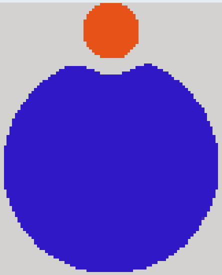
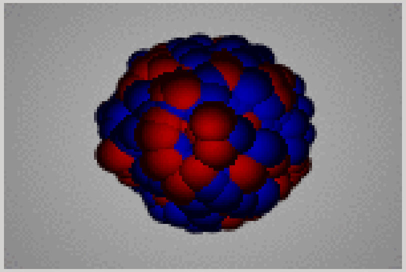
Determination of neutron-skin thickness from giant resonance studies





A. Krasznahorkay, N. Paar, D. Vretenar

for the R3B and EXL collaborations

Strongly interacting bulk matter at the nuclear, hadronic and partonic levels

Nuclear Equation of State **(Relationship between energy, temperature pressure, and density in nuclear matter)**

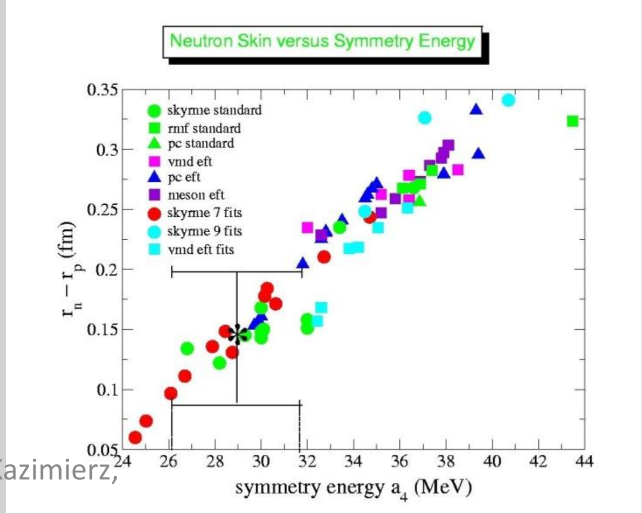
✓*Nuclear Astrophysics* – *What is the nature of neutron stars and dense nuclear matter?*

✓ *Nuclear Structure* – *What is the nature of the nuclear force that binds protons and neutrons into stable nuclei and rare isotopes?*

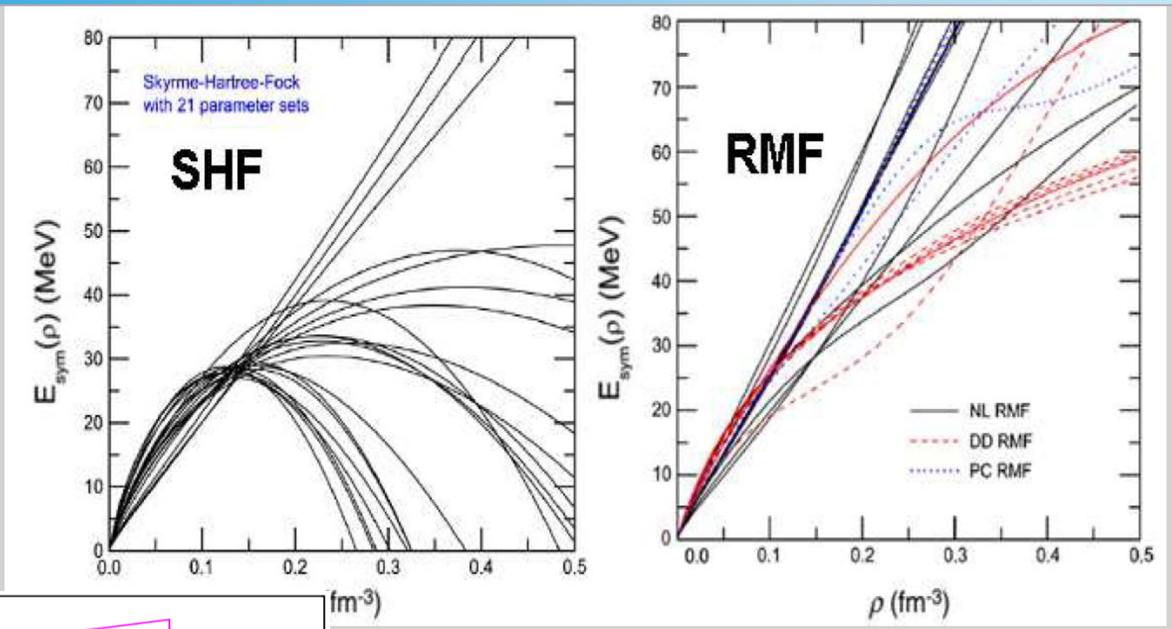
$$E(\rho,\alpha) = E(\rho,0) + S(\rho)\alpha^2 + O(\alpha^4) + \ldots$$

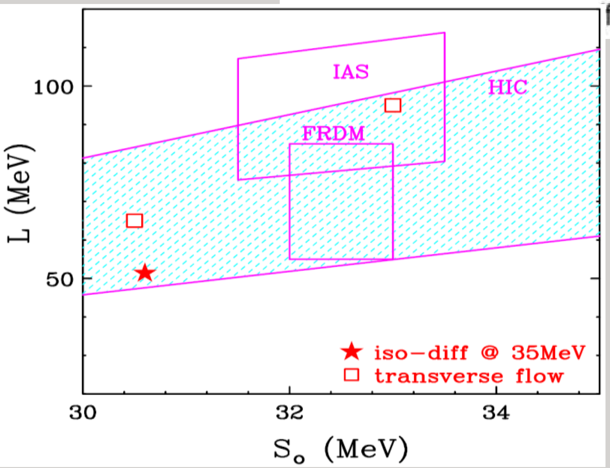
$$\alpha = \frac{N-Z}{A}$$

$$S(\rho) = \frac{1}{2}\frac{\partial^2 E(\rho,\alpha)}{\partial \alpha^2}\Big|_{\alpha=0} = a_4 + \frac{p_0}{\rho_0^2}(\rho-\rho_0) + \ldots$$

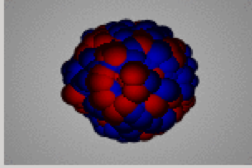


The symmetry energy and their density dependence





M.B. Tsang et al., PRC 86 (2012) 015802.



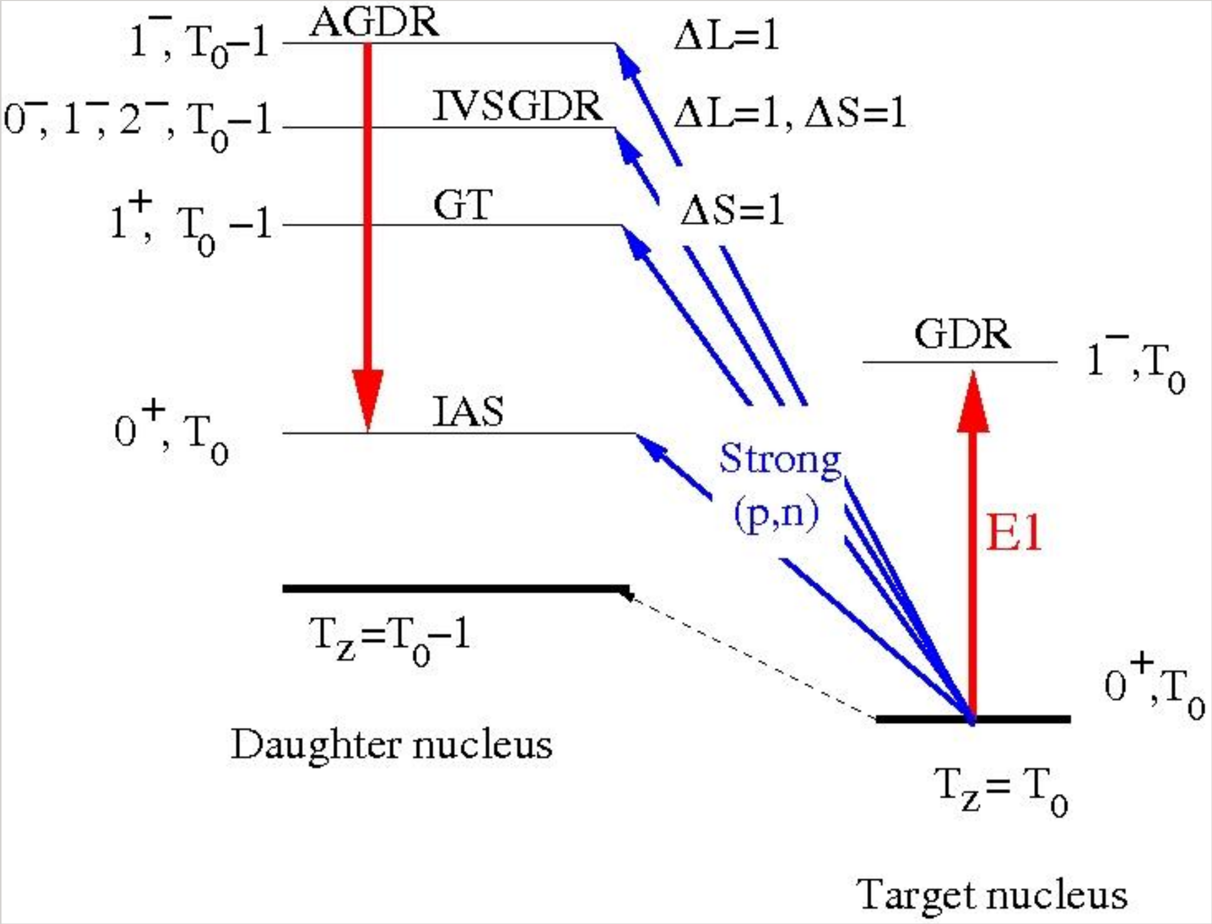
Experiment S408 at GSI

Spokesperson: A. Krasznahorkay

- Excitation of the Antianalog Giant Dipole Resonance (AGDR) in (p,n) reaction
- Very little quenching, and it is precisely known for the whole nuclear chart
- Ground-state γ-decay of the GDR

