Anti-analog giant resonances and the neutron-skin of nuclei

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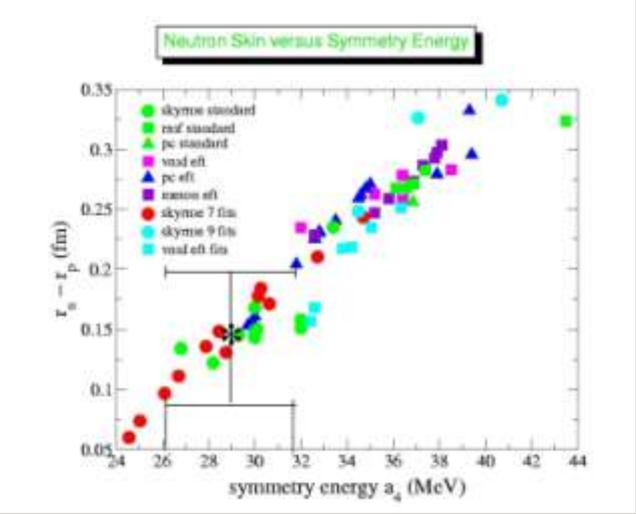
Nuclear Equation of State
(Relationship between energy, temperature pressure, and density in nuclear matter)

✓*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?*

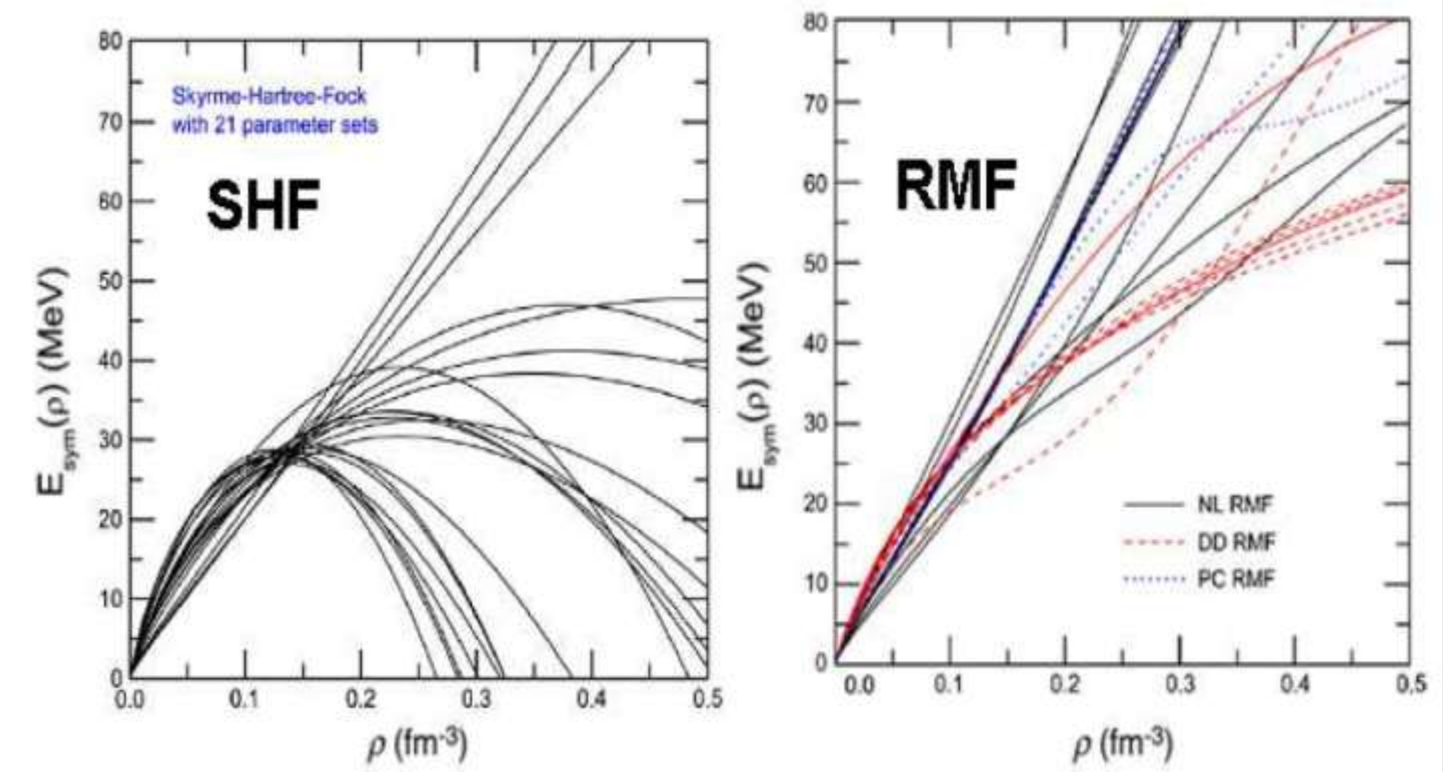
$$E(\rho,\alpha) = E(\rho,0) + S(\rho)\alpha^2 + O(\alpha^4) + \ldots$$

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

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

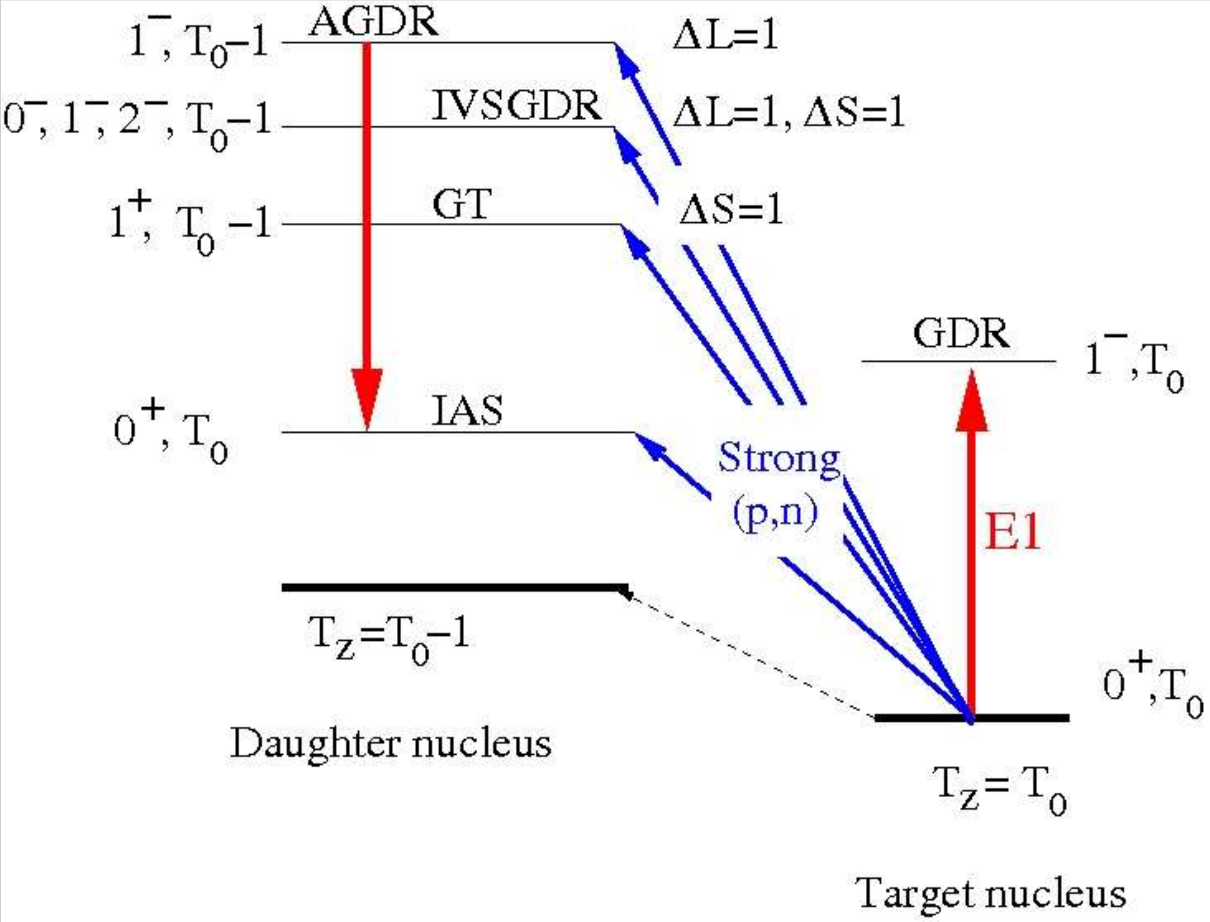


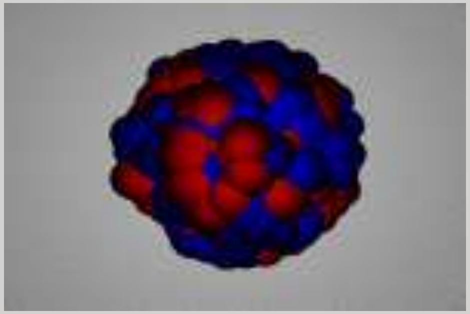
The symmetry energy and their density dependence



