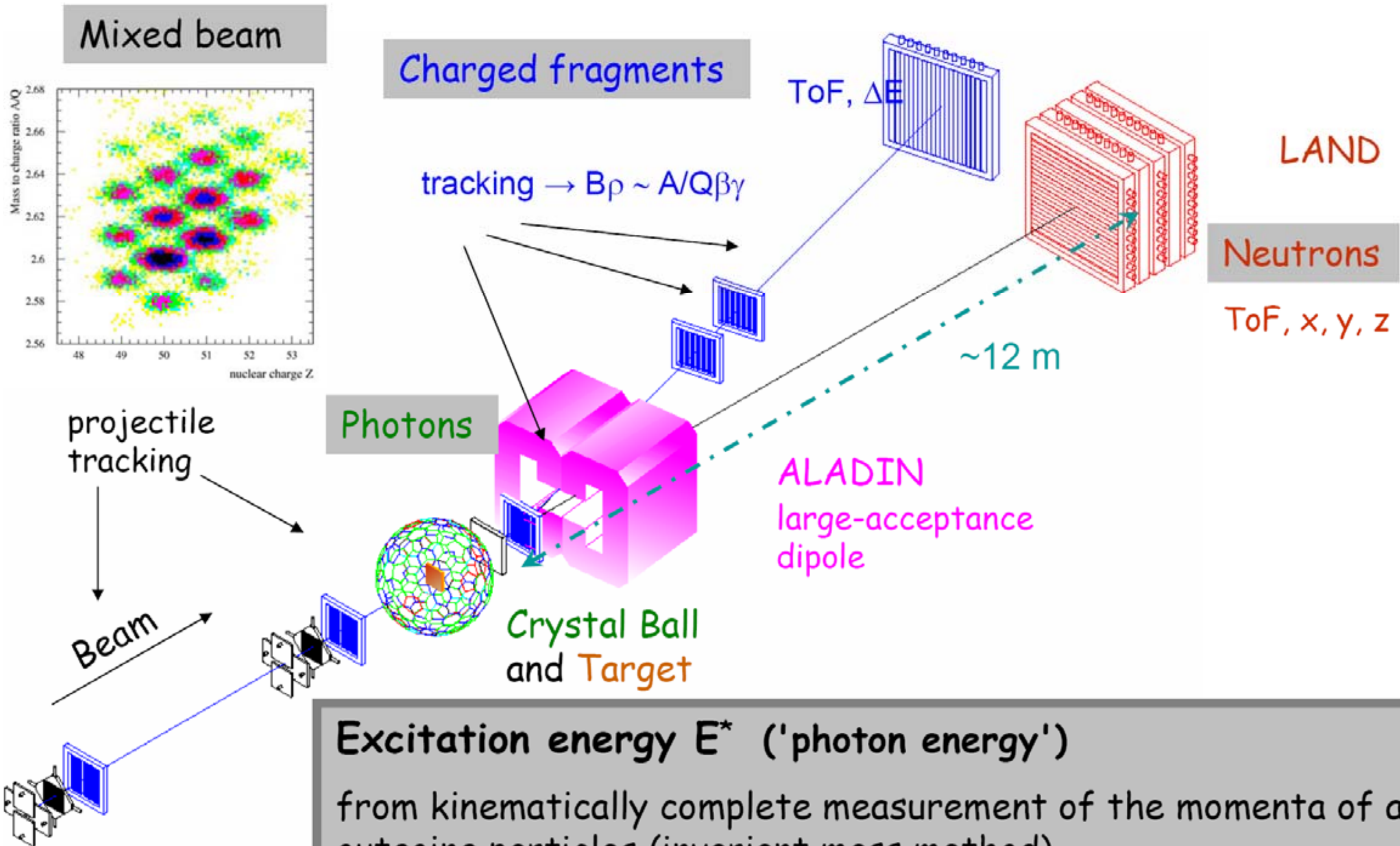
Z – from ΔE



^{132}Sn



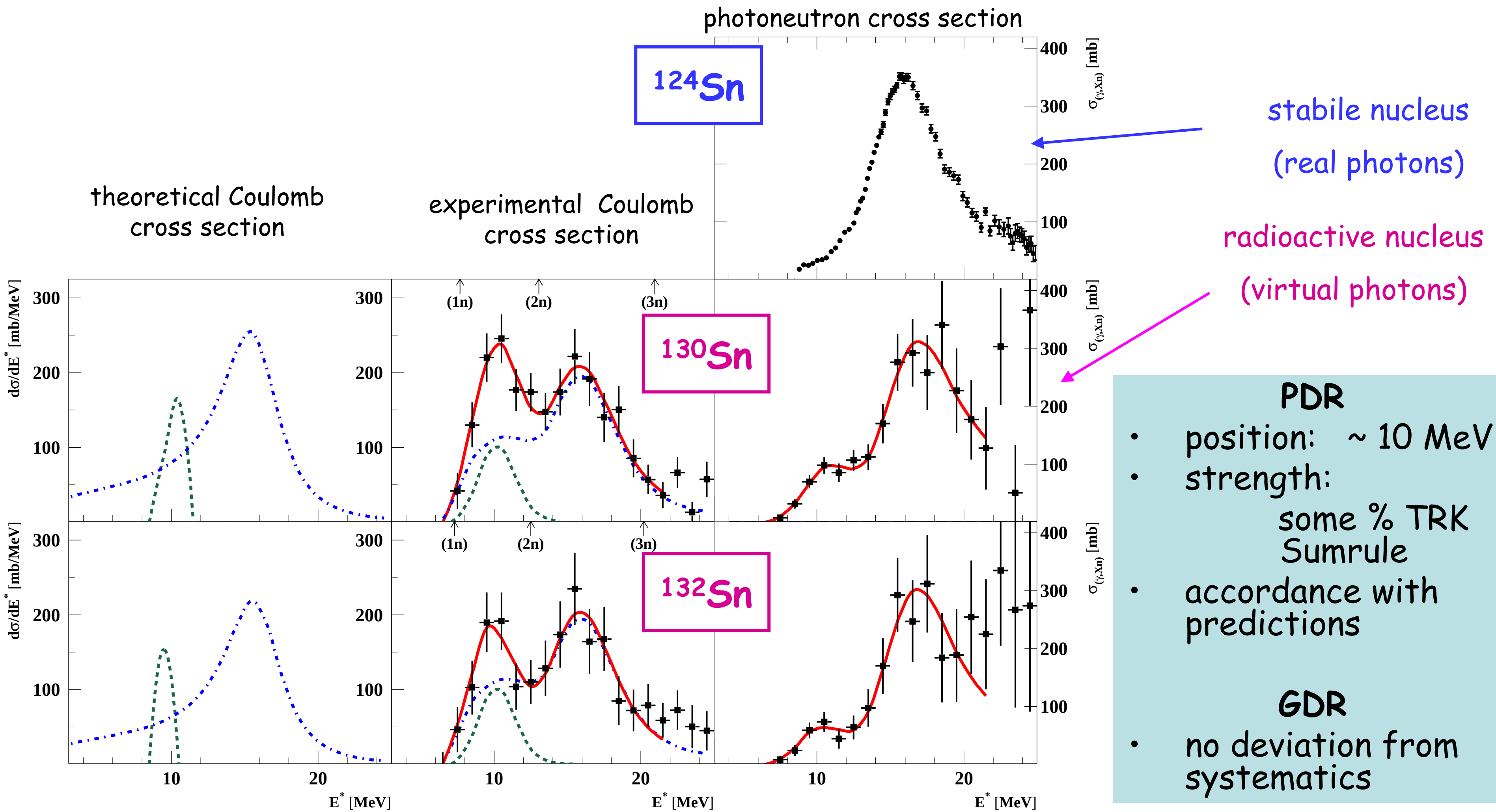
Experimental Approach: The LAND reaction setup @ GSI