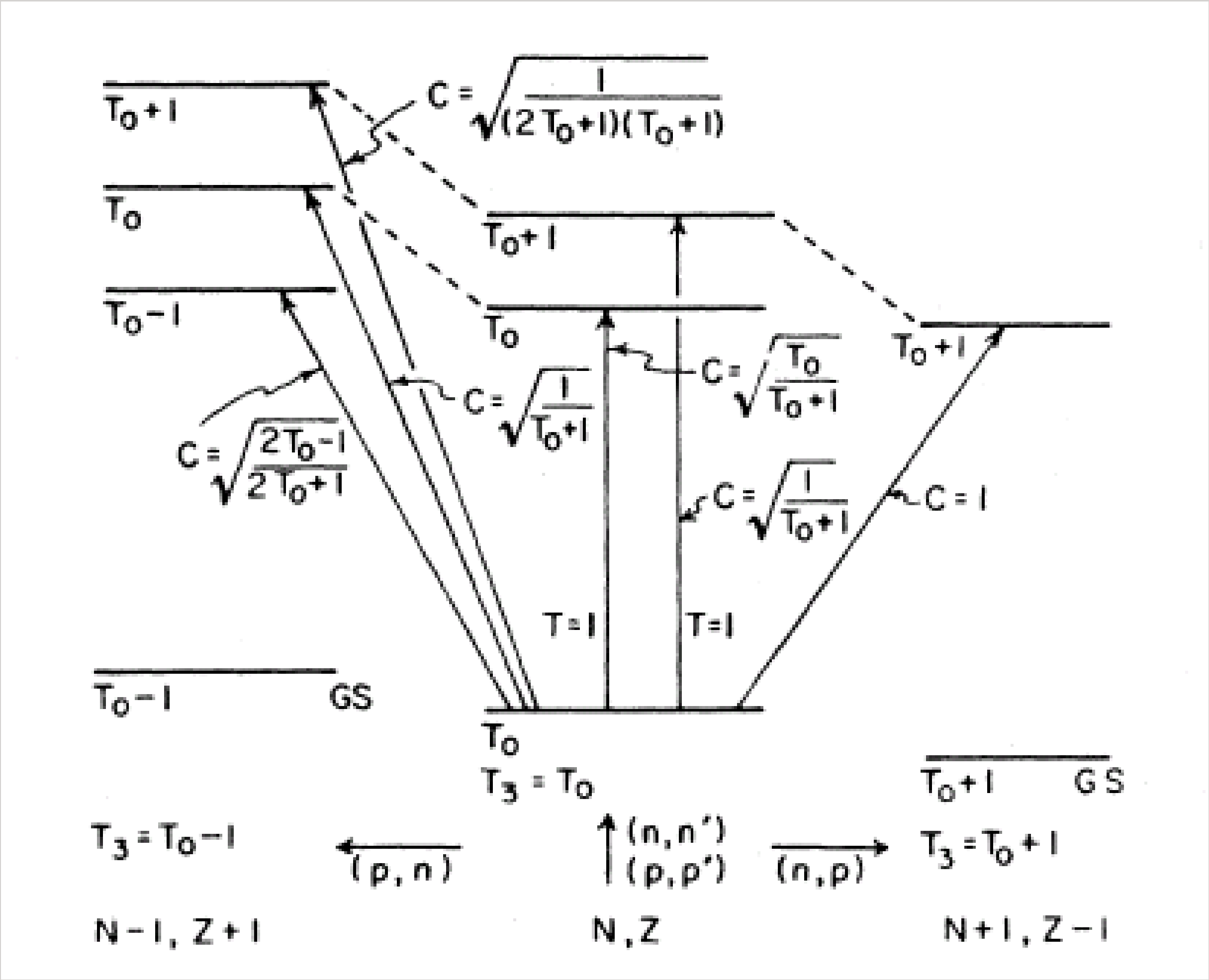
$$\frac{\Gamma_\gamma(E_\gamma)}{\Gamma} = \frac{E_\gamma^2}{3\pi^2\hbar c\Gamma}\int \sigma_{abs}(E_\gamma)dE_\gamma$$

Excitation and γ-decay of the AGDR



Isospin Clebsch-Gordan coefficients

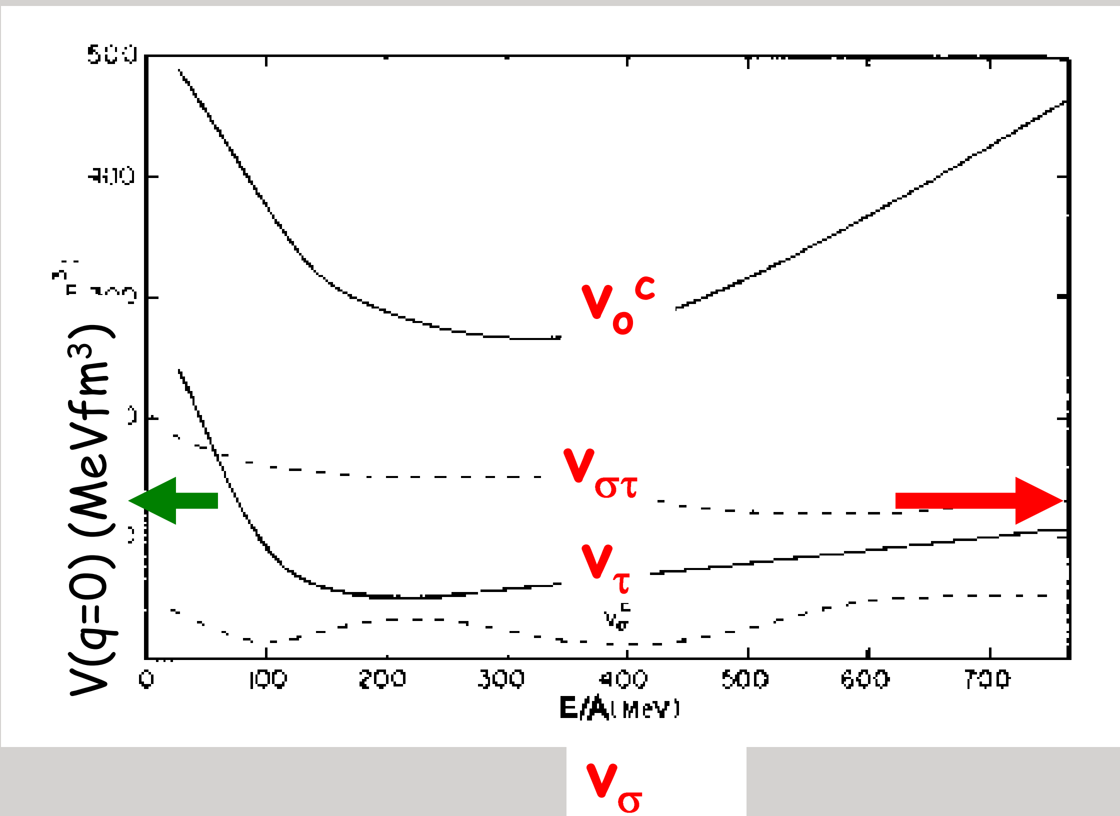
(F. Osterfeld, Rev. Mod. Phys. , **64**, (1992), 491)