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

Excitation and γ-decay of the AGDR





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,**]
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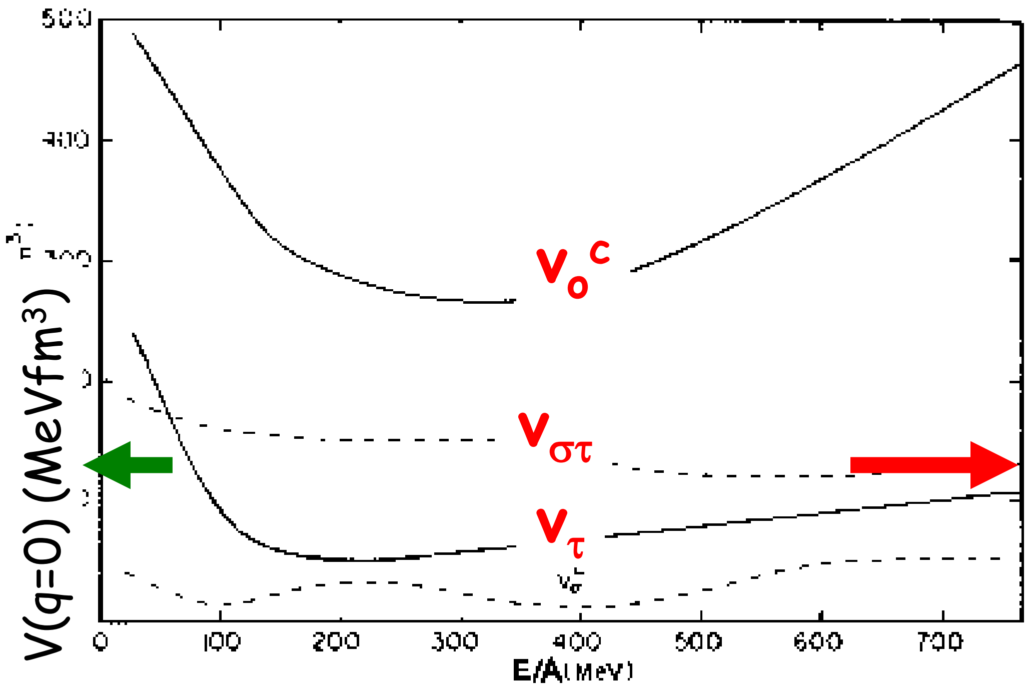
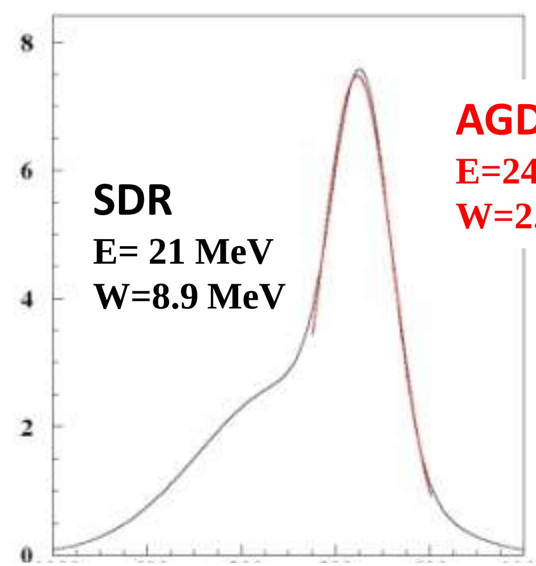
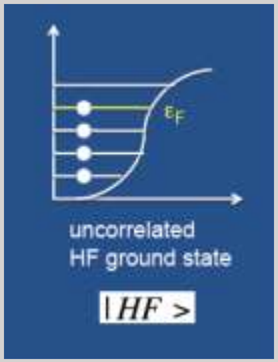
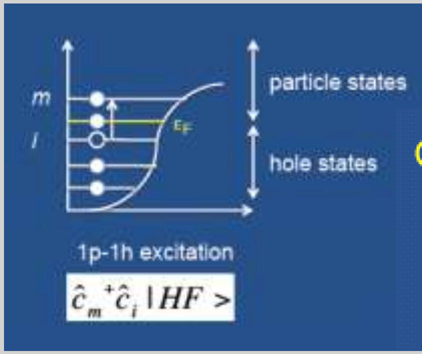




Theoretical results



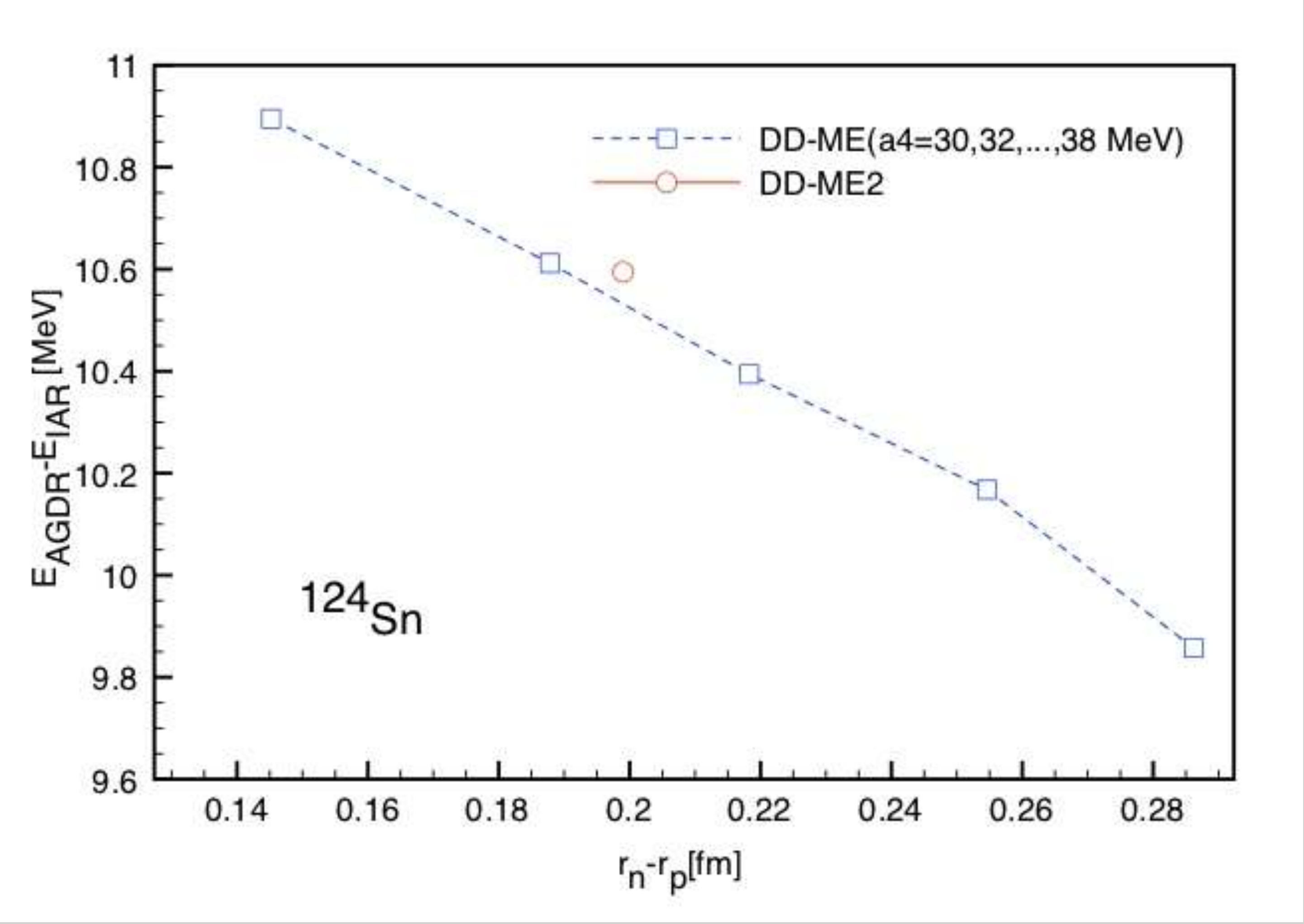


Collective vibration = coherent superposition of large number of p-h excitations

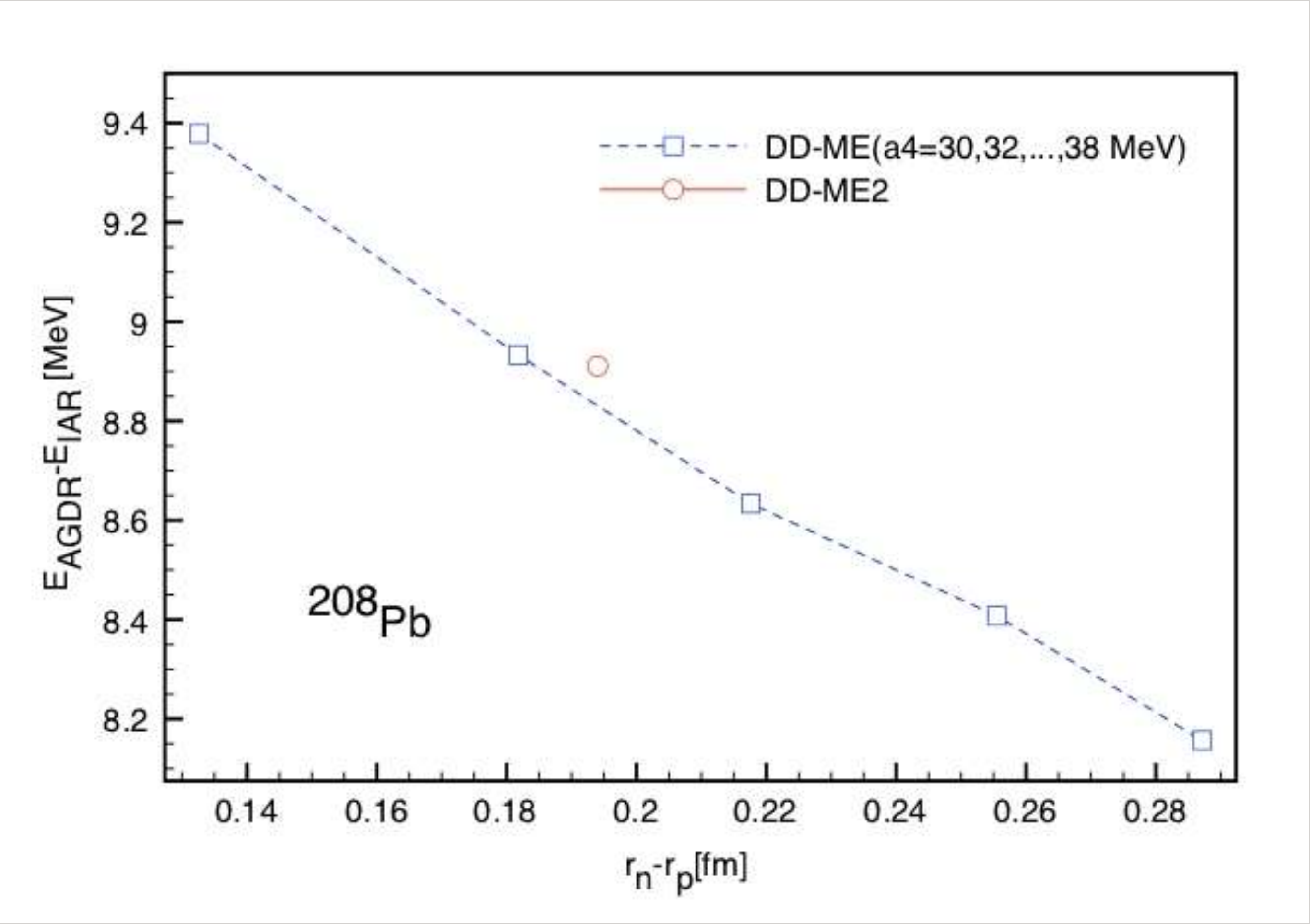
$$|\nu_{RPA}\rangle = \sum_{m,i} A^{\nu}_{mi} (\hat{c}_m^{+} \hat{c}_i) | HF \rangle$$