Excitation energy E^* ('photon energy')

from kinematically complete measurement of the momenta of all outgoing particles (invariant mass method)

Results: even neutron rich Sn isotopes



PDR

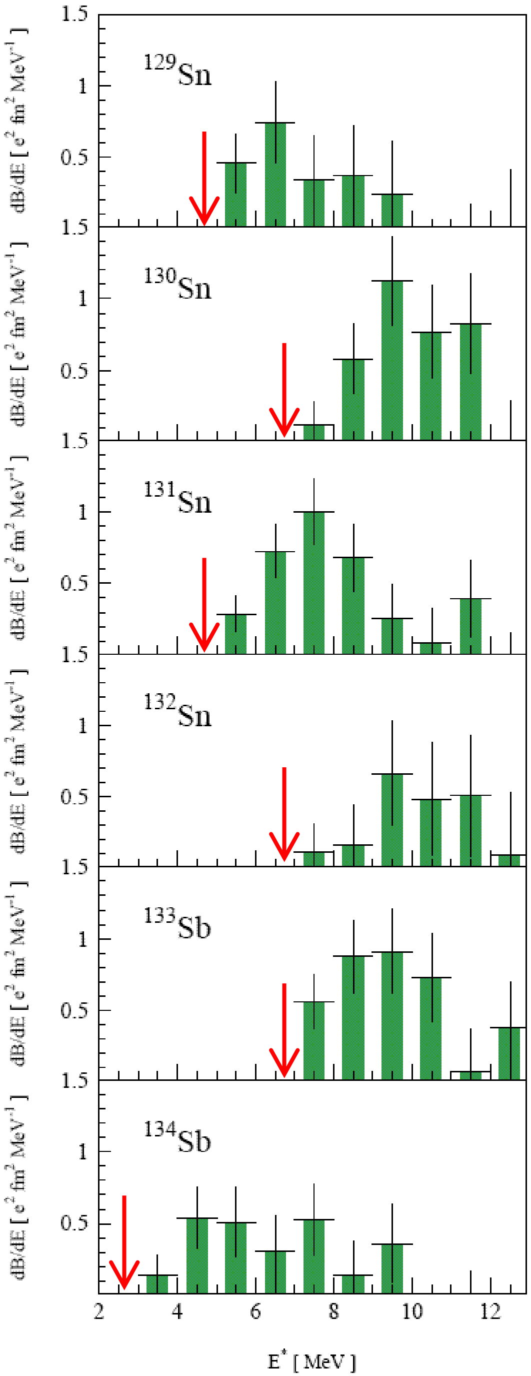
- position: ~ 10 MeV
- strength: some % TRK Sumrule
- accordance with predictions

GDR

- no deviation from systematics

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

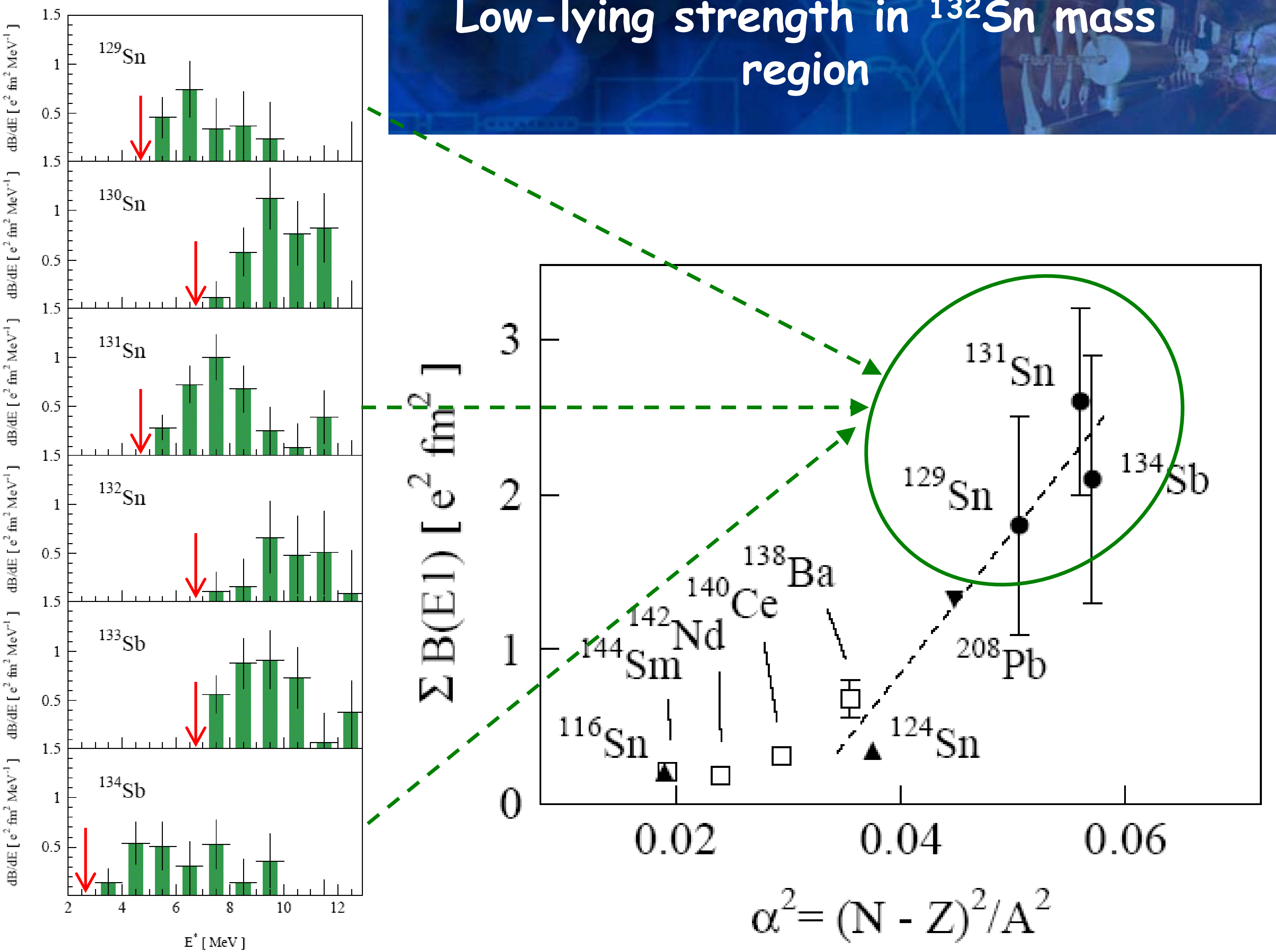
Low-lying strength in ^{132}Sn mass region