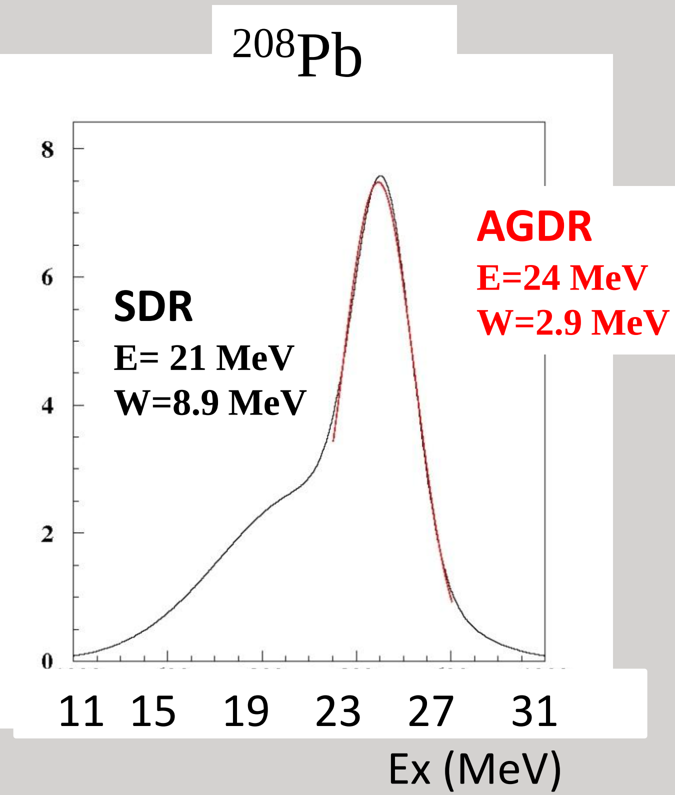


PHYSICAL REVIEW C, VOLUME 63, 034322 (2001)

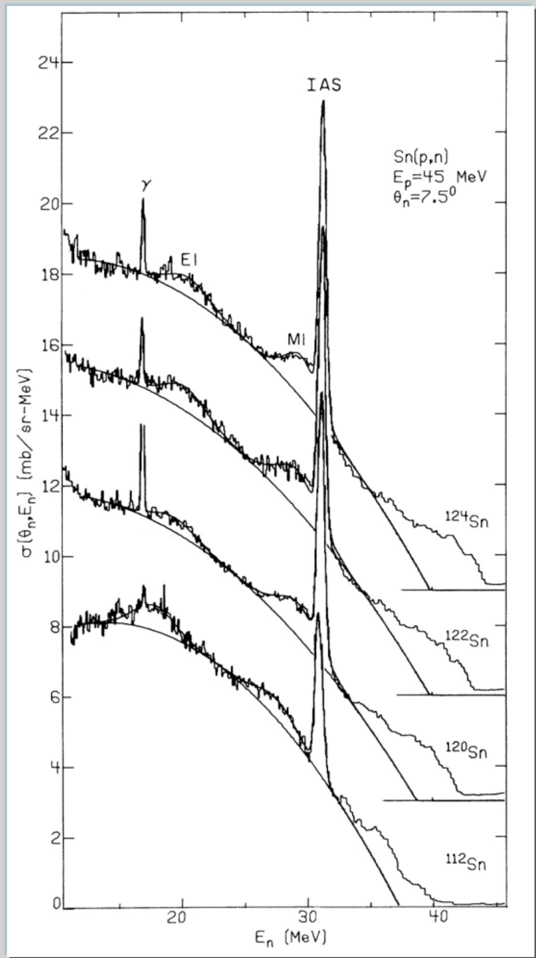
Splitting of the dipole and spin-dipole resonances

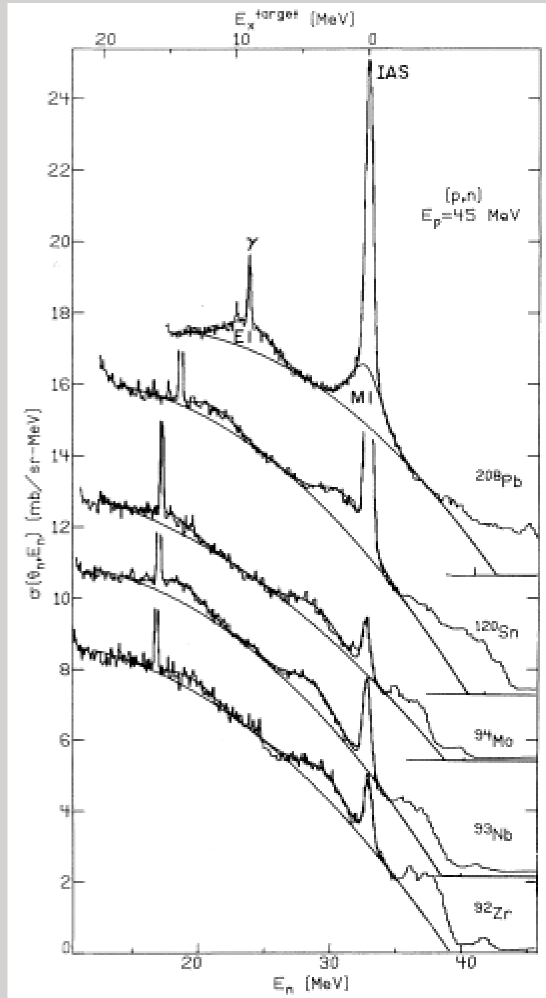
Sam M. Austin,[1,*] E. Adamides,[1] A. Galonsky,[1] T. Nees,[1] W. A. Sterrenburg,[1,†] D. E. Bainum,[2,‡] J. Rapaport,[3] E. Sugarbaker,[4,§] C. C. Foster,[5] C. D. Goodman,[5] D. J. Horen,[6,∥] C. A. Goulding,[7,¶] and M. B. Greenfield[7,**]
[1] *National Superconducting Cyclotron Laboratory and Department of Physics and Astronomy, Michigan State University, East Lansing, Michigan 48824*