- 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

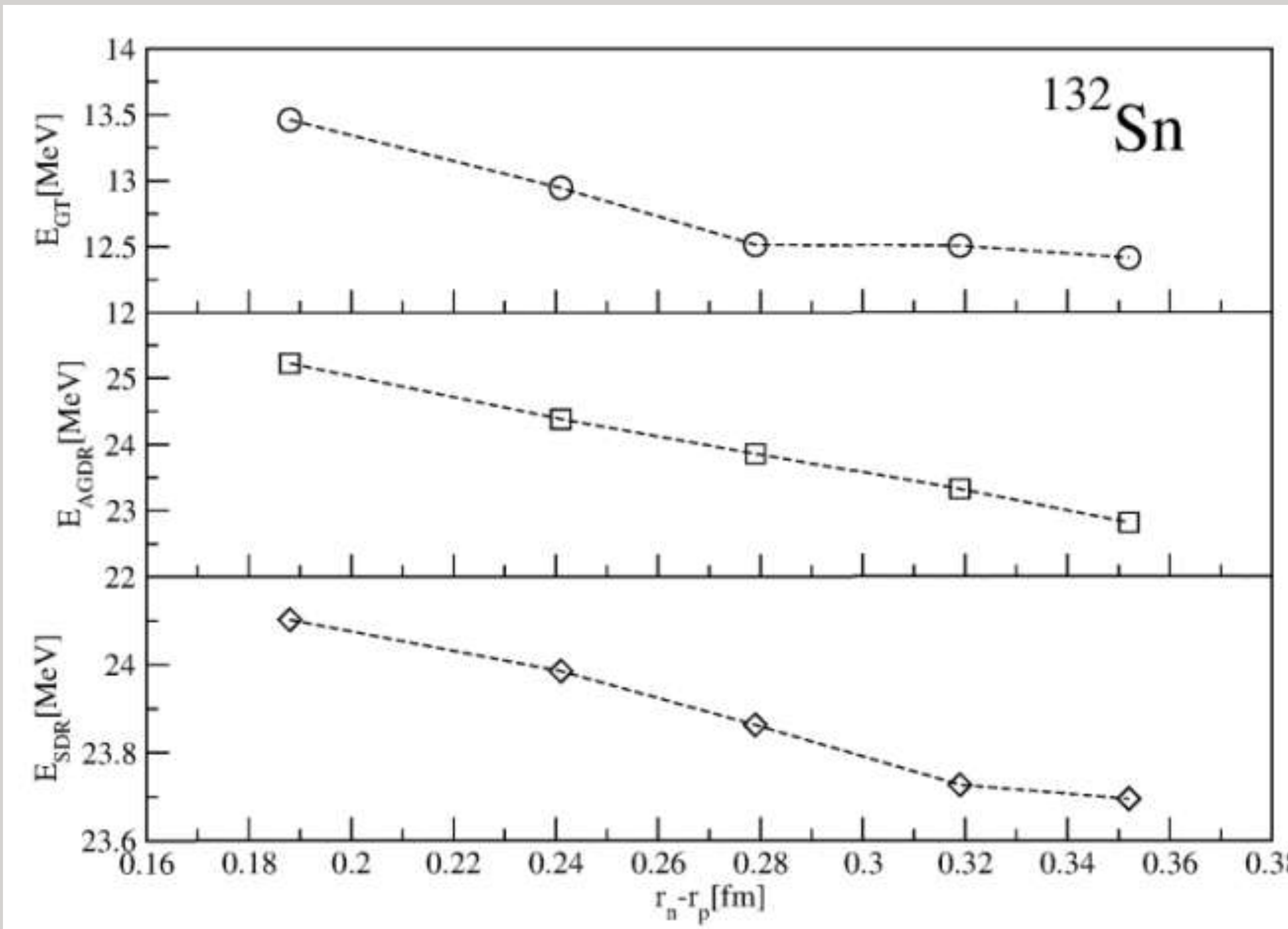
The energy of the AGDR relative to the IAS as a function of the neutron-skin thickness in ^{124}Sn



The energy of the AGDR relative to the IAS as a function of the neutron-skin thickness in ^{208}Pb



The energy of the GT, AGDR and SDR relative to the IAS as a function of the neutron-skin thickness



ΔE=1 MeV

ΔE=2 MeV

ΔE=0.4 MeV

Physics Letters B 720 (2013) 428–432

Contents lists available at SciVerse ScienceDirect

Physics Letters B

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ARTICLE INFO

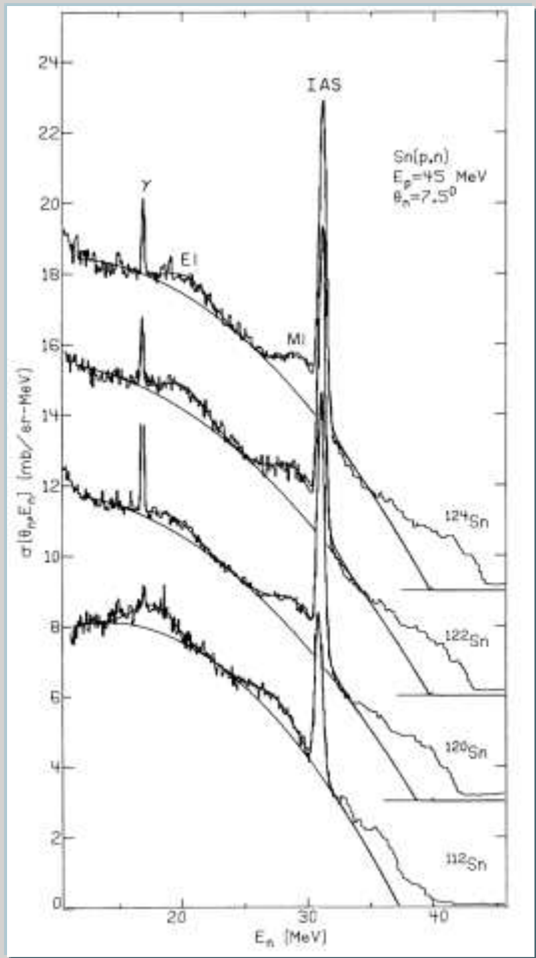
Article history:
Received 27 August 2012
Received in revised form 15 January 2013
Accepted 24 February 2013
Available online 27 February 2013
Editor: J.-P. Blaizot

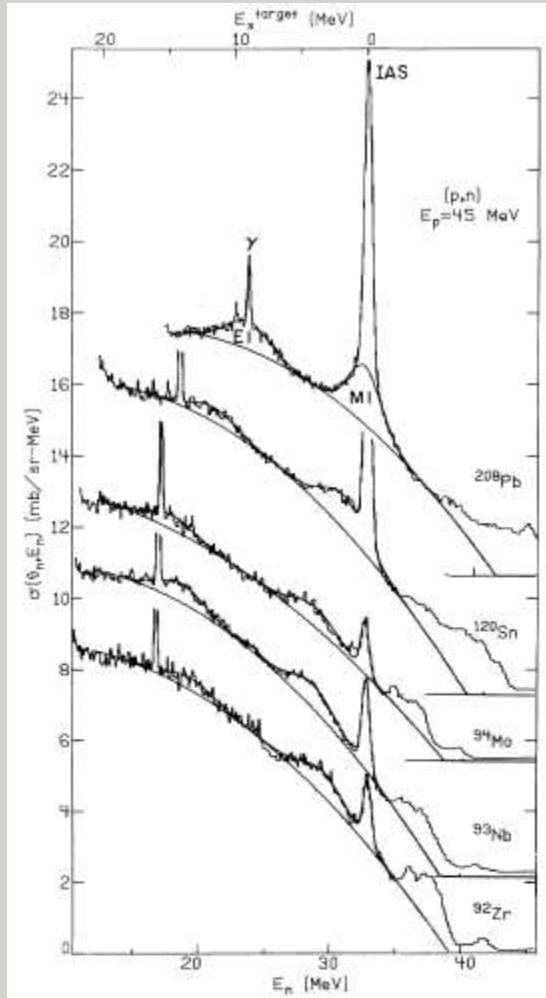
Keywords:
Neutron-skin thickness
Giant dipole resonances
Relativistic random-phase approximation
Rare-isotope beams

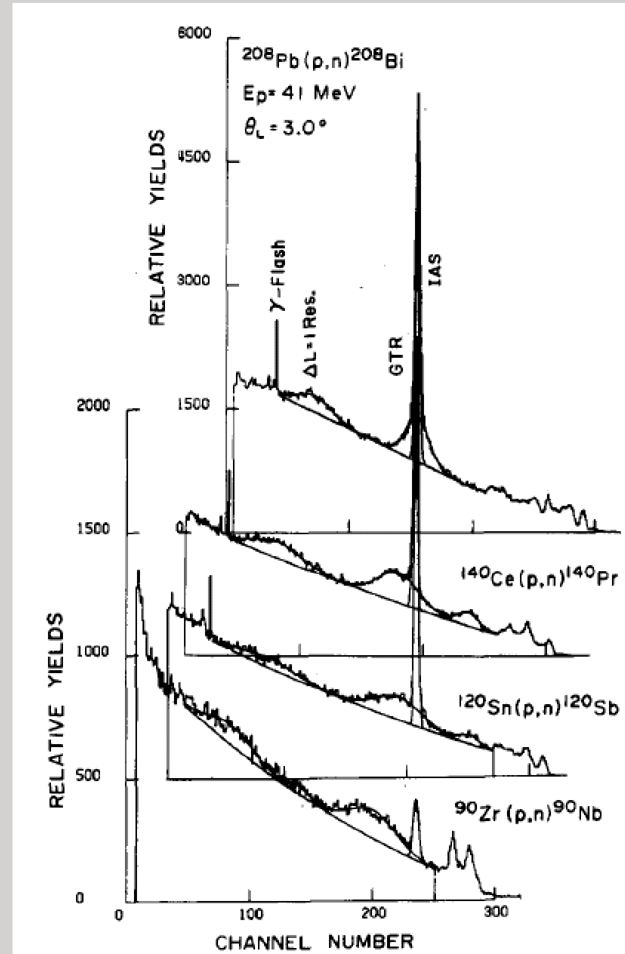
ABSTRACT

We examine a method to determine the neutron-skin thickness of nuclei using data on the charge-exchange anti-analog giant dipole resonance (AGDR). Calculations performed using the relativistic proton–neutron quasiparticle random-phase approximation (pn-RQRPA) reproduce the isotopic trend of the excitation energies of the AGDR, as well as that of the spin-flip giant dipole resonances (IVSGDR), in comparison to available data for the even–even isotopes $^{112-124}$Sn. It is shown that the excitation energies of the AGDR, obtained using a set of density-dependent effective interactions which span a range of the symmetry energy at saturation density, supplemented with the experimental values, provide a stringent constraint on value of the neutron-skin thickness. For ^{124}Sn, in particular, we determine the value $\Delta R_{pn} = 0.21 \pm 0.05$ fm. The result of the present study shows that a measurement of the excitation energy of the AGDR in (p,n) reactions using rare-isotope beams in inverse kinematics, provides a valuable method for the determination of neutron-skin thickness in exotic nuclei.