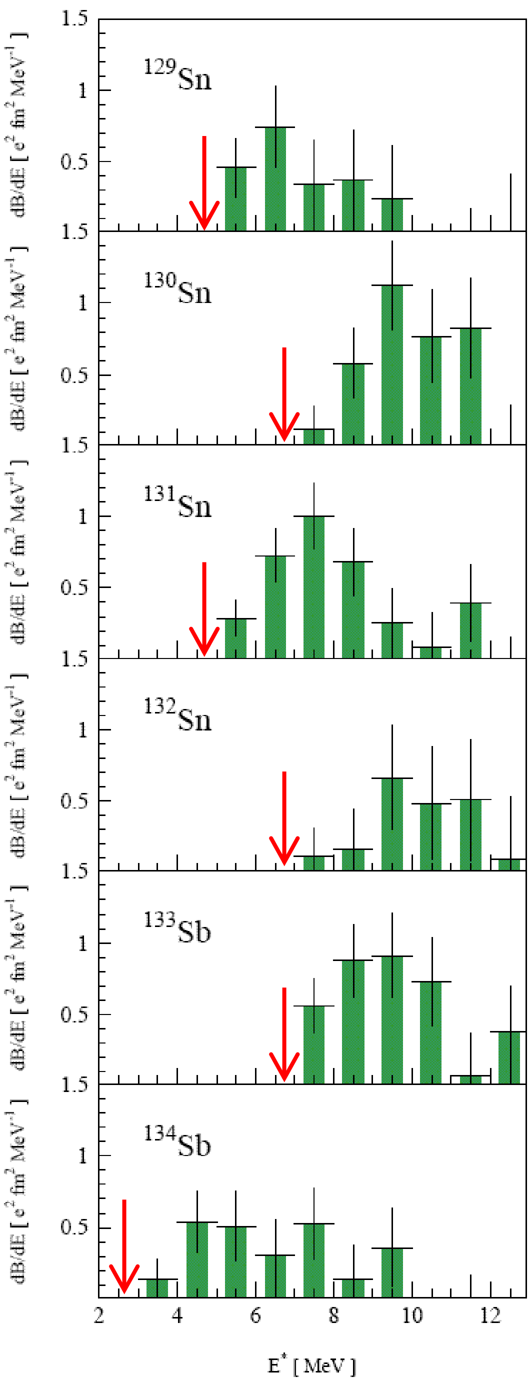
observed in **all** isotopes

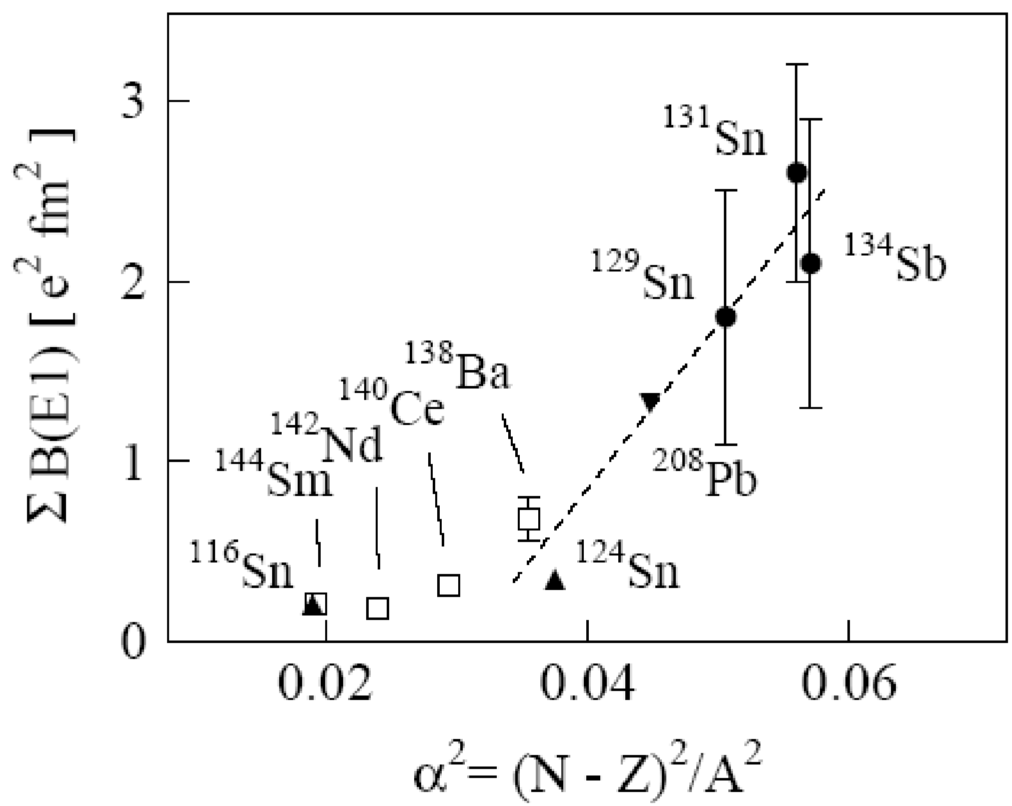
difference between even and odd isotopes due to neutron separation threshold location and unpaired neutrons