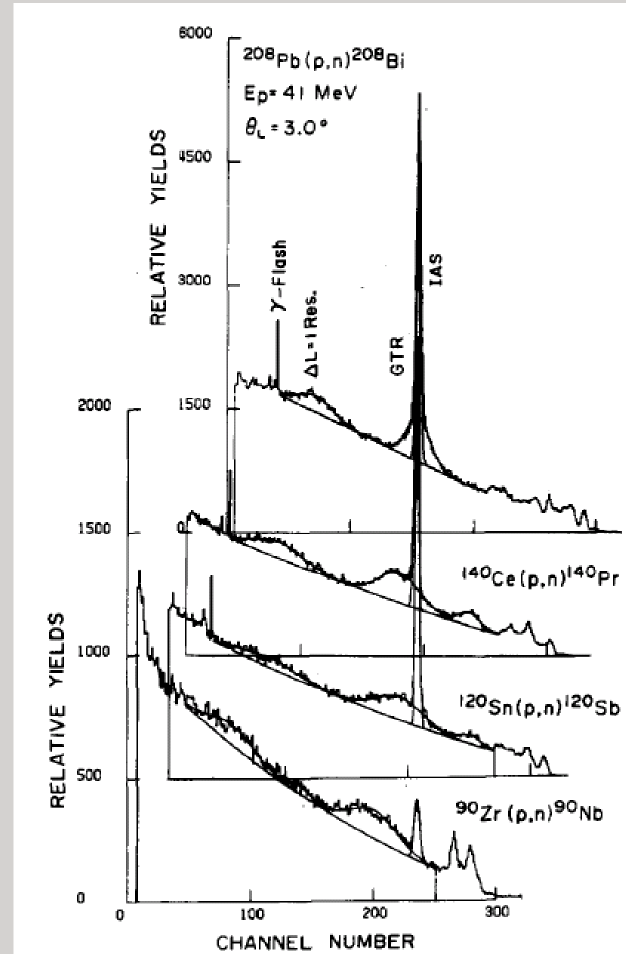




Experimental data for the AGDR



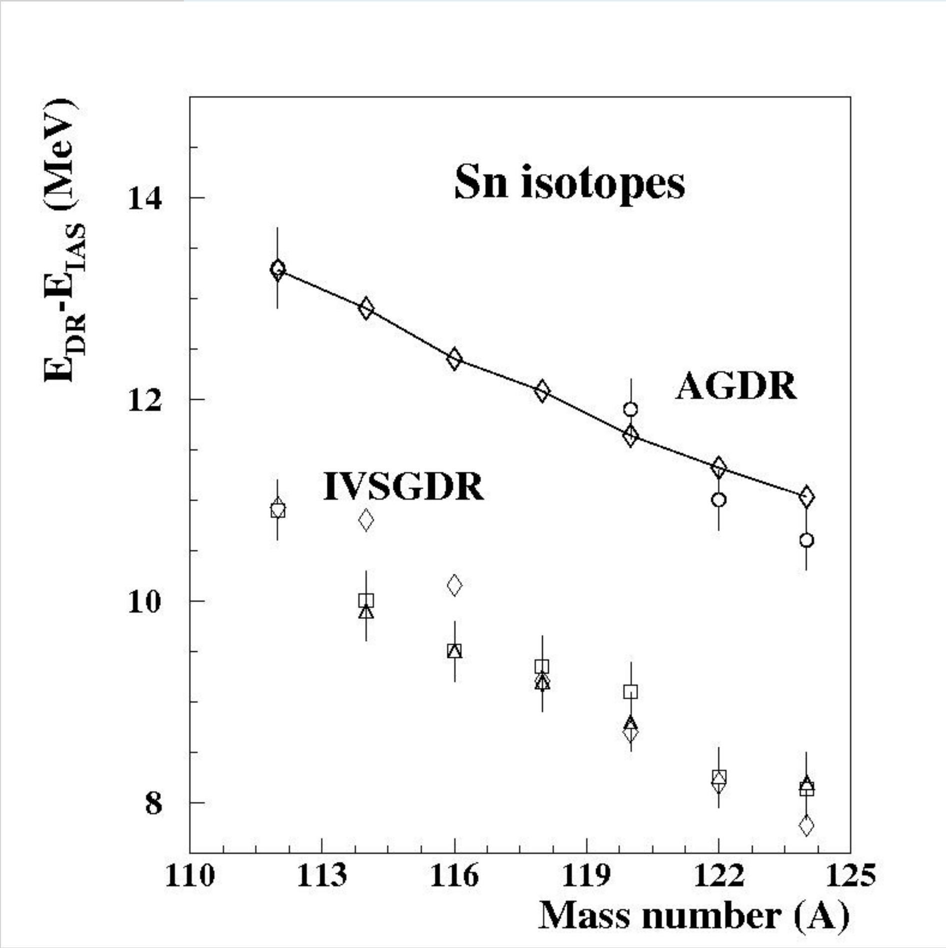


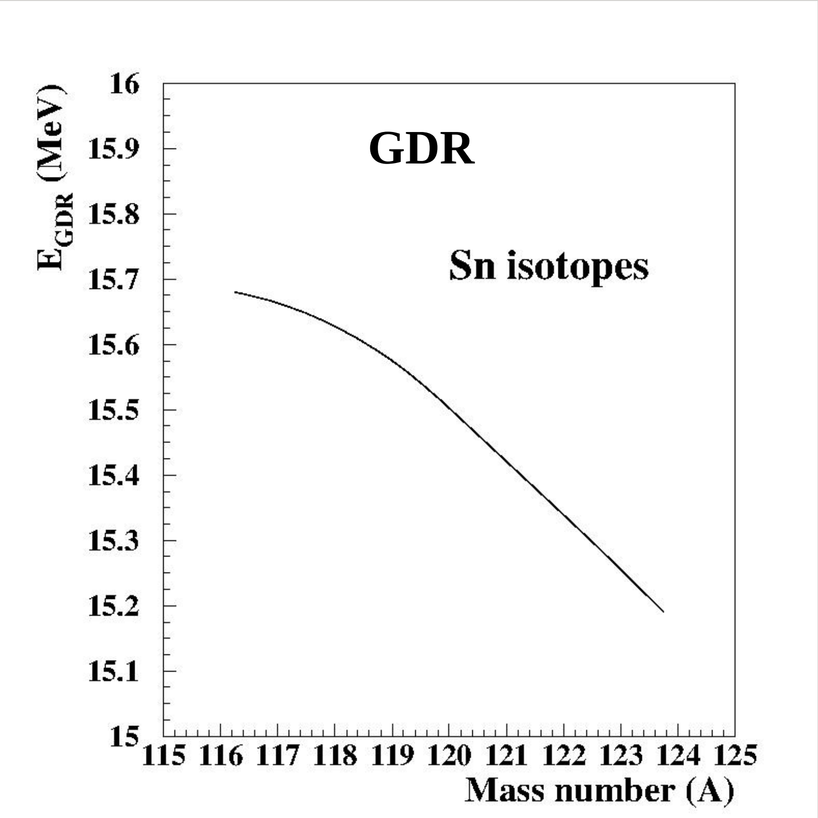


Sterrenburg et al., Phys. Rev. Lett. 45, 1839 (1980). L= 7 m.