Experimental data for the AGDR



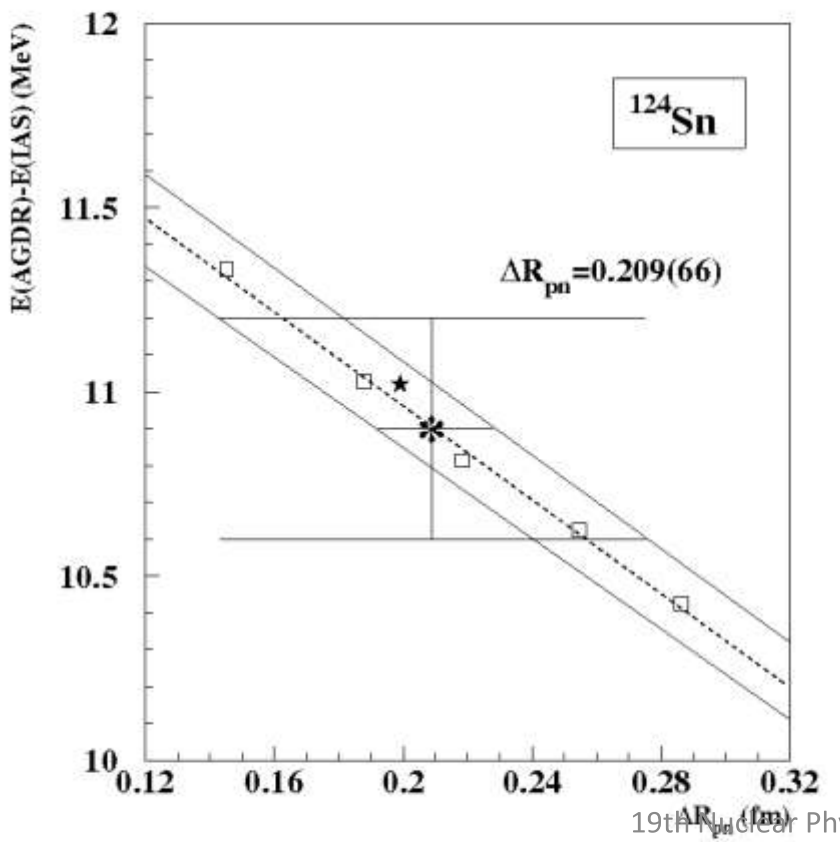




Sterrenburg et al., Phys. Rev. Lett. 45, 1839 (1980). L= 7 m.

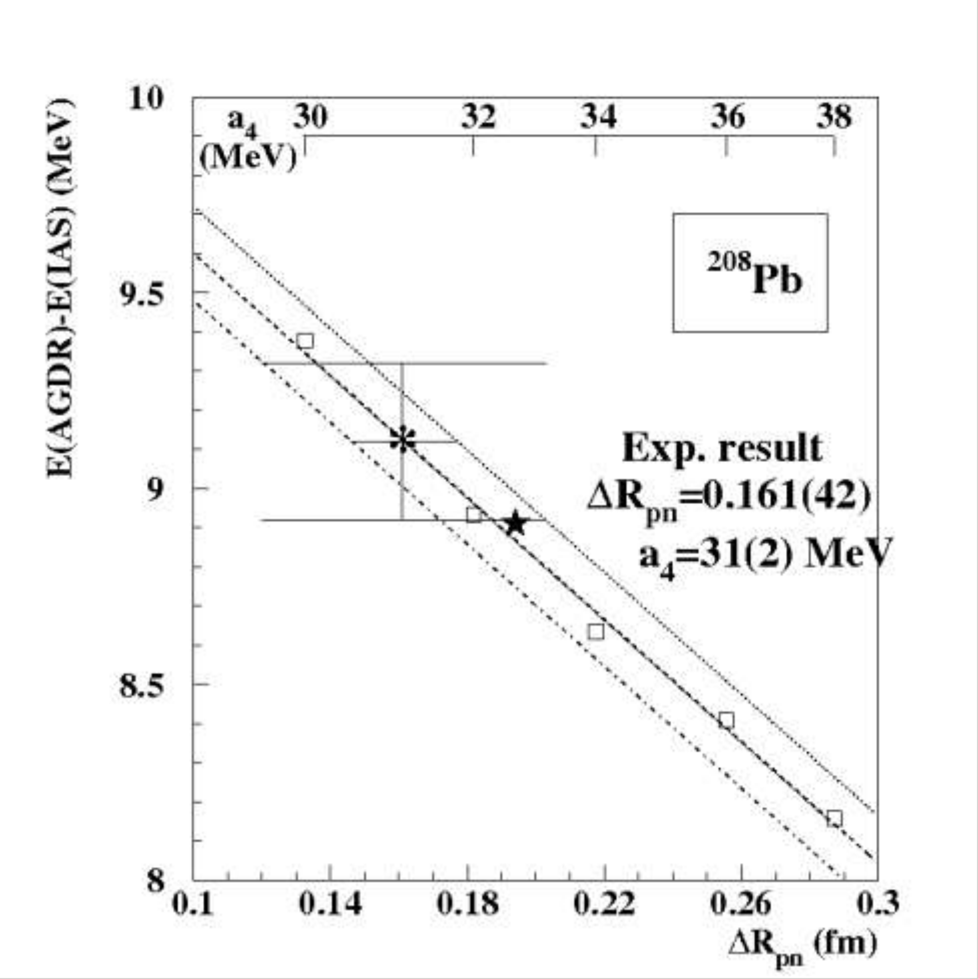
S. Nishihara et al., Phys. Lett. B 160, 369 (1985). L= 18 m.

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.

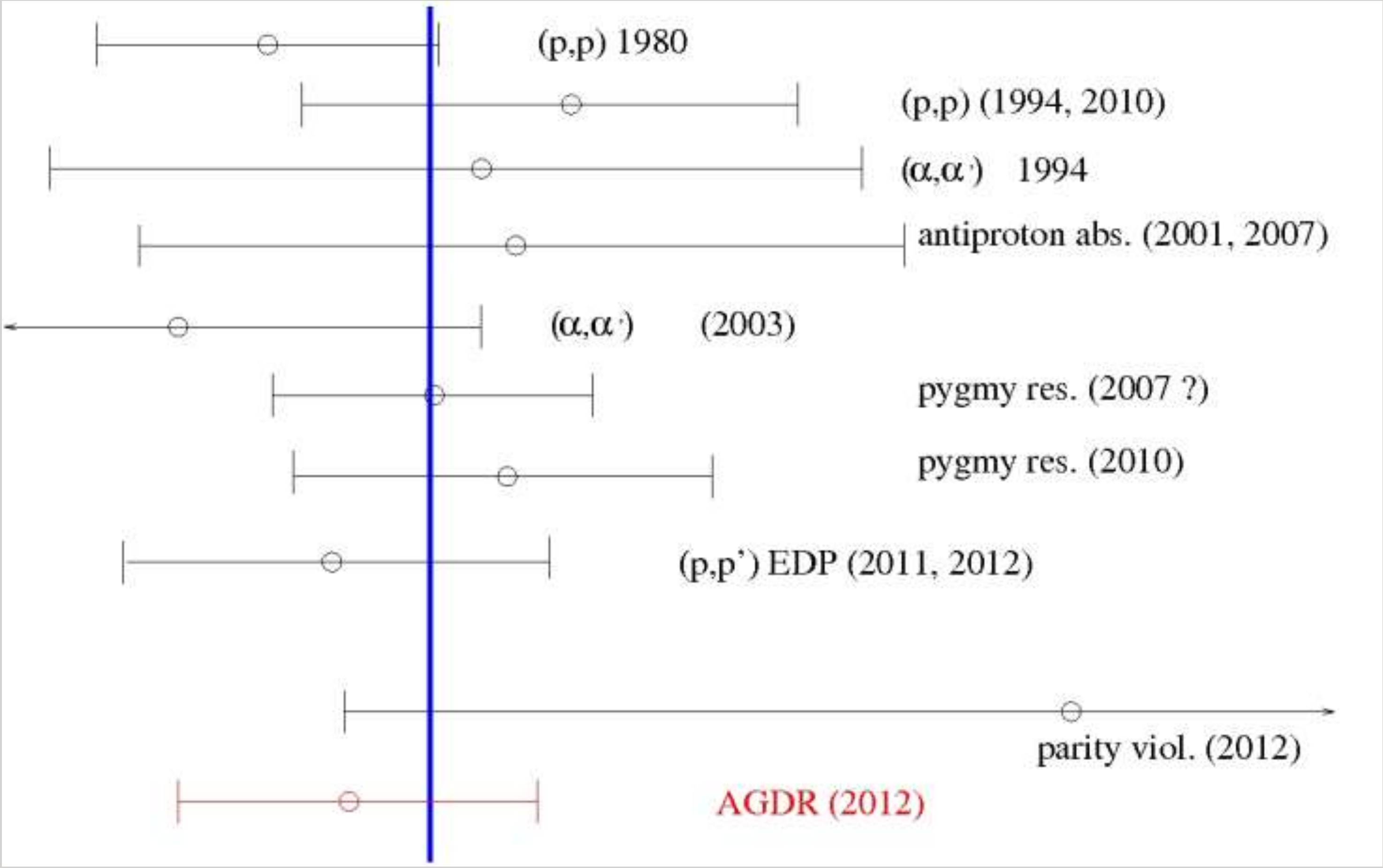


Method	Ref.	Date	ΔR_{pn} (fm)
(p,p) 0.8 GeV	[35]	1979	0.25 ± 0.05
(α,α') GDR 120 MeV	[8]	1994	0.21 ± 0.11
antiproton absorption	[34, 37]	2001	0.19 ± 0.09
$(^3$He$,t)$ IVSGDR+AGDR	[10]	2004	0.27 ± 0.07
pygmy dipole res.	[12, 36]	2007	0.19 ± 0.05
(p,p) 295 MeV	[1, 36]	2008	0.185 ± 0.05
AGDR present res.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