Low-lying strength in ^{132}Sn mass region



Low-lying strength in ^{132}Sn mass region





real photon measurements at S-Dalinac:

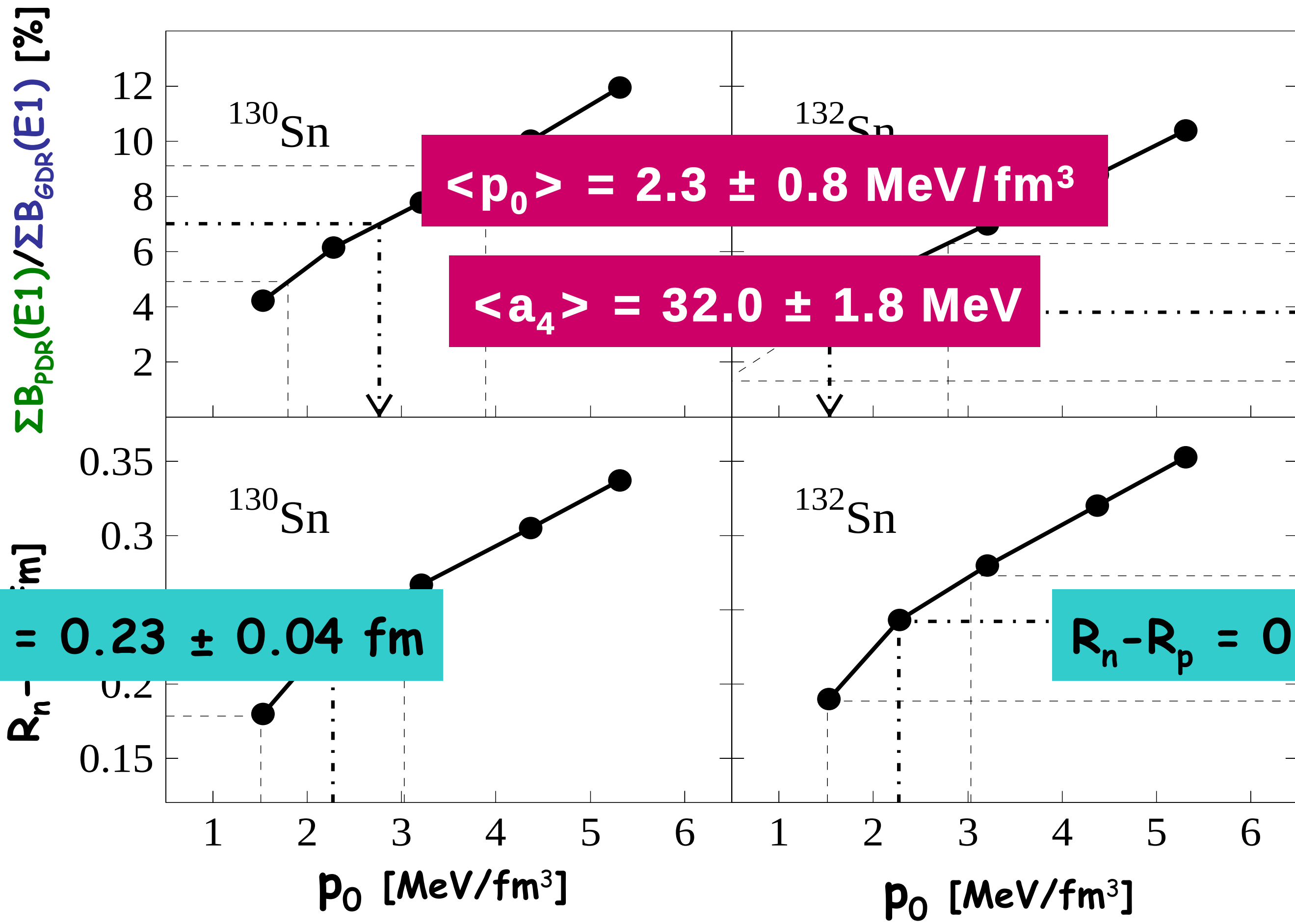
N=82: PLB 542 (2002) 43

208Pb: PRL 89 (2002) 272502

40-48Ca: PRL 93 (2004) 192501

116,124Sn: PRC 57 (1998) 2229

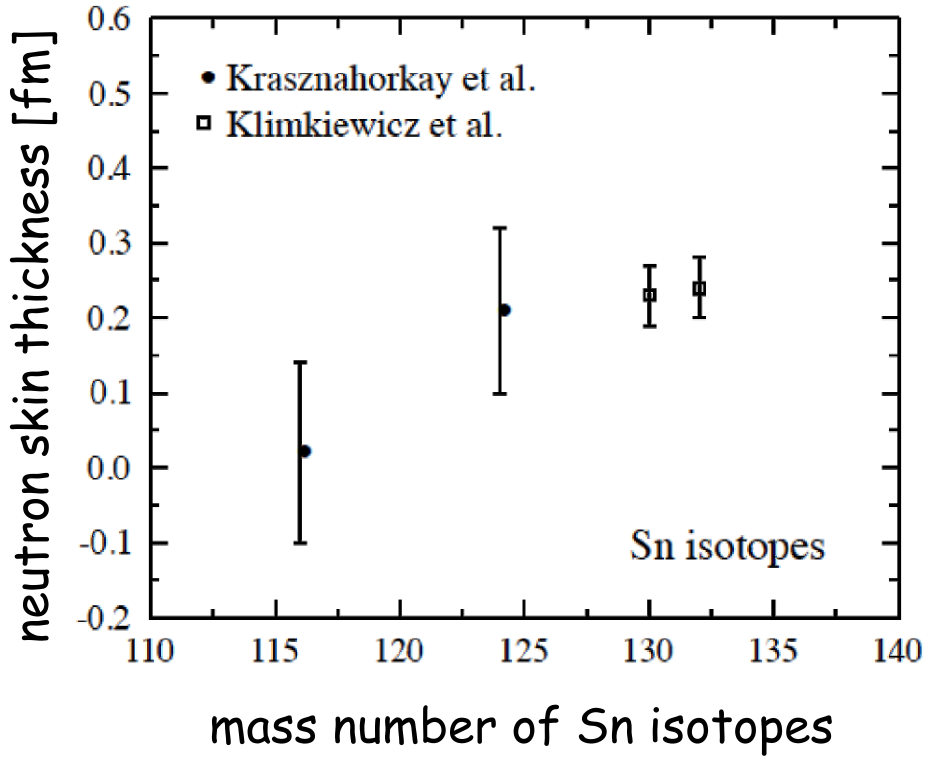
Asymmetry parameters and neutron skins from experimental dipole response