S. Nishihara et al., Phys. Lett. B 160, 369 (1985). L= 18 m.

Energy of the AGDR and the IVSGDR (SDR) resonances





Sum rules

$$S^- - S^+ = N\langle r_n\rangle^2 - Z\langle r_p\rangle^2$$

A. Krasznahorkay et al., PRL 82, 3216 (1999).

$$S^- E^- + S^+ E^+ = \left(\frac{3\hbar^2}{4\pi m}\right) A(1+\kappa+\eta)$$

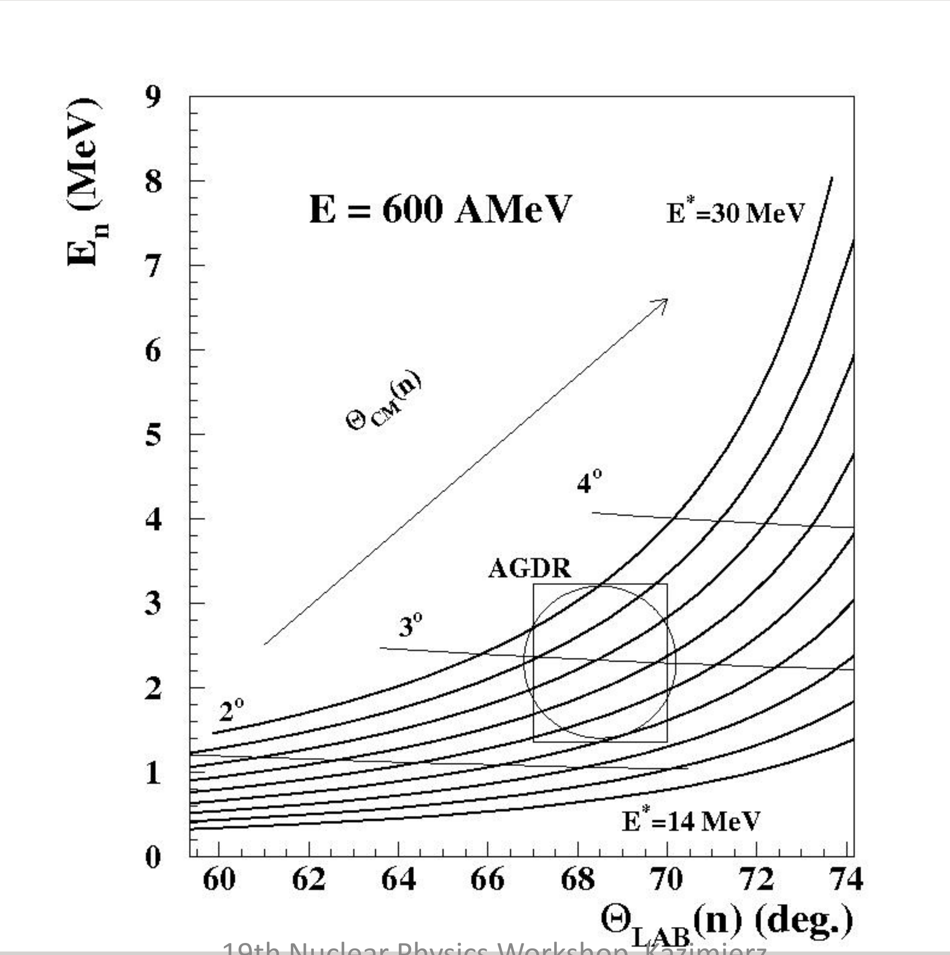
N. Auerbach et al., PLB 106(1981)347

$$\mathrm{TRK} = \left(\frac{3\hbar^2}{8\pi m}\right) A(1+\kappa)$$

if $S^+ = 0$

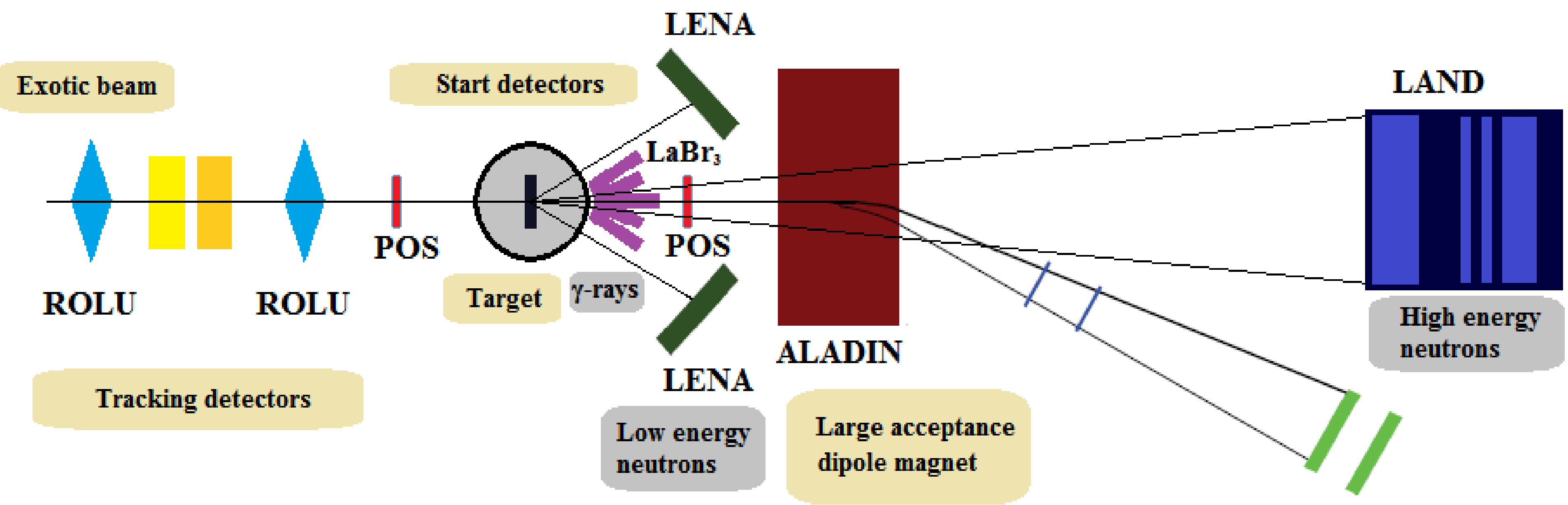
$$E^- = \left(\frac{3\hbar^2 A}{8N\pi m R_p}\right) \frac{1}{\Delta R_{pn} + R_p (N-Z)/2N}$$

(p,n) reaction in inverse kinematics $p(^{132}Sn,n)$ E=600 AMeV



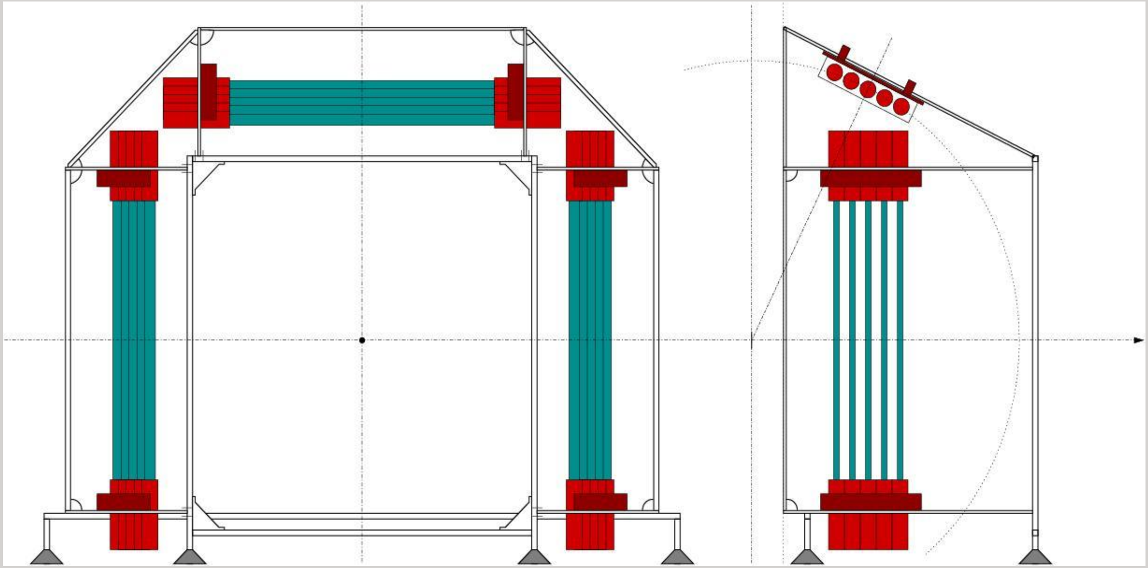
Schematic layout of the setup

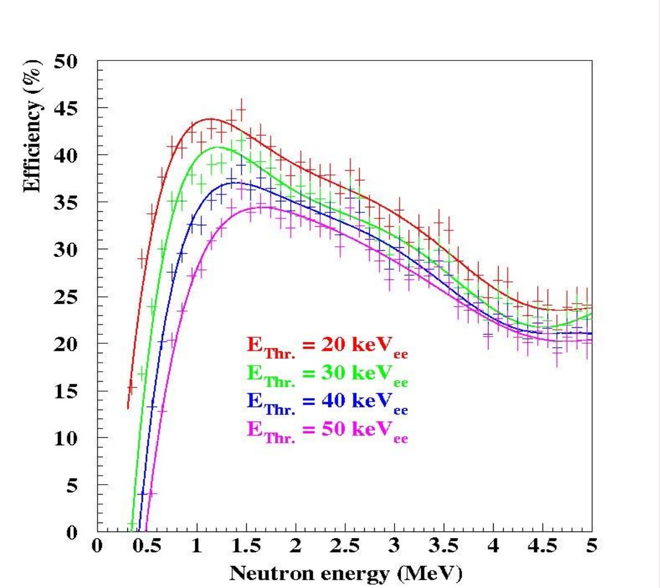
p(^{124}Sn,n) E = 600 AMeV



γ detector: 6x (3.5”x 8”)state-of-the art LaBr$_3$
(University of Milano)

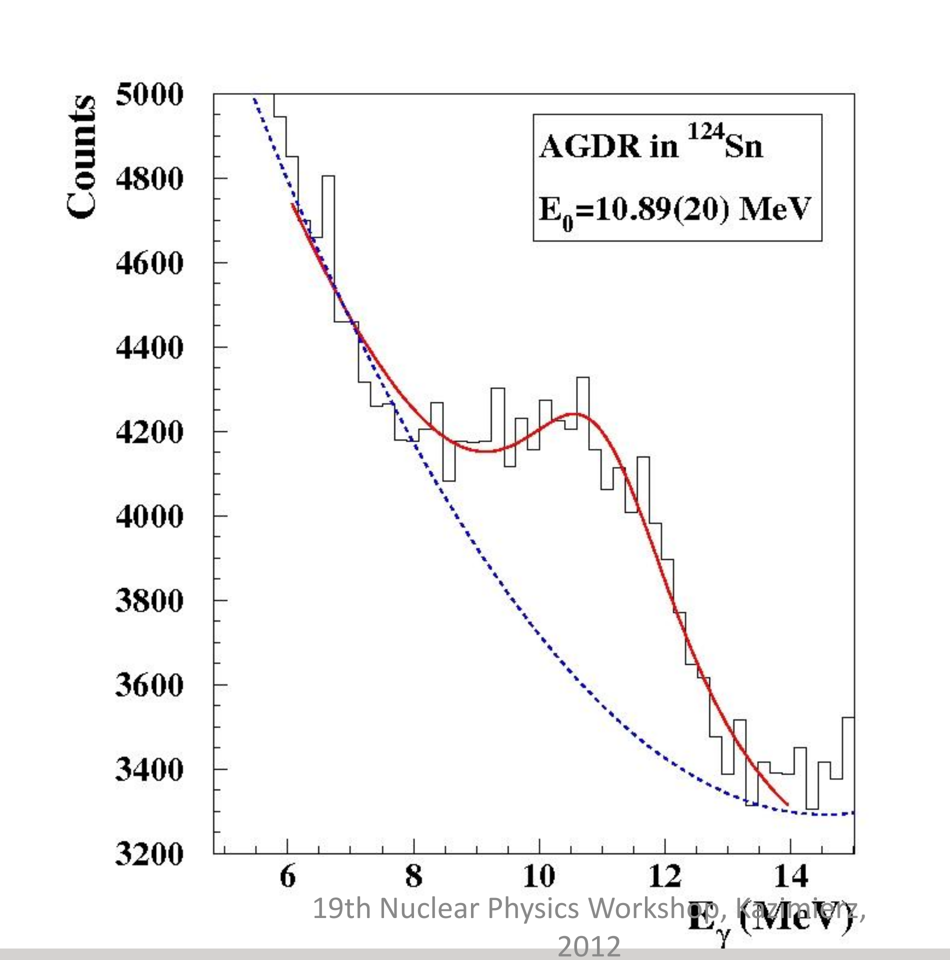
Geometrical arrangement and characteristics of LENA





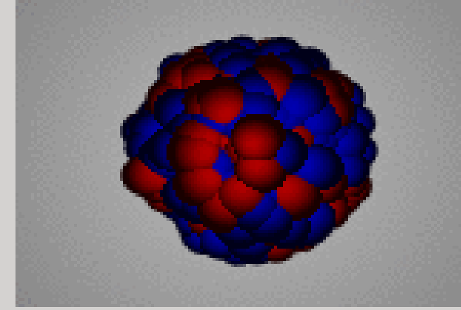
Time resolution (FWHM)	< 0.8 ns
Angular resolution(L= 1 m)	< 1^{o}
Energy resolution (E_n = 1 MeV)	< 10 %
Detection efficiency (E_n= 0.5 - 5 MeV)	20 - 40 %