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

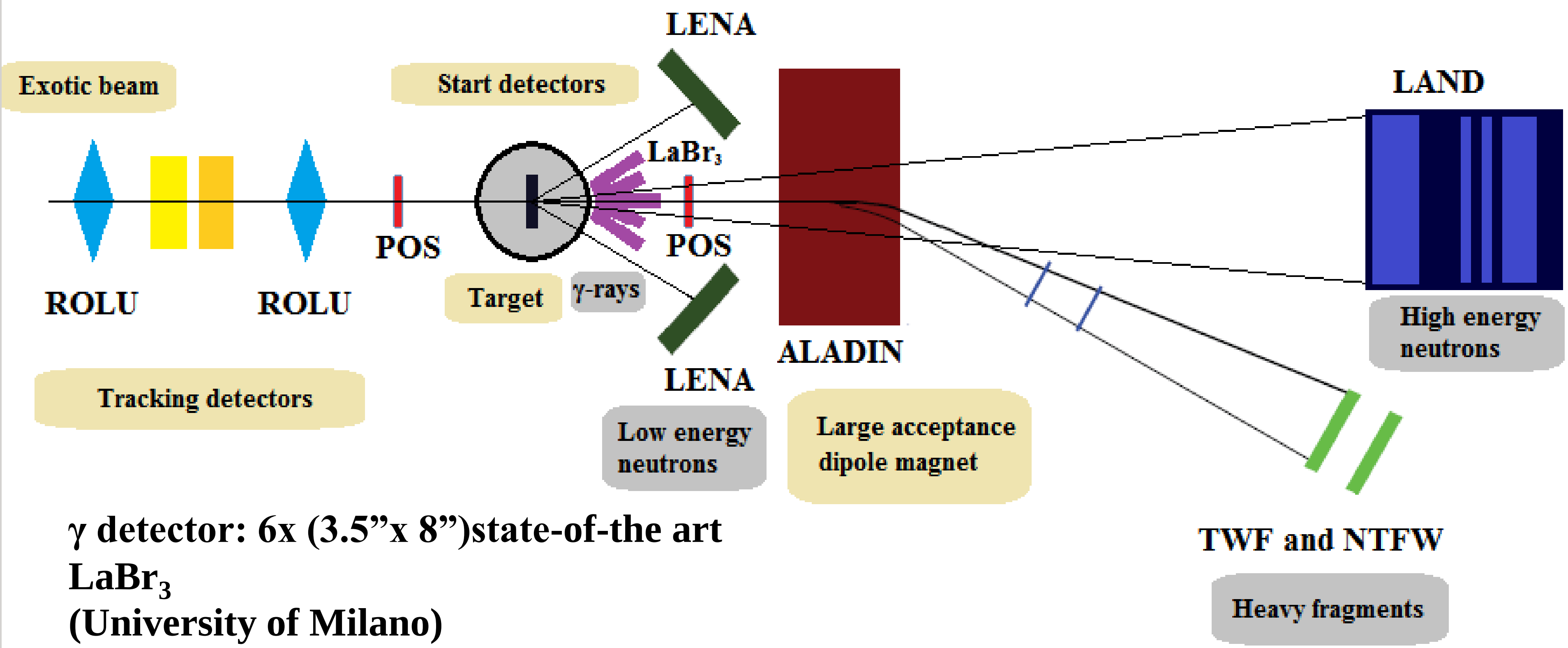


Summary of the results obtained so far for the neutron-skin thickness of ^{208}Pb



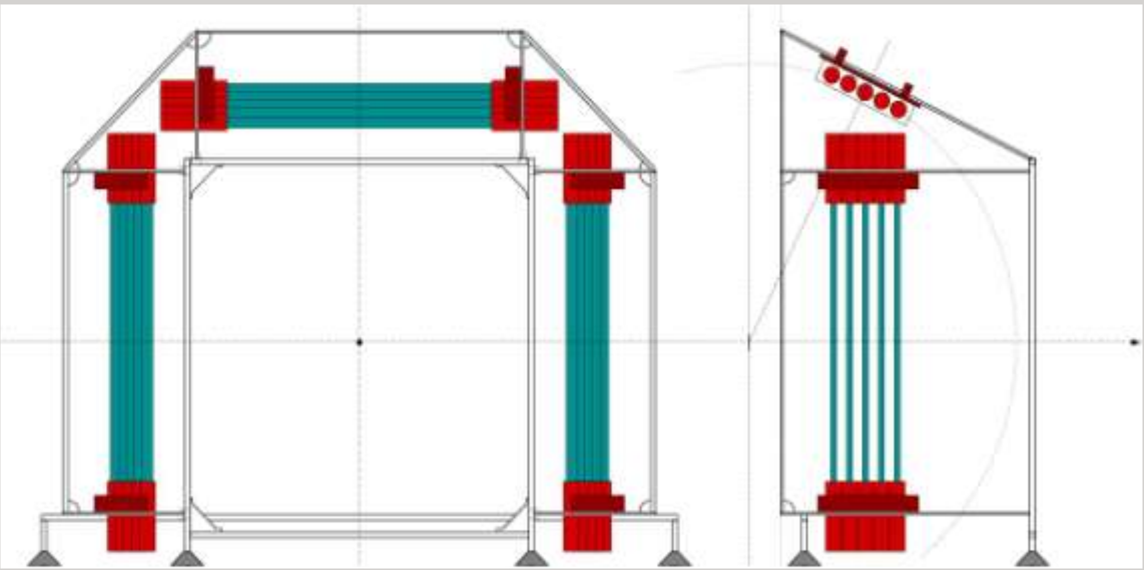
Schematic layout of the setup

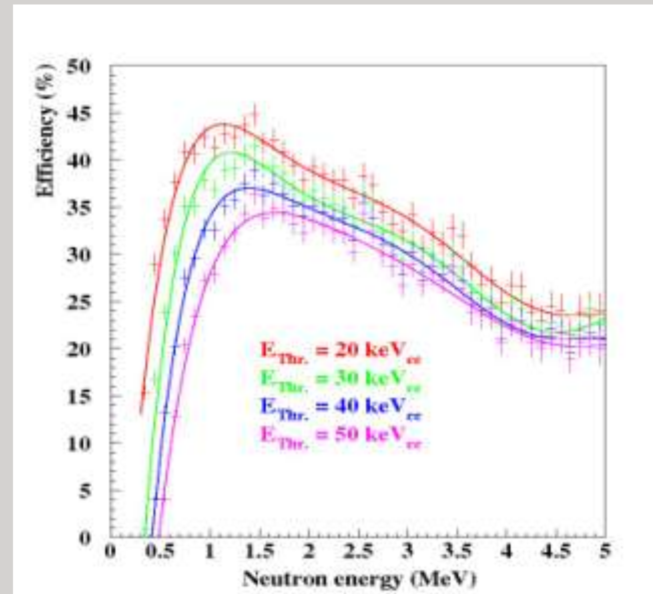
p(^{124}Sn,n) E = 600 AMeV S408 Spokesperson: A. Krasznahorkay



γ detector: 6x (3.5”x 8”)state-of-the art $LaBr_3$
(University of Milano)

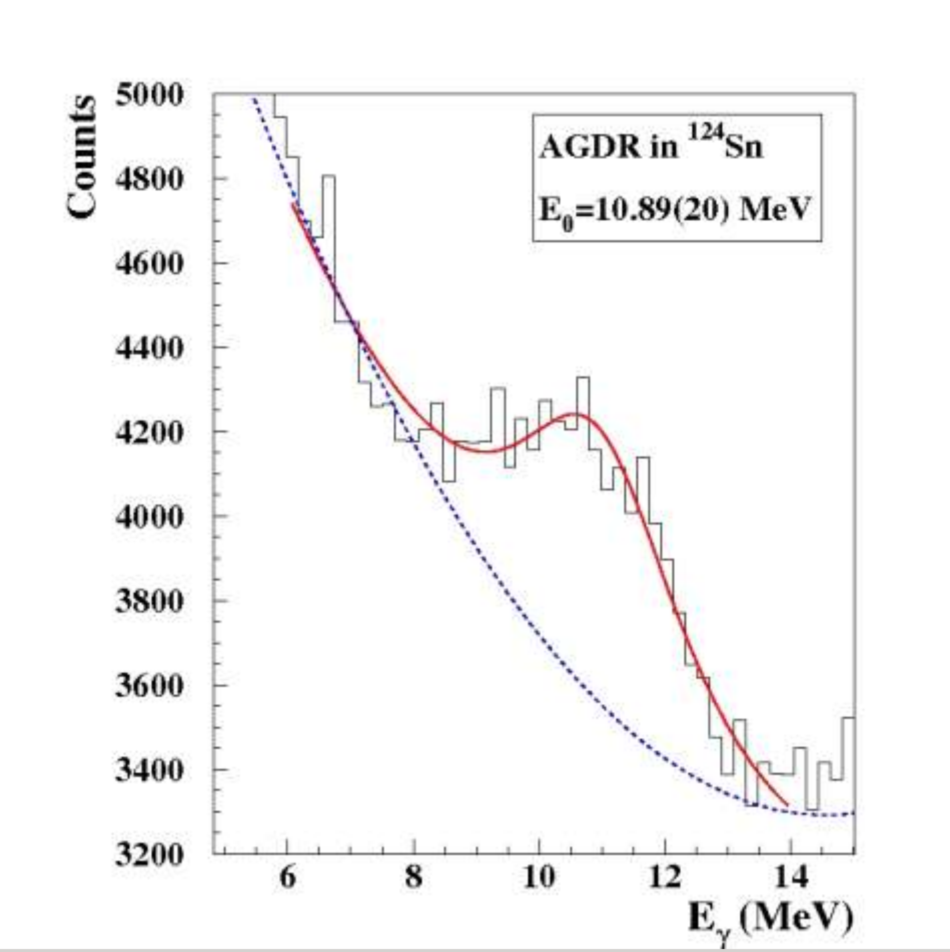
Geometrical arrangement and characteristics of ELENS



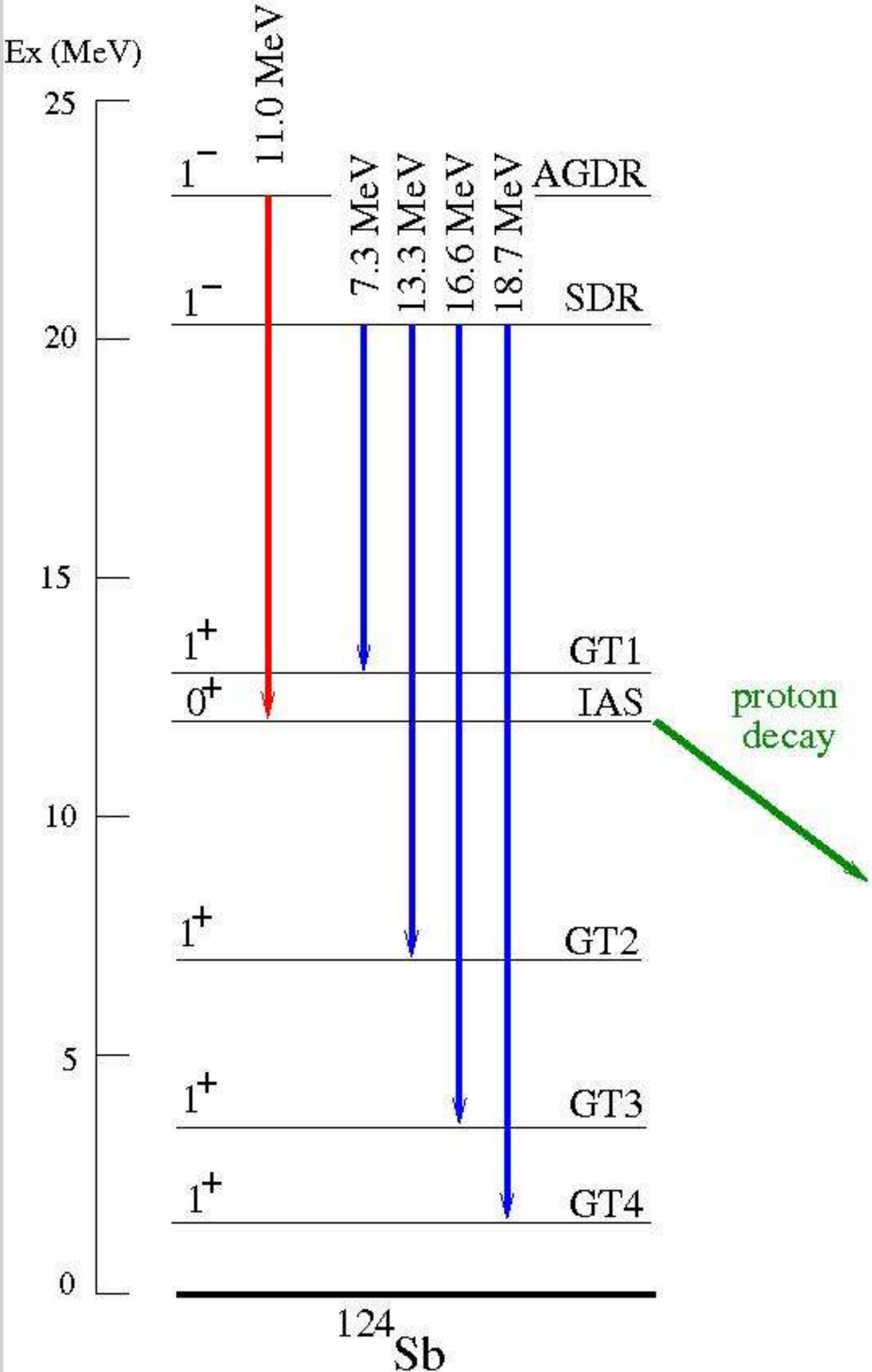


Time resolution (FWHM)	< 0.8 ns
Angular resolution(L= 1 m)	< 1^{o}
Energy resolution (E_n = 1 MeV)	< 10 %
Detection efficiency (E_n= 0.5 - 5 MeV)	20 - 40 %