RQRPA calculations
from
N. Paar

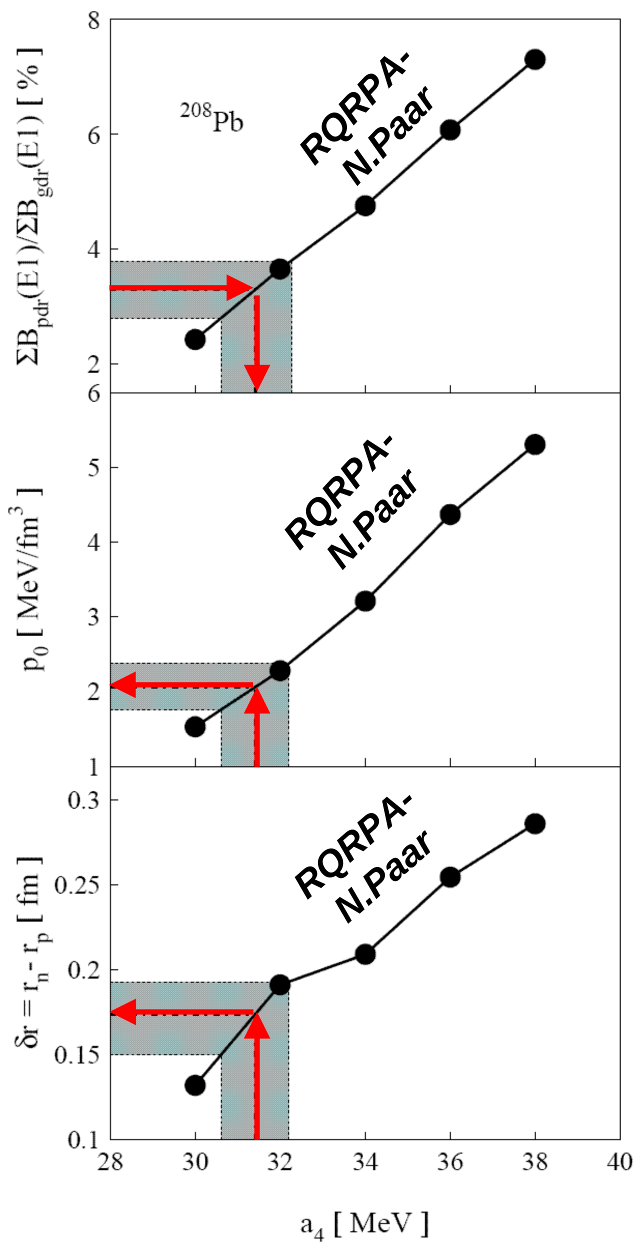
A. Klimkiewicz, N. Paar et al.,
PHYSICAL REVIEW C **76**, 051603(R) (2007)

neutron skin thickness in Sn isotopes



stable isotopes: iv. GDR method *A.Krasznahorkay et al., NPA **567** (1994) 521-540*
radioactive isotopes: PDR/GDR method *A. Klimkiewicz et al., PRC **76** (2007) 051603(R)*

^{208}Pb analysis



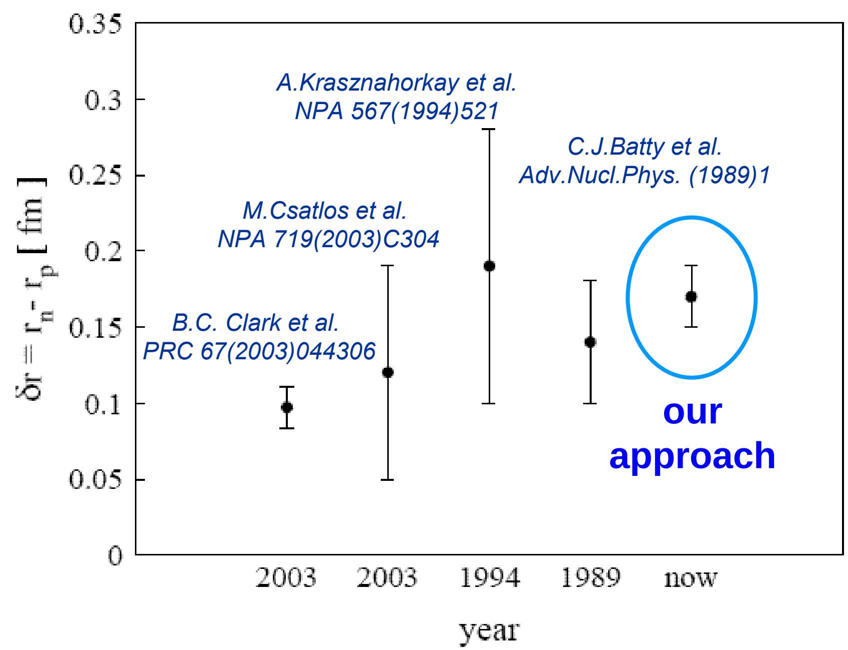
$\sum B_{pdr}(E1)=1.98\ e^2\ fm^2$

from N.Ryezayeva et al., PRL 89(2002)272501

$\sum B_{gdr}(E1)=60.8\ e^2\ fm^2$

from A.Veyssiere et al.,NPA 159(1970)561

$$a_4 = 31.4 \pm 0.8\ \text{MeV}$$
$$p_0 = 2.1 \pm 0.3\ \text{MeV / fm}^3$$
$$\delta r = 0.17 \pm 0.02\ \text{fm}$$