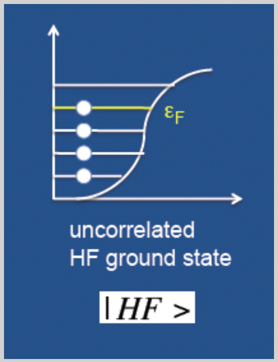
γ-ray spectrum measured in coincidence with the neutrons ($0.5<E_n<3.5$ MeV and $66^\circ<\Theta_{LAB}< 68^\circ$)

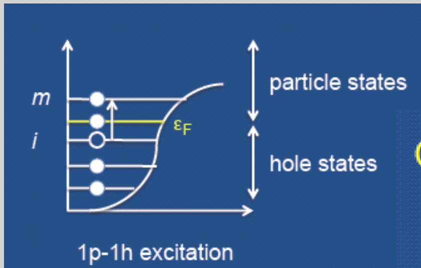


E(GDR) = 15.19
FWHM(GDR)=4.81

Theoretical results







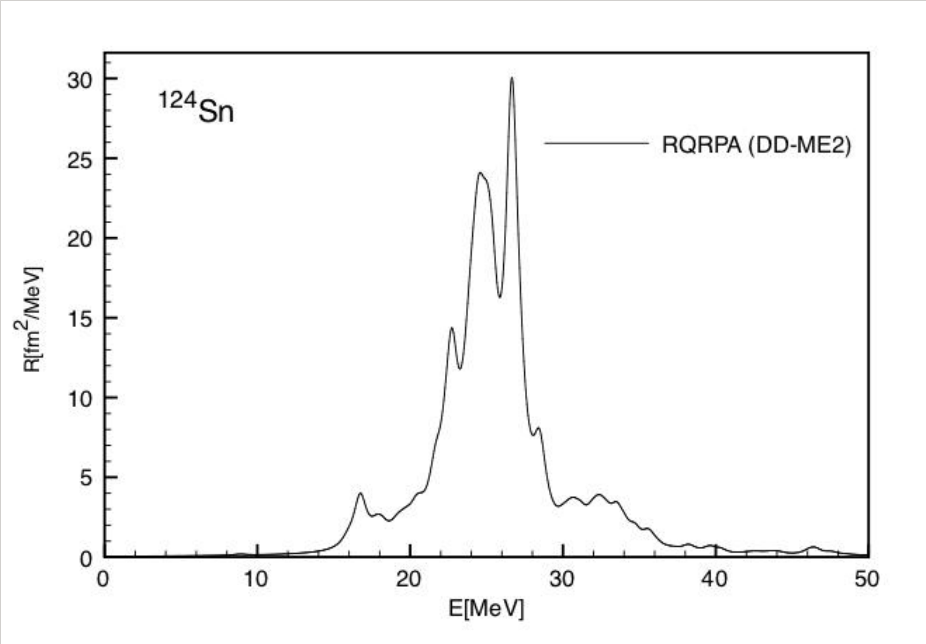
$\hat{c}_m^{+}\hat{c}_i\,|HF>$

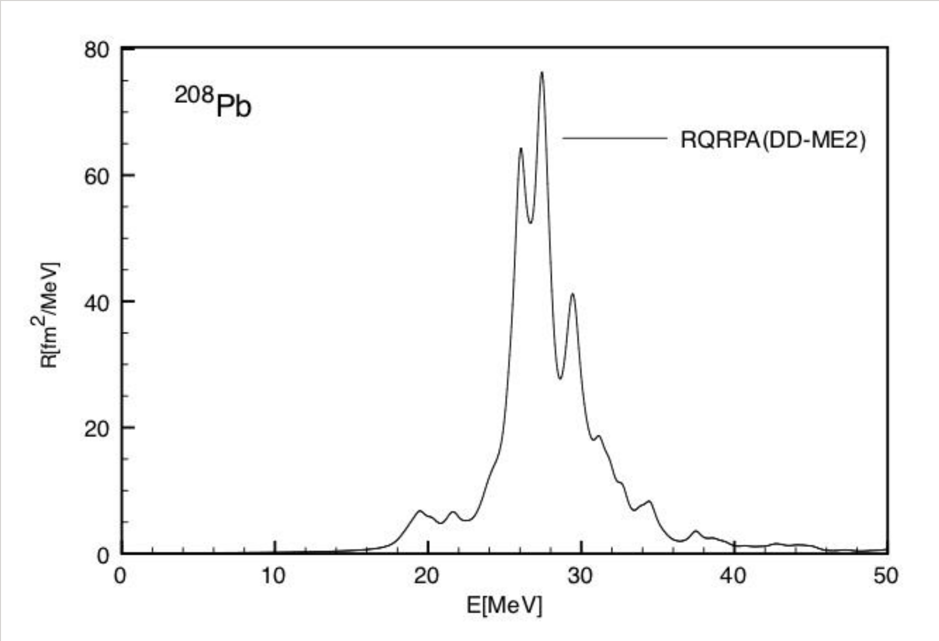
Collective vibration = coherent superposition of large number of p-h excitations

$$|\nu_{RPA}>=\sum_{m,i} A^{\nu}_{mi}(\hat{c}_m^{+}\hat{c}_i)\,|HF>$$

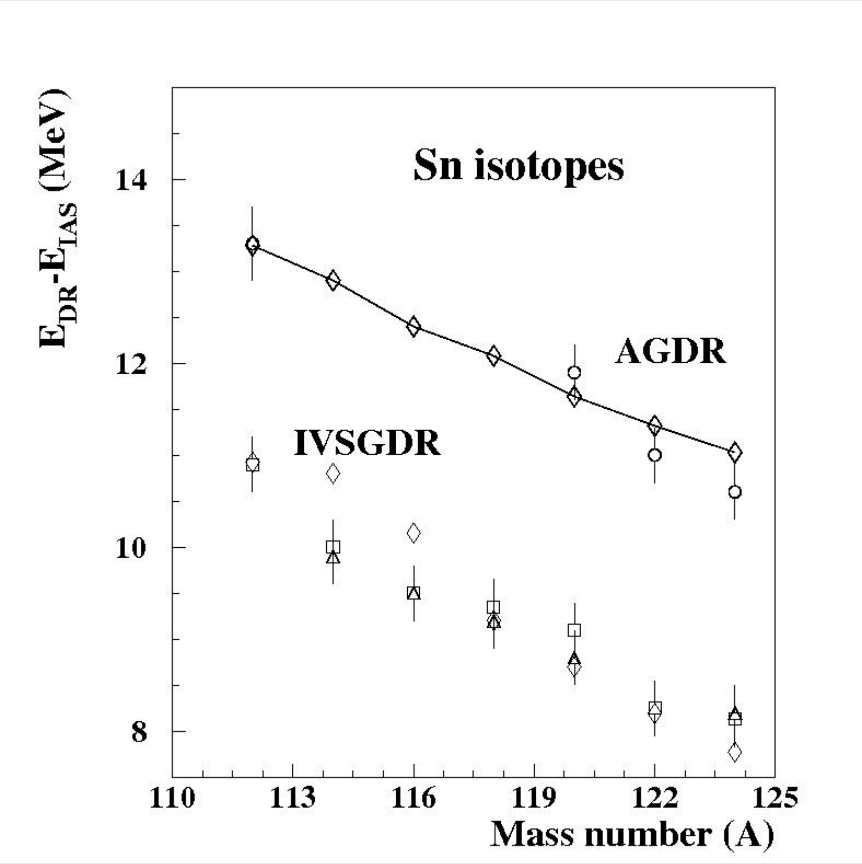
- Fully self-consistent relativistic proton-neutron quasiparticle random phase approximation (pn-RQRPA) based on the Relativistic Hartree-Bogoliubov model (RHB) [Vretenar & Paar].
- density-dependent meson-exchange (DD-ME) interactions