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



Ex (MeV)
25
20
15
10
5
0
11.0 MeV
7.3 MeV
13.3 MeV
16.6 MeV
18.7 MeV
1⁻ AGDR
1⁻ SDR
1⁺ GT1
0⁺ IAS
proton decay
1⁺ GT2
1⁺ GT3
1⁺ GT4
124Sb

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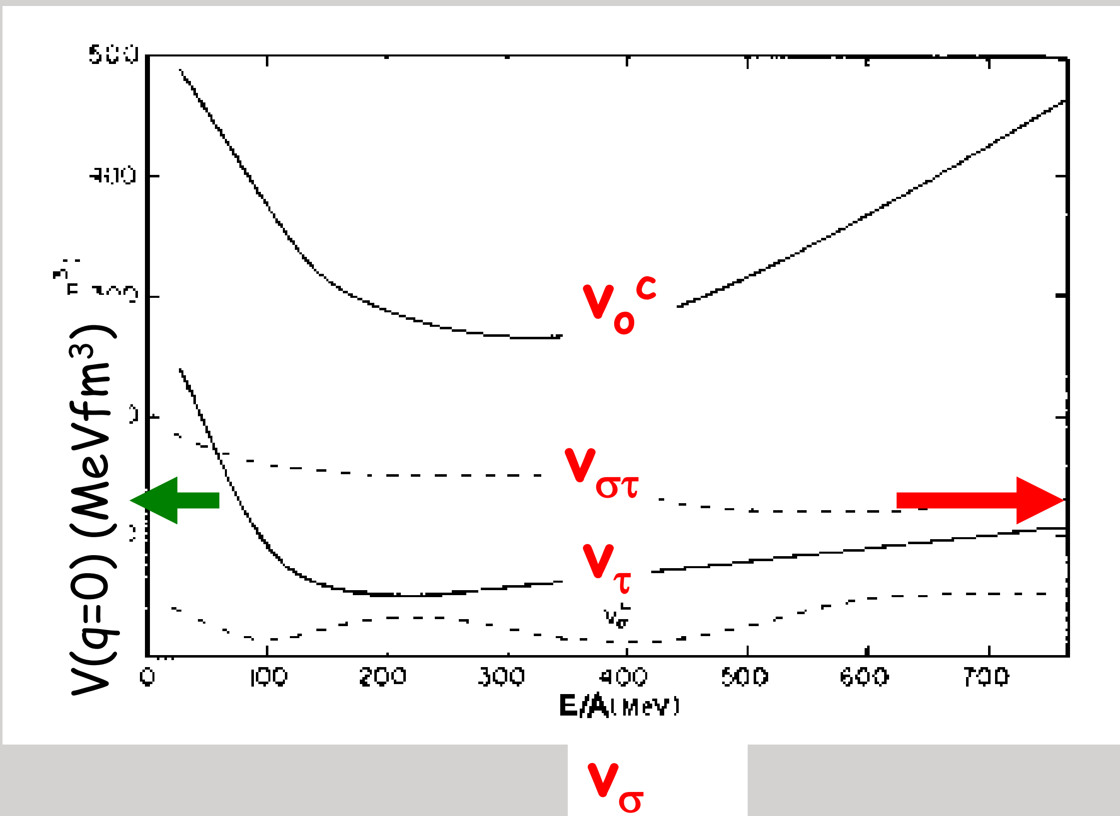
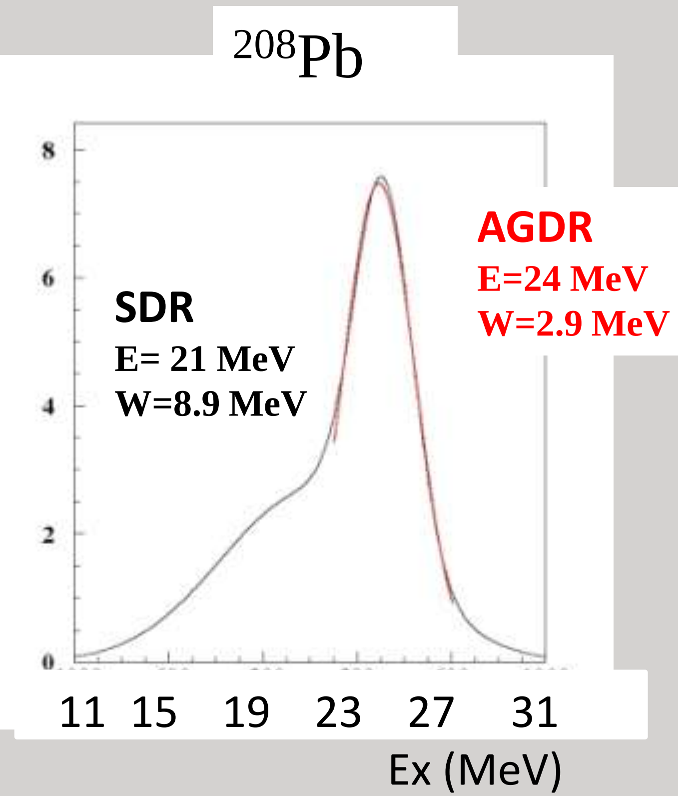
[1] *National Superconducting Cyclotron Laboratory and Department of Physics and Astronomy, Michigan State University, East Lansing, Michigan 48824*





PHYSICAL REVIEW C VOLUME 6, NUMBER 1 JULY 1972

Proton Decay of the Isobaric Analogs of the Ground States of ^{206}Pb, ^{207}Pb, ^{208}Pb, and ^{209}Bi†

G. M. Crawley and P. S. Miller
Cyclotron Laboratory, Michigan State University, East Lansing, Michigan 48823
(Received 30 December 1971)

The $(p,n\bar{p})$ reaction has been measured on the lead isotopes ^{206}Pb, ^{207}Pb, and ^{208}Pb and on ^{209}Bi. Coulomb-energy differences are extracted from the positions of the $\bar{p}$ peaks. Proton decay widths are also obtained and compared with values from resonance experiments and with a previous value from ^{209}Bi$(p,n\bar{p})$.

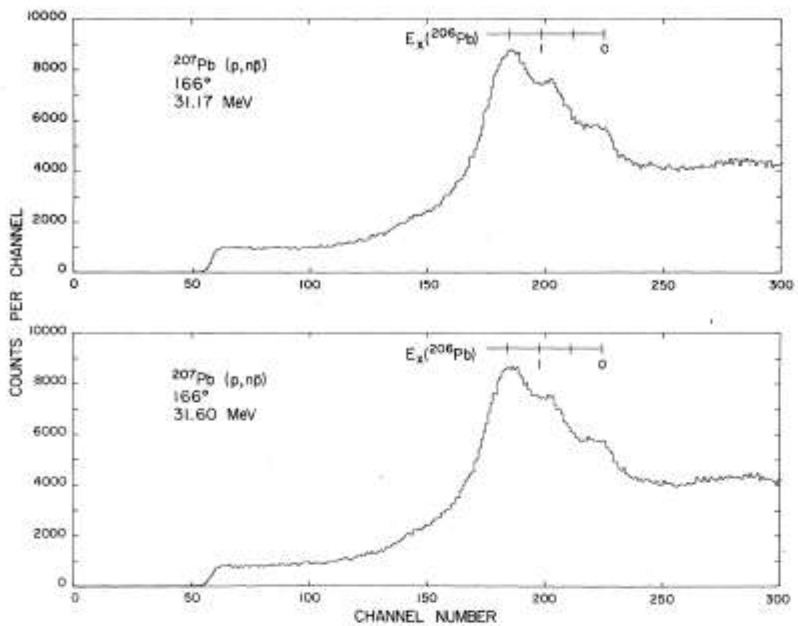
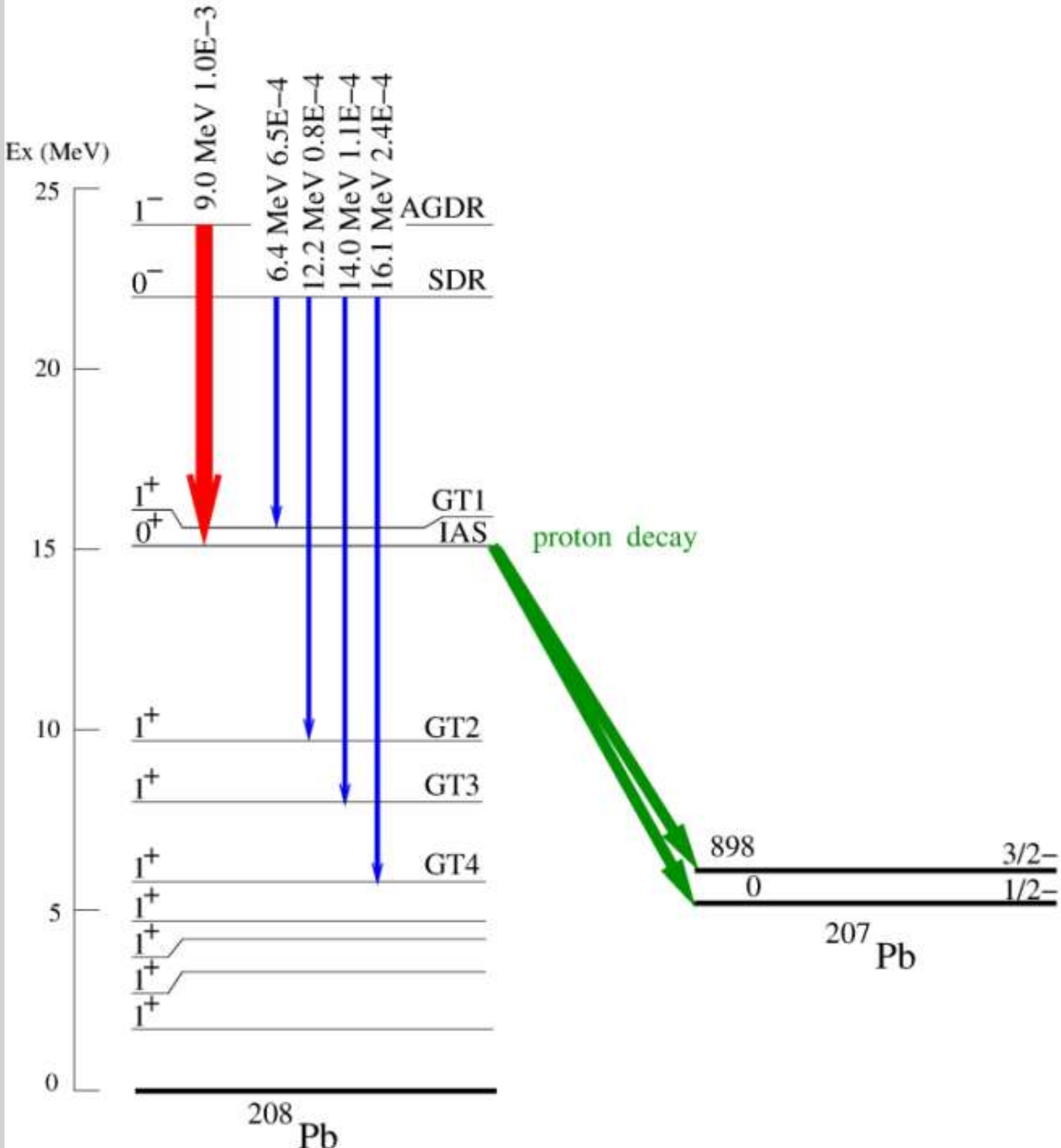