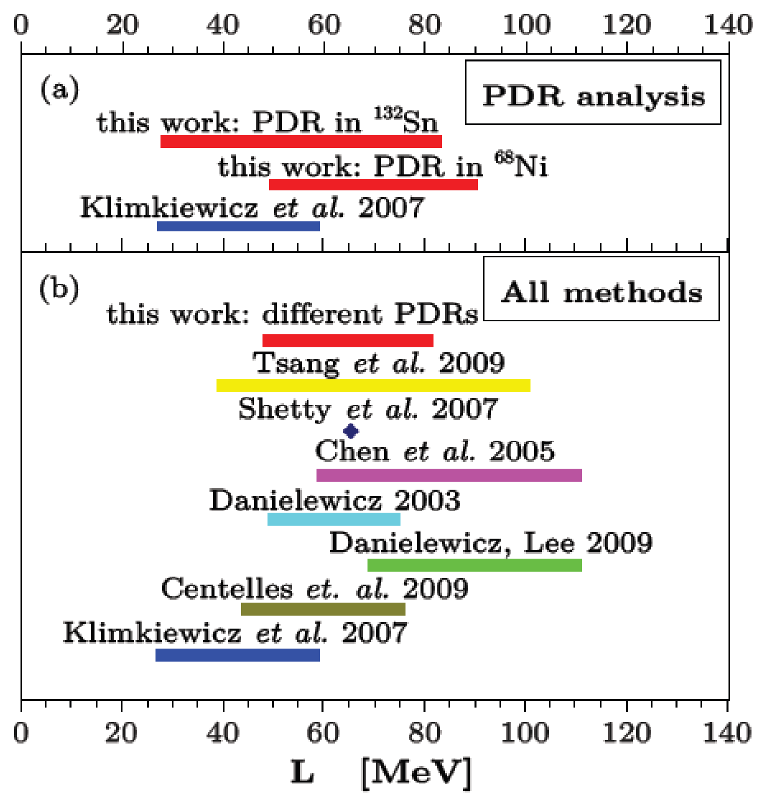


new contributions/contradictions

PHYSICAL REVIEW C **81**, 041301(R) (2010)

Constraints on the symmetry energy and neutron skins from pygmy resonances in ^{68}Ni and ^{132}Sn

Andrea Carbone,[1] Gianluca Colò,[1,2] Angela Bracco,[1,2] Li-Gang Cao,[1,2,3,4] Pier Francesco Bortignon,[1,2]
Franco Camera,[1,2] and Oliver Wieland[2]

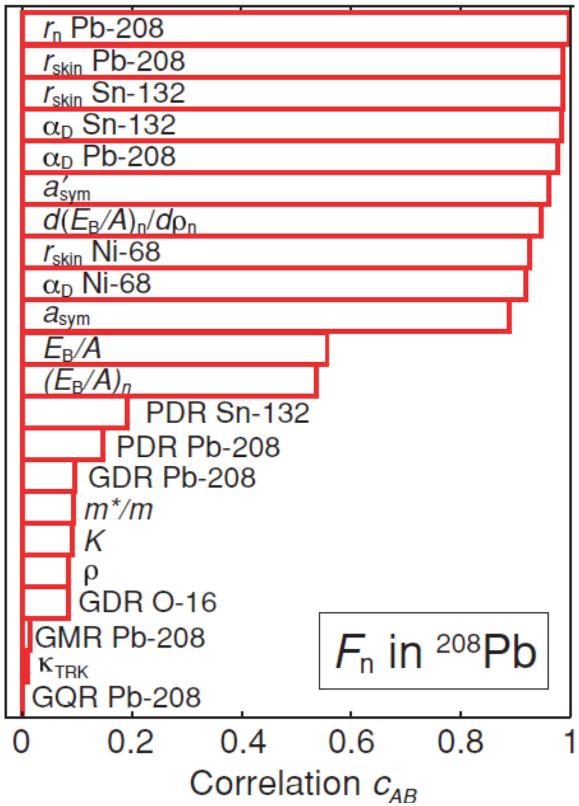


new contributions/contradictions

PHYSICAL REVIEW C **81**, 051303(R) (2010)

Information content of a new observable: The case of the nuclear neutron skin

P.-G. Reinhard[1] and W. Nazarewicz[2,3,4,5]



such as symmetry energy and pressure. An indicator that is particularly attractive, as it can be measured in finite nuclei, is dipole polarizability. Unfortunately, the current best experimental value of α_D in ^{208}Pb is not known precisely enough to offer an independent check on the neutron skin or to provide a quality constraint on EDF. We also demonstrate that nuclear and neutron matter binding energy, low-energy $E1$ strength, giant resonance energies, isoscalar and isovector effective mass, incompressibility, and saturation density are poor indicators of isovector properties, at least those related to r_{skin}.

$$\int \frac{\sigma(\omega)}{\omega^2} d\omega \equiv 2\pi^2 \frac{e^2}{\hbar c} \alpha_D$$

open questions

- **theory:**
  - connection between PDR and symmetry energy parameters?

- **experiment:**
  - systematics of dipole strength function? (mass, binding energies, asymmetry…)
    → new more systematic measurements
  - collectivity?
    → decay modes (direct gamma and particle decay modes)
  - role of the particle threshold?
    → sensitivity above and below threshold for exotic nuclei
    → connection to measurements for stable nuclei
  - structure of low-lying strength?
    → use of different probes, i.e. isoscalar probes
  - PDR strength in proton-rich nuclei?
    → adressed in ^{32}Ar experiment – under analysis