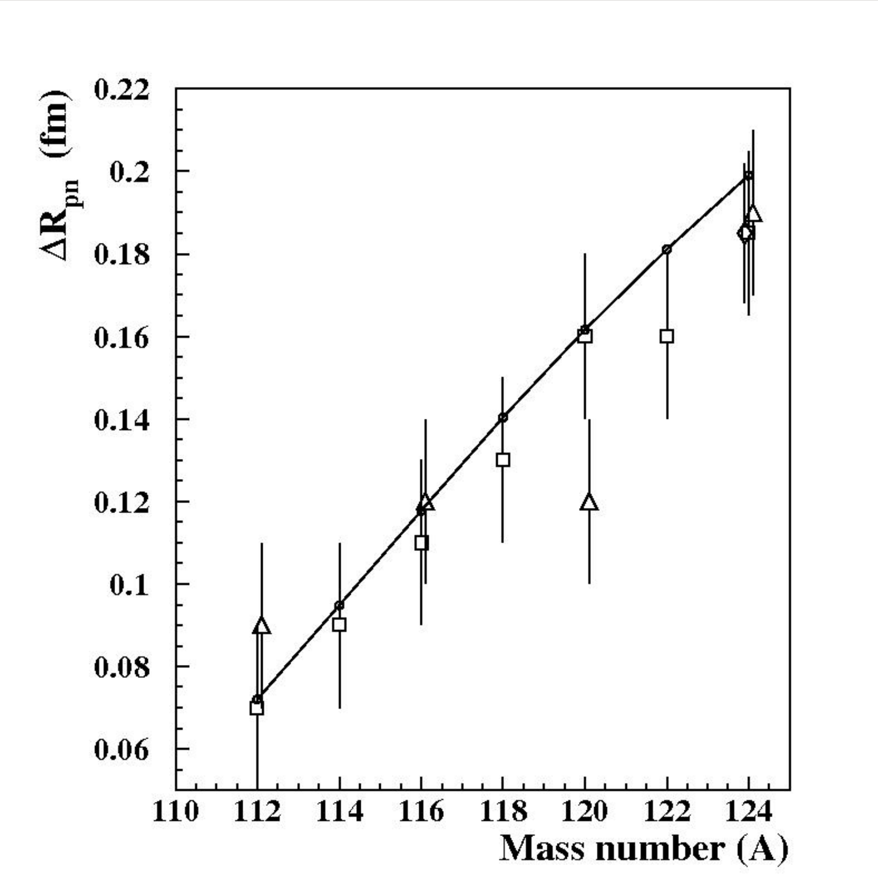
AGDR strength distributions



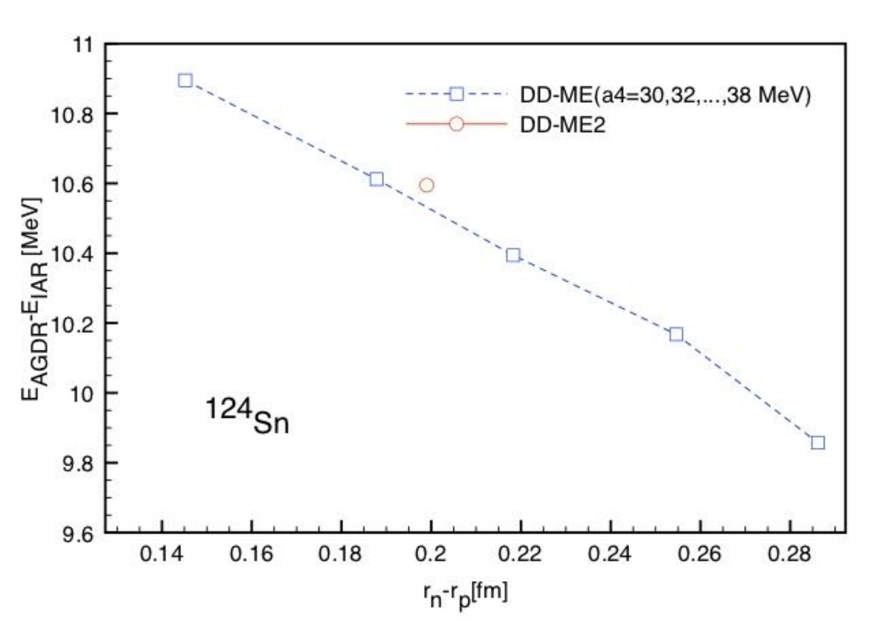


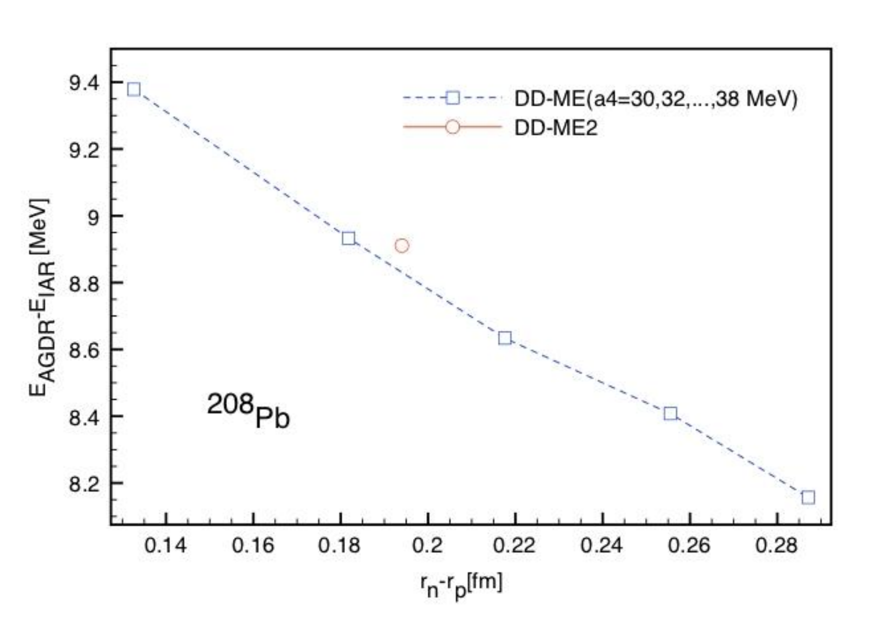
Results for the Sn isotopes



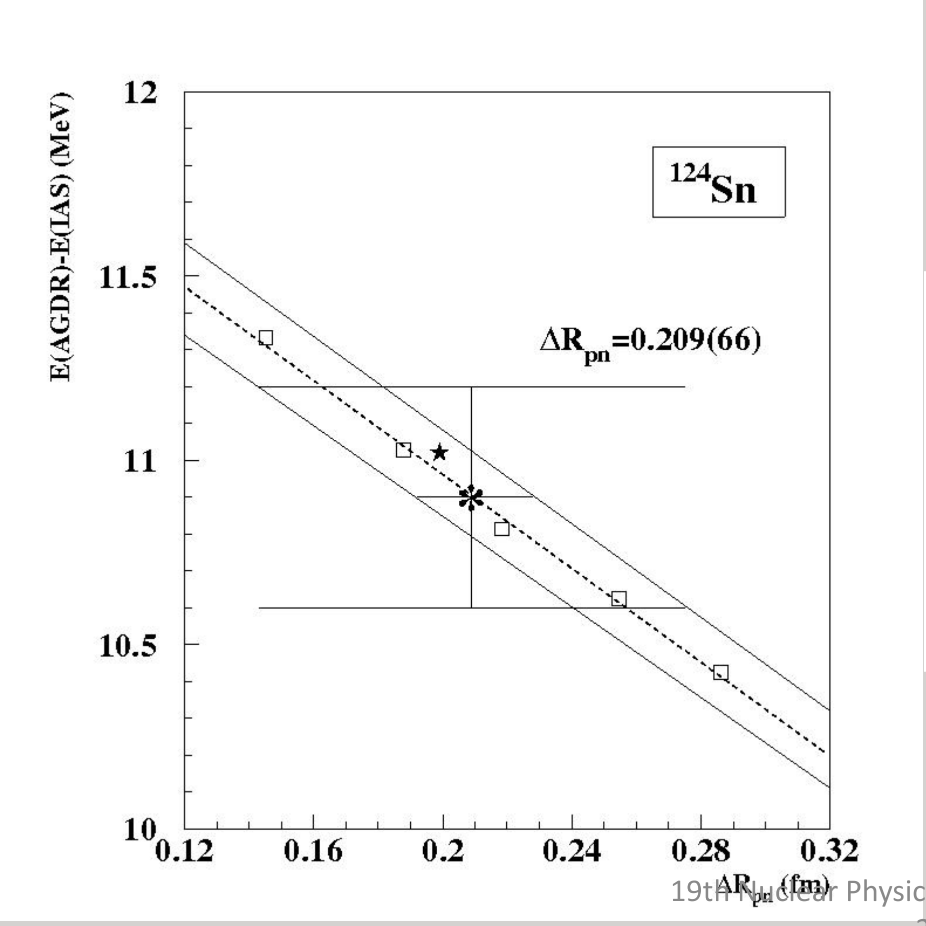


Sensitivity of the AGDR to the neutron-skin thickness



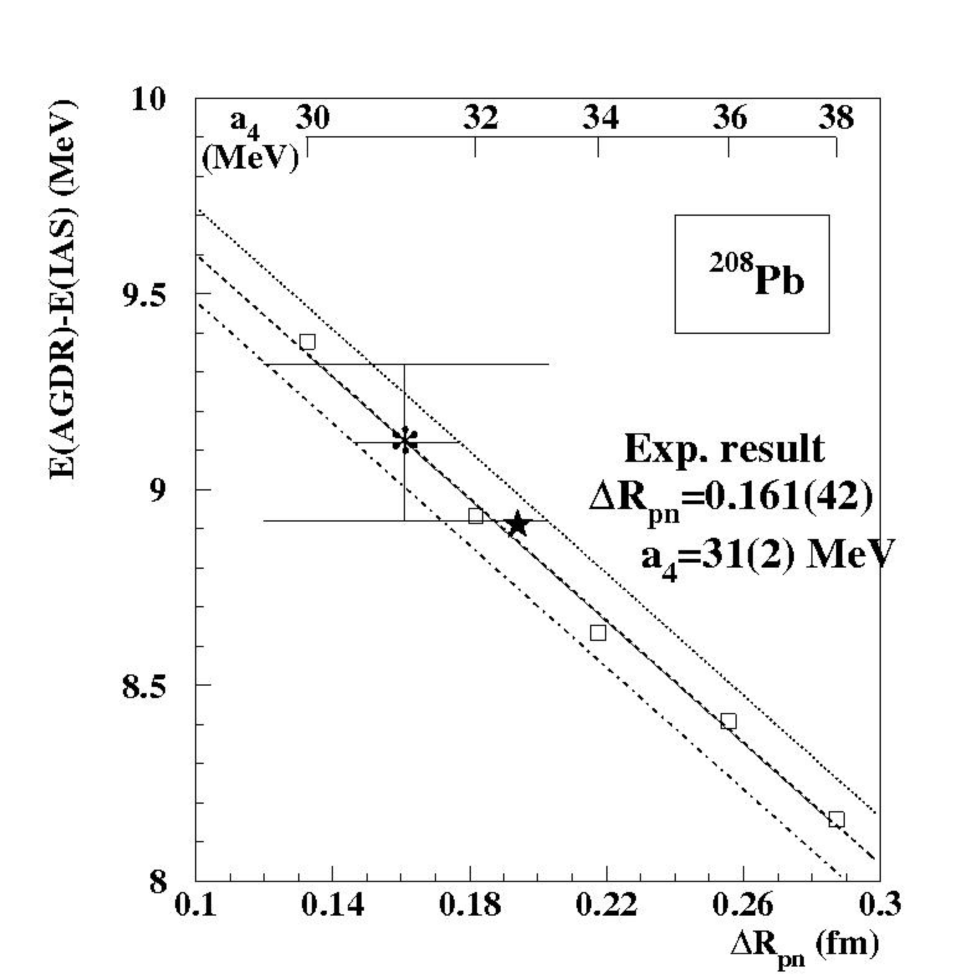


The theoretical values E(AGDR)−E(IAS) are plotted as functions of the corresponding ground-state neutron skin thickness R_{pn}, and compared to the experimental value E(AGDR) − E(IAS) = 10.90 ± 0.32 MeV.

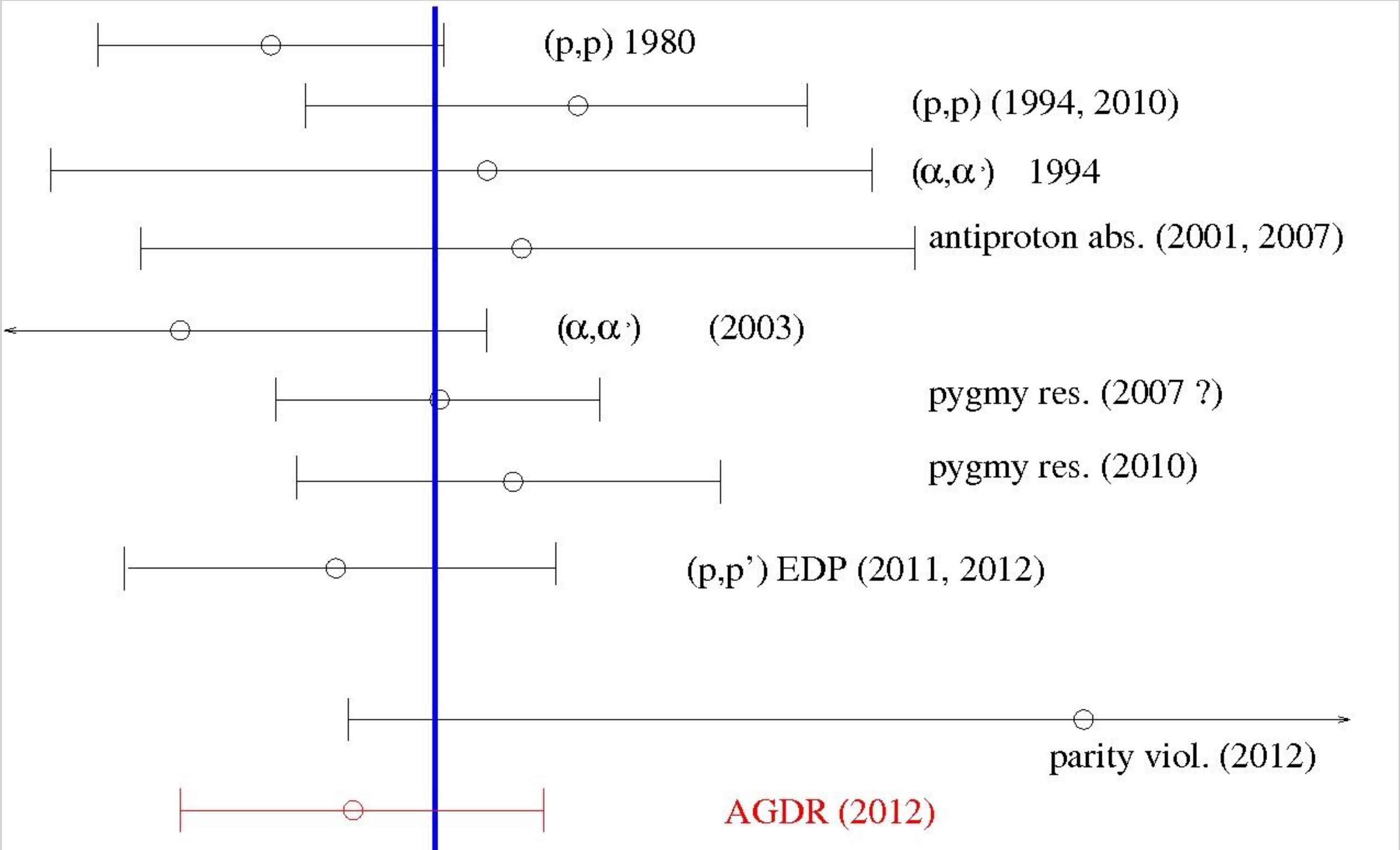


Method	Ref.	Date	ΔR_{pn} (fm)
(p,p) 0.8 GeV	[35]	1979	0.25 ± 0.05
(α,α') GDR 120 MeV	[8]	1994	0.21 ± 0.11