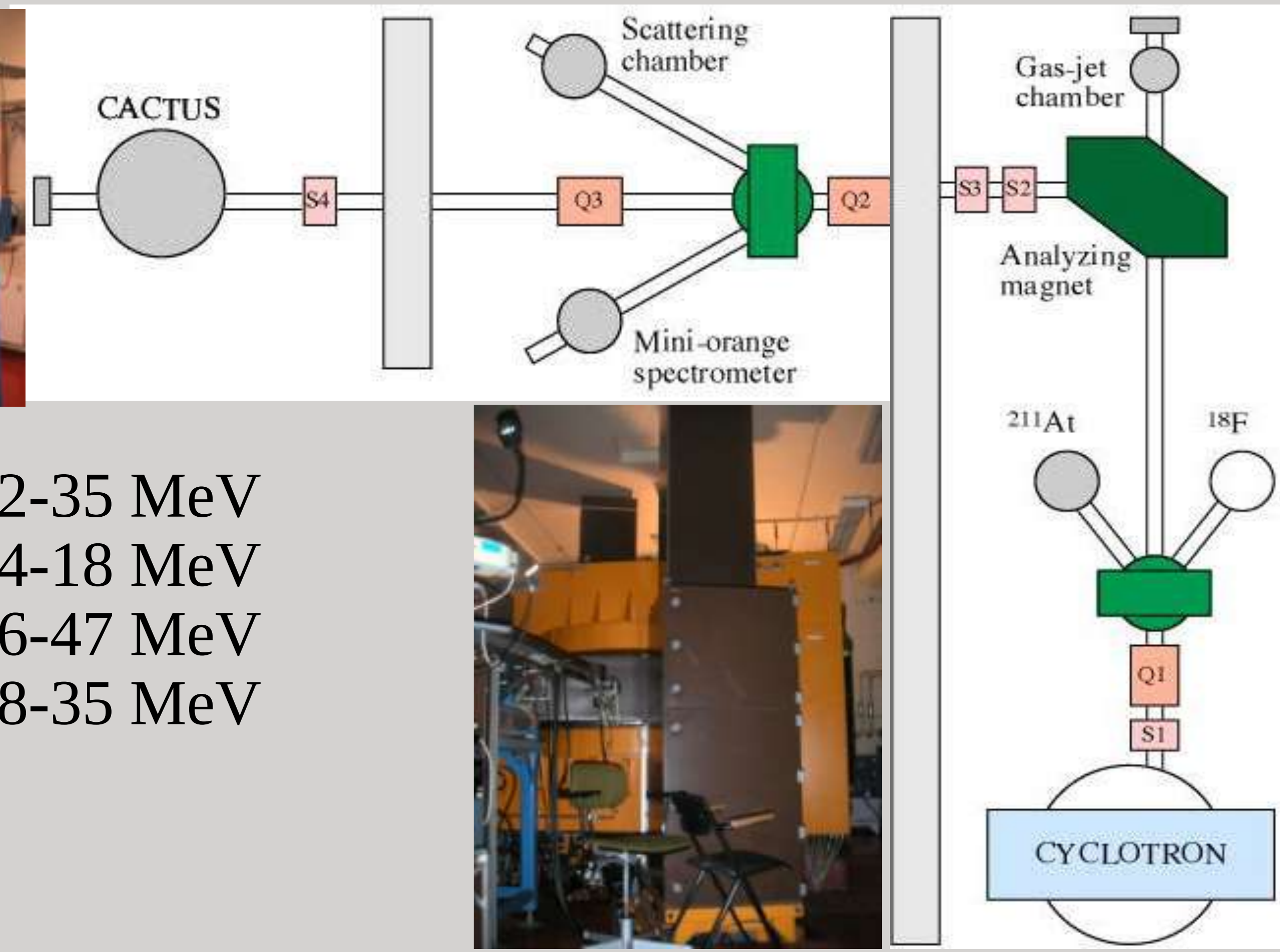
FIG. 8. Proton energy spectra showing the reaction $^{207}Pb(p,n\bar{p})^{206}Pb$.

$$Q(p,n) = -3.661\ \mathrm{MeV}$$



Ex (MeV)
25
20
15
10
5
0
9.0 MeV 1.0E−3
6.4 MeV 6.5E−4
12.2 MeV 0.8E−4
14.0 MeV 1.1E−4
16.1 MeV 2.4E−4
1−
AGDR
0−
SDR
1+
GT1
0+
IAS
proton decay
1+
GT2
1+
GT3
1+
GT4
1+
1+
1+
1+
208Pb
898
3/2−
0
1/2−
207Pb

Oslo Cyclotron Laboratory (OCL)

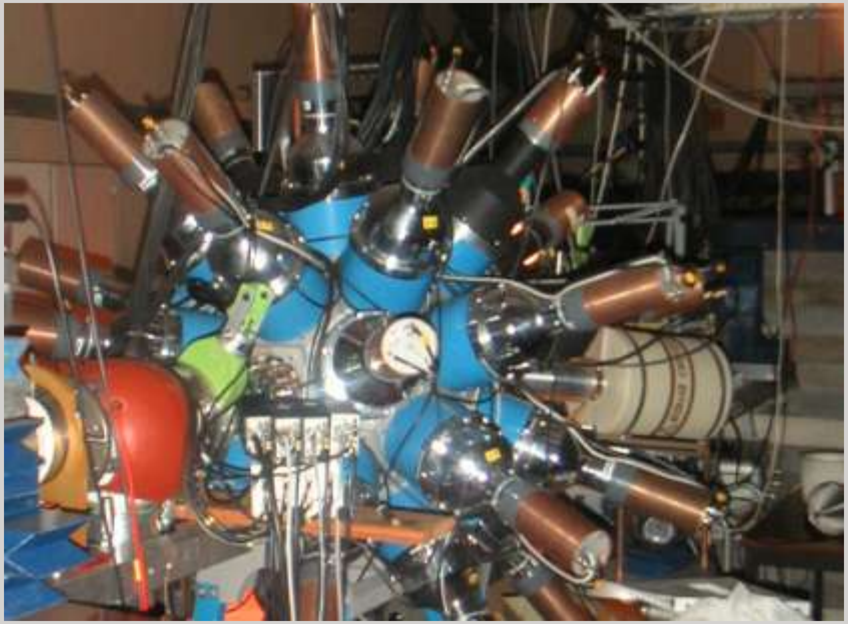


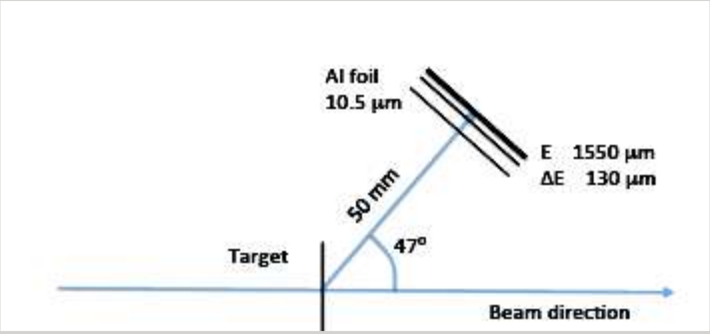
Protons	2-35 MeV
Deuterons	4-18 MeV
3He	6-47 MeV
4He	8-35 MeV

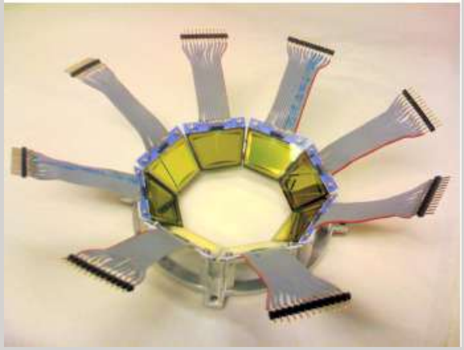
Experimental set-up

CACTUS:

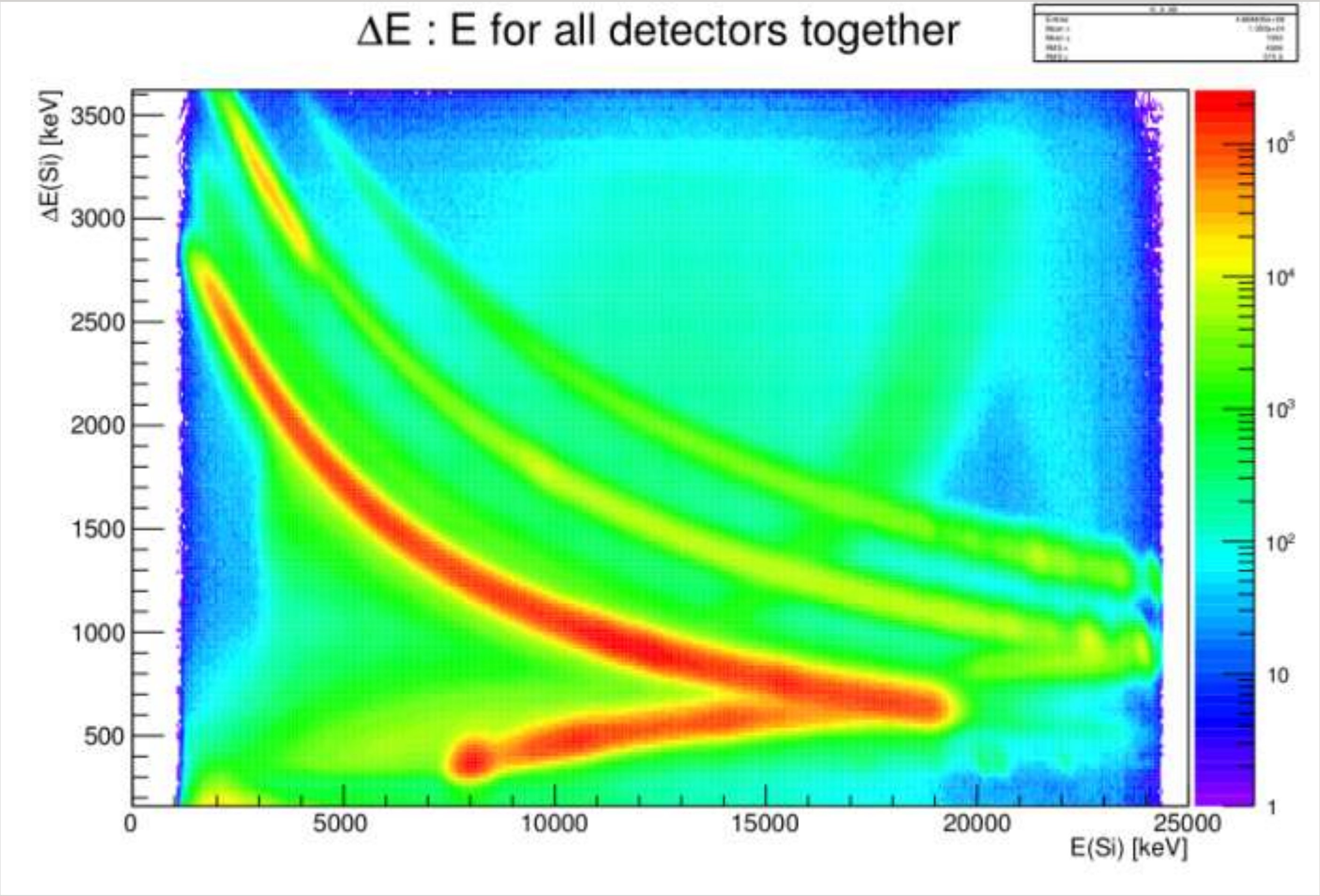
28 NaI 5”x5”   and   SiRI telescopes



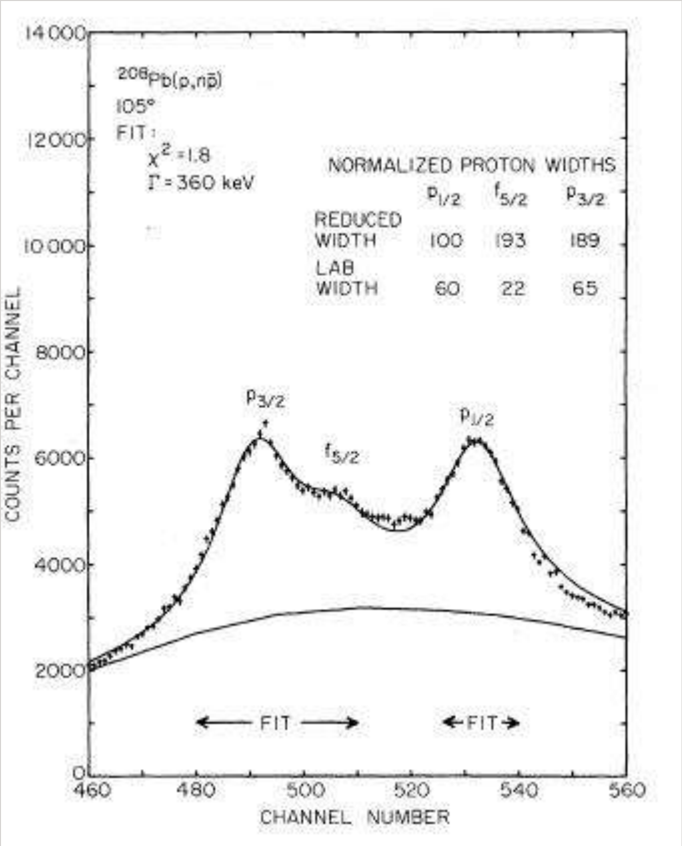


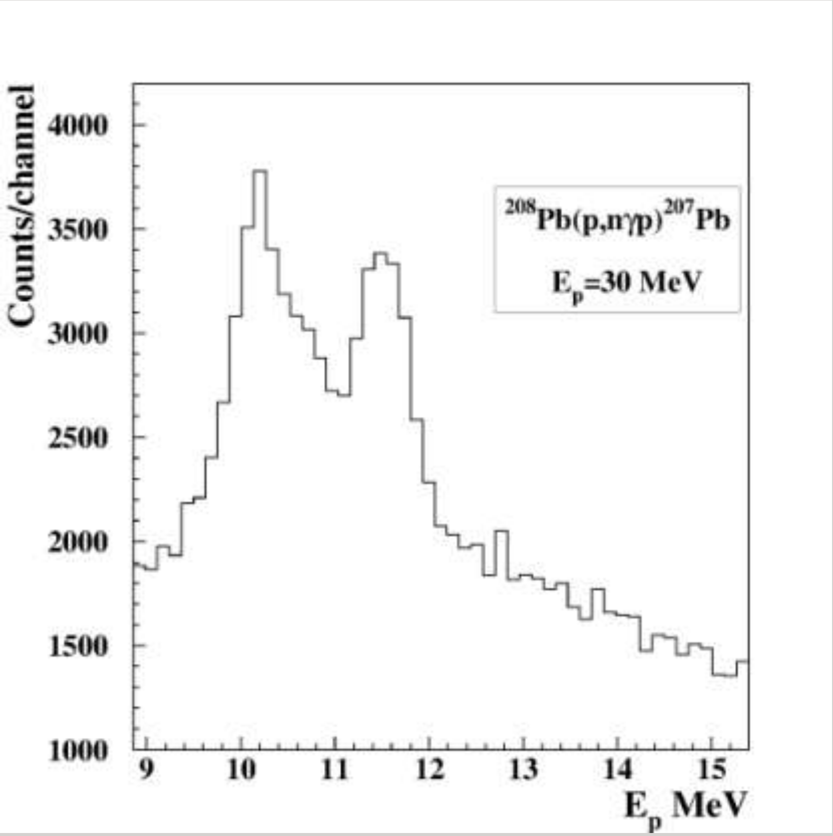


Excitation of the AGDR in the $^{208}Pb(p,n)^{208}Bi$ reaction at Ep=30 MeV

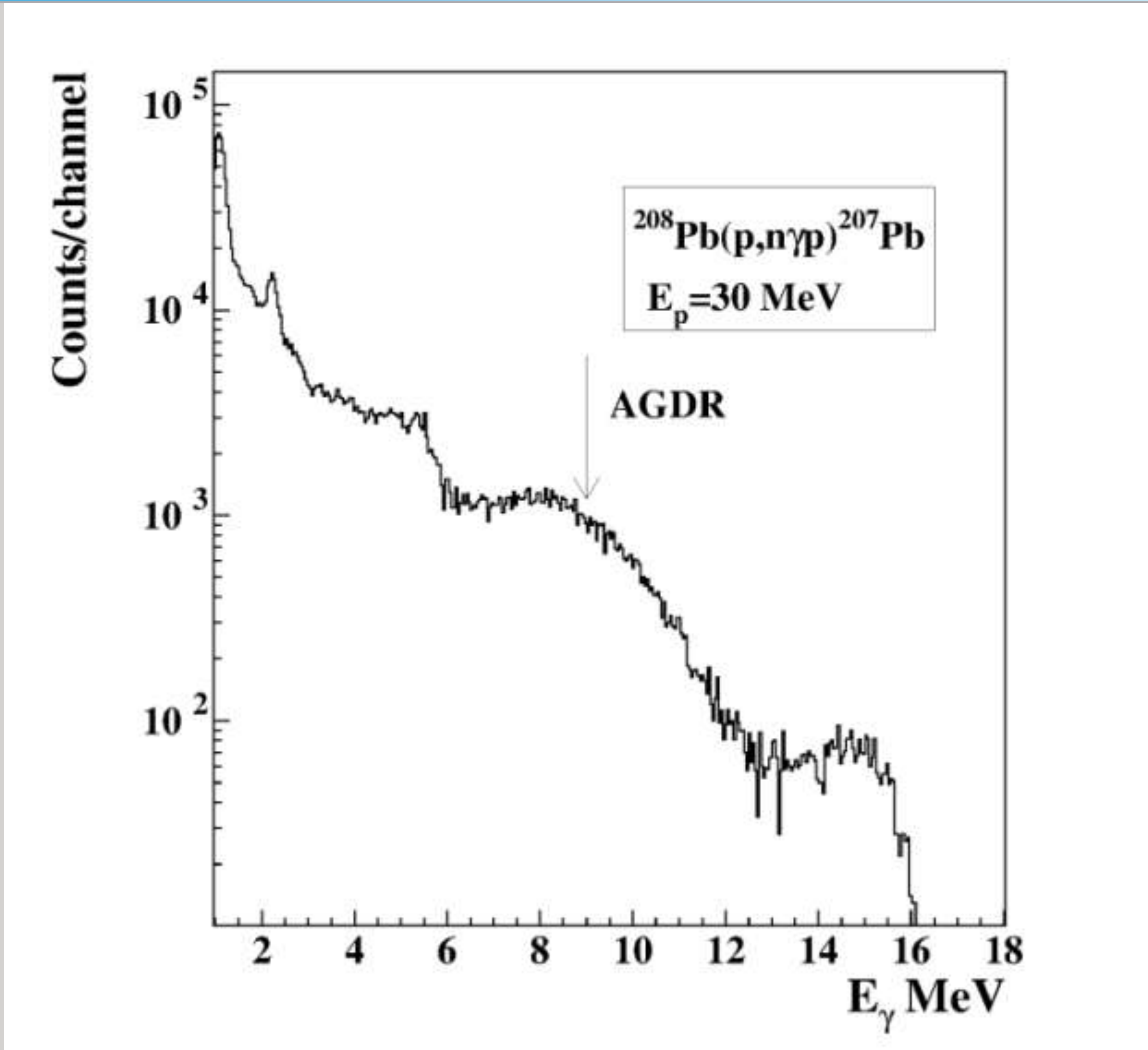


Proton energy spectra from the decay of the IAS