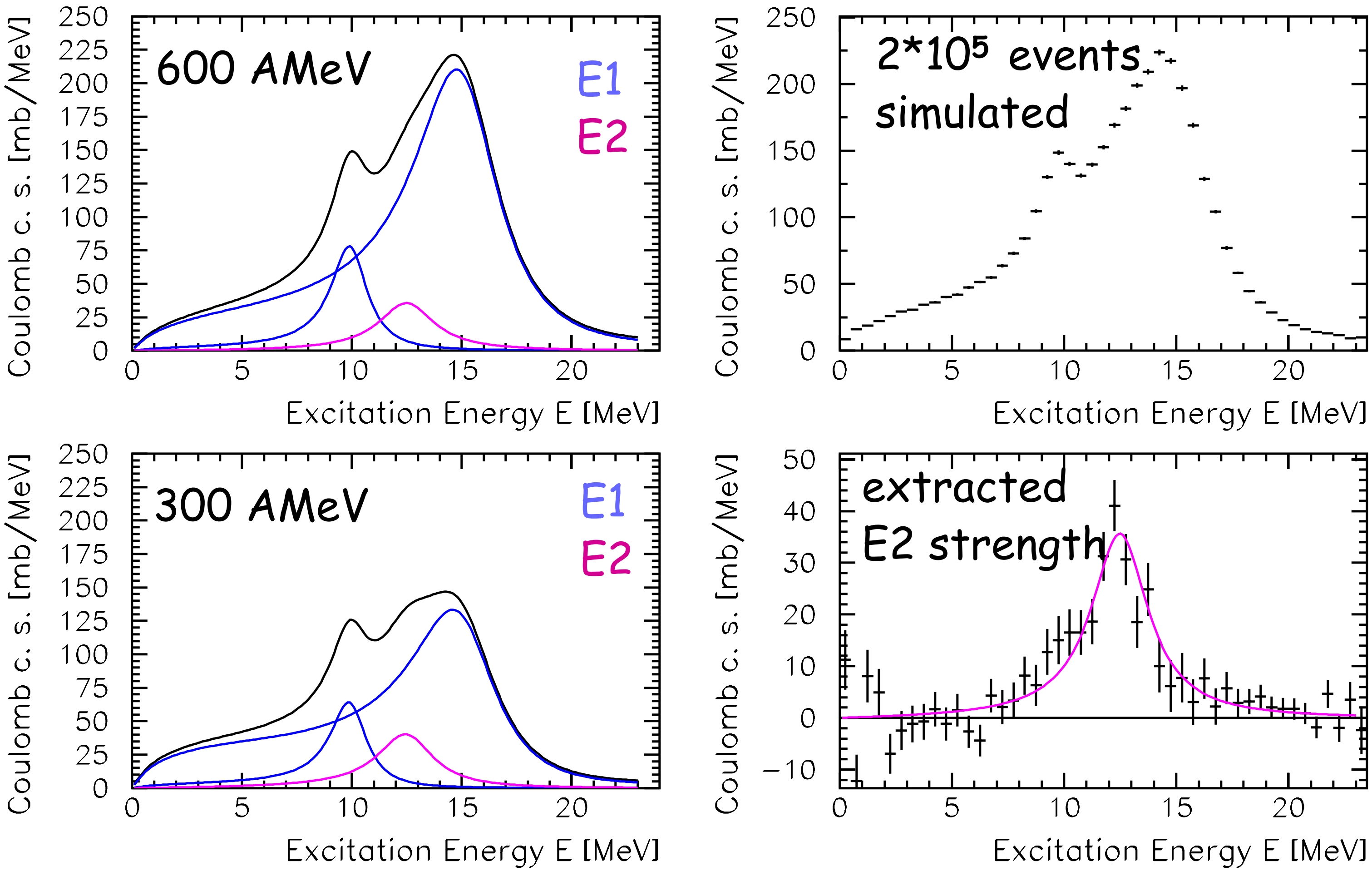
Isovector and isoscalar electric dipole and quadrupole response of neutron-rich Sn nuclei

accepted proposal at GSI

What is new?

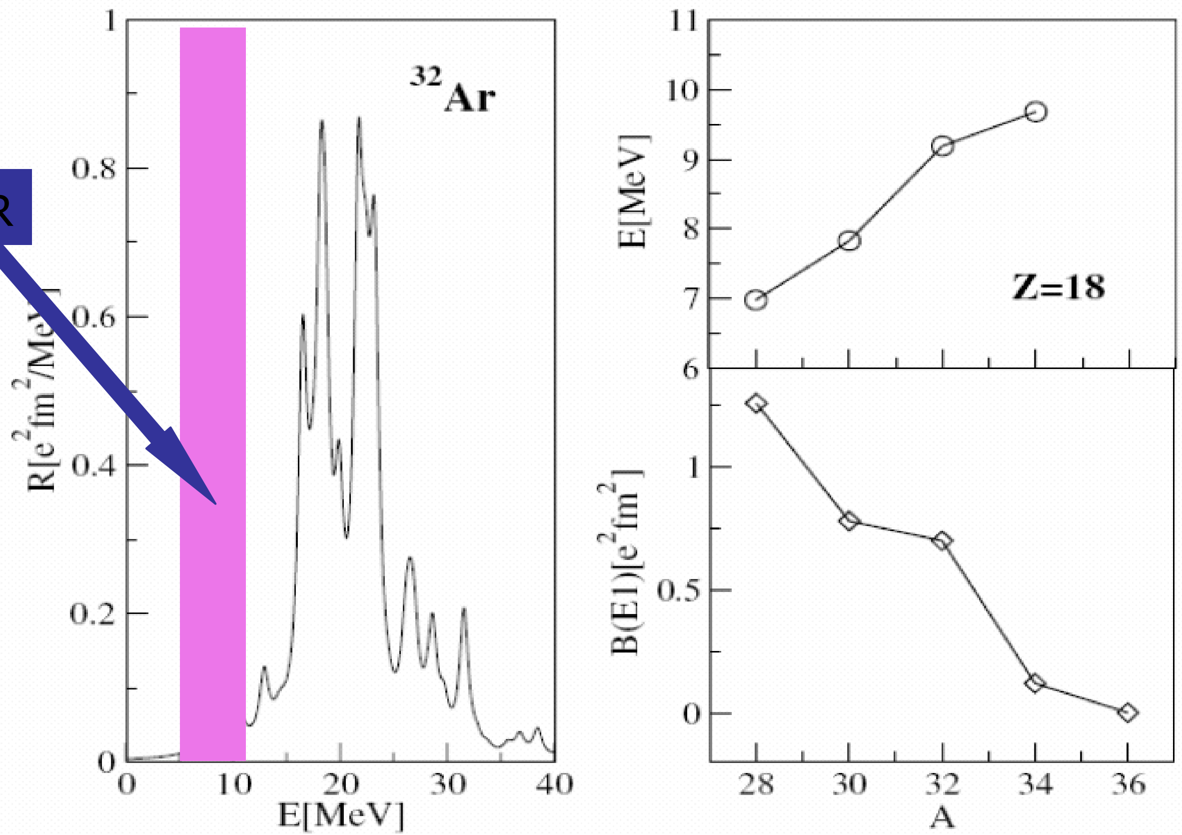
- adress ^{124}Sn to ^{134}Sn
- higher intensities
- higher resolution, better mass reconstruction, less complex detector response system
- measurement above and below the neutron threshold
- determination of E2 components
- excitation via an isoscalar probe using CD_2 target