antiproton absorption	[34, 37]	2001	0.19 ± 0.09
$(^3He,t)$ IVSGDR+AGDR	[10]	2004	0.27 ± 0.07
pygmy dipole res.	[12, 36]	2007	0.19 ± 0.05
(p,p) 295 MeV	[1, 36]	2008	0.185 ± 0.05
AGDR present res.		2012	0.19 ± 0.05

Same as described previously for ^{124}Sn but for the target nucleus ^{208}Pb.



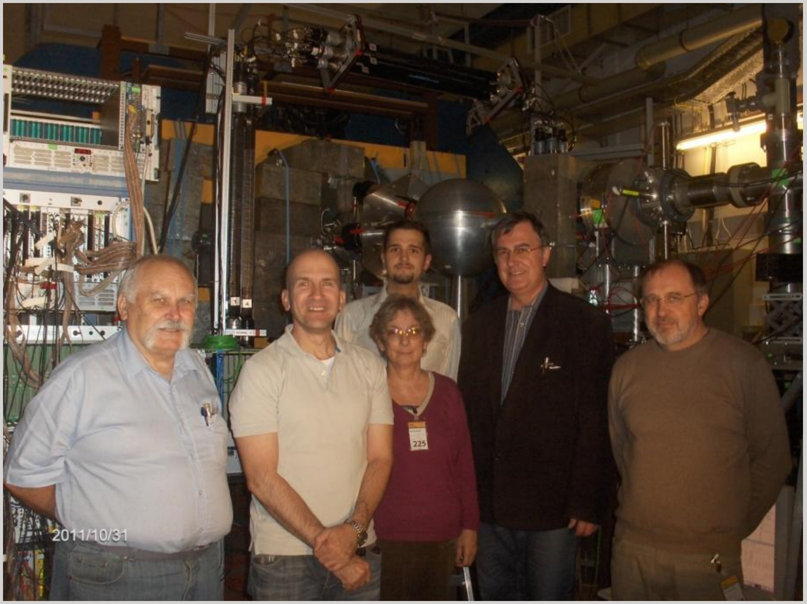
Summary of the results obtained so far for the neutron-skin thickness of ^{208}Pb



V. Conclusions

- A new method was introduced to measure the neutron-skin thickness
- GR studies in stable beams
- GR studies proposed in RIB's
- Challenges for the detectors

THANK YOU VERY MUCH !



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