Coulombexcitation of ^{132}Sn on Pb target at 300 and 600 AMeV



proton pygmy predictions

≈ 6 % EWSR

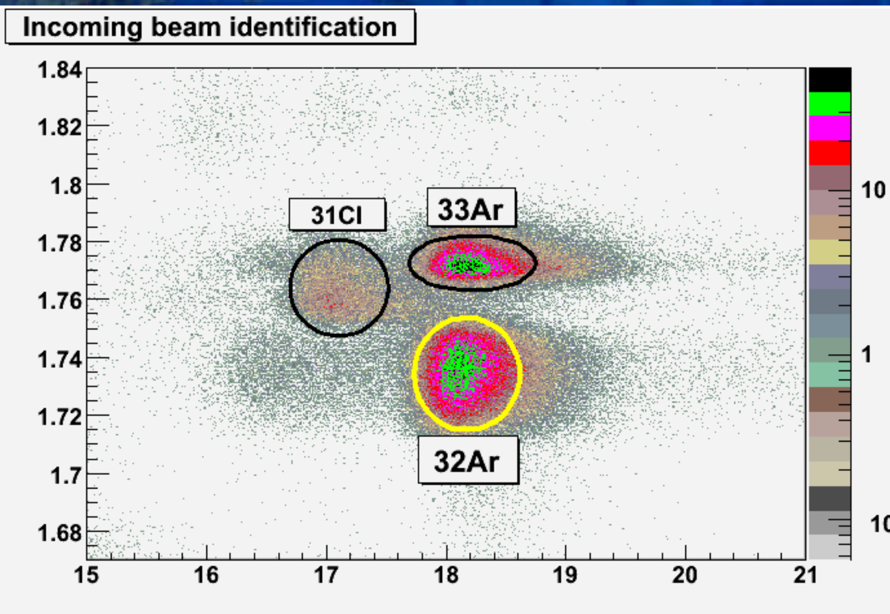


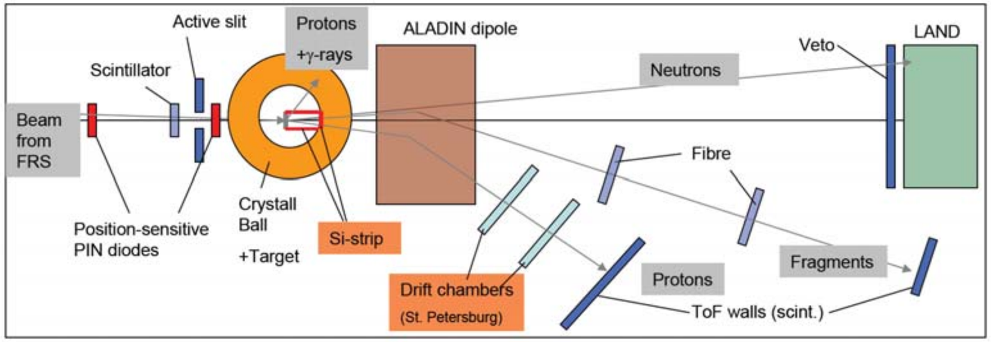
N.Paar et al.,

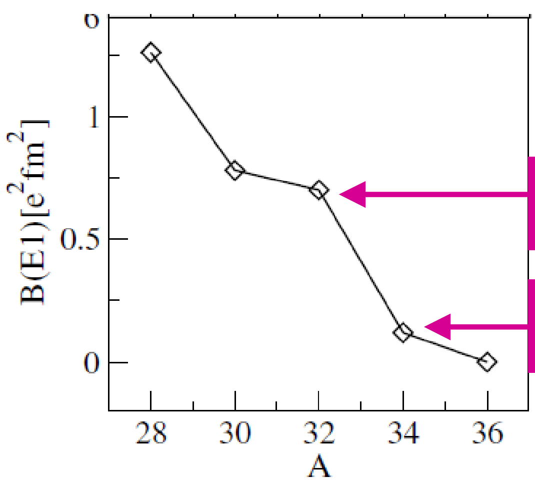
Phys.Rev.Lett. 94 (2005) 182501

Fig.1: *The isovector dipole strength distribution in ^{32}Ar, calculated in the framework of RHB and RQRPA (left panel). In the right panel the mass dependence of the pygmy peak and the corresponding integrated dipole strength below 10 MeV are shown. From [Paa-05b].*

Dipole response studies in ^{32}Ar and ^{34}Ar







statistics expected:

^{32}Ar ~500 events in PDR region, ~1000 in GDR region

^{34}Ar ~150 events in PDR region, ~1500 in GDR region

The LAND-FRS Collaboration

$^{127-132}$Sn (Exp. S221) – $^{57-72}$Ni (Exp. S287)

A. Klimkiewicz[1,2], N. Paar[3], P. Adrich[1,2], M. Fallot[1], T. le Bleis[4,5], D. Rossi[6], K. Boretzky[1], T. Aumann[1], H. Alvarez-Pol[7], F. Aksouh[1], K.H. Behr[1], J. Benlliure[7], T. Berg[6], M. Boehmer[8], A. Bruenle[1], E. Casarejos[7], M. Chartier[9], A. Chatillon[1], D. Cortina-Gil[7], U. Datta Pramanik[10], Th.W. Elze[5], H. Emling[1], O. Ershova[1,4], B. Fernando-Dominguez[9], H. Geissel[1], M. Gorska[1], M. Heil[1], M. Hellström[1], G. Ickert[1], H. Johansson[1,11], K. Jones[1], A. Junghans[12], O. Kiselev[6], J.V. Kratz[6], R. Kulessa[2], N. Kurz[1], M. Labiche[13], R. Lemmon[14], Y. Litvinov[1], K. Mahata[1], P. Maierbeck[8], T. Nilsson[11], C. Nociforo[1], R. Palit[1], S. Paschalis[9], R. Plag[1,6], W. Prokopowicz[1], R. Reifarth[1,6], H. Simon[1], K. Sümmerer[1], G. Surówka[2], D. Vretenar[3], A. Wagner[12], W. Waluś[2], H. Weick[1], and M. Winkler[1]

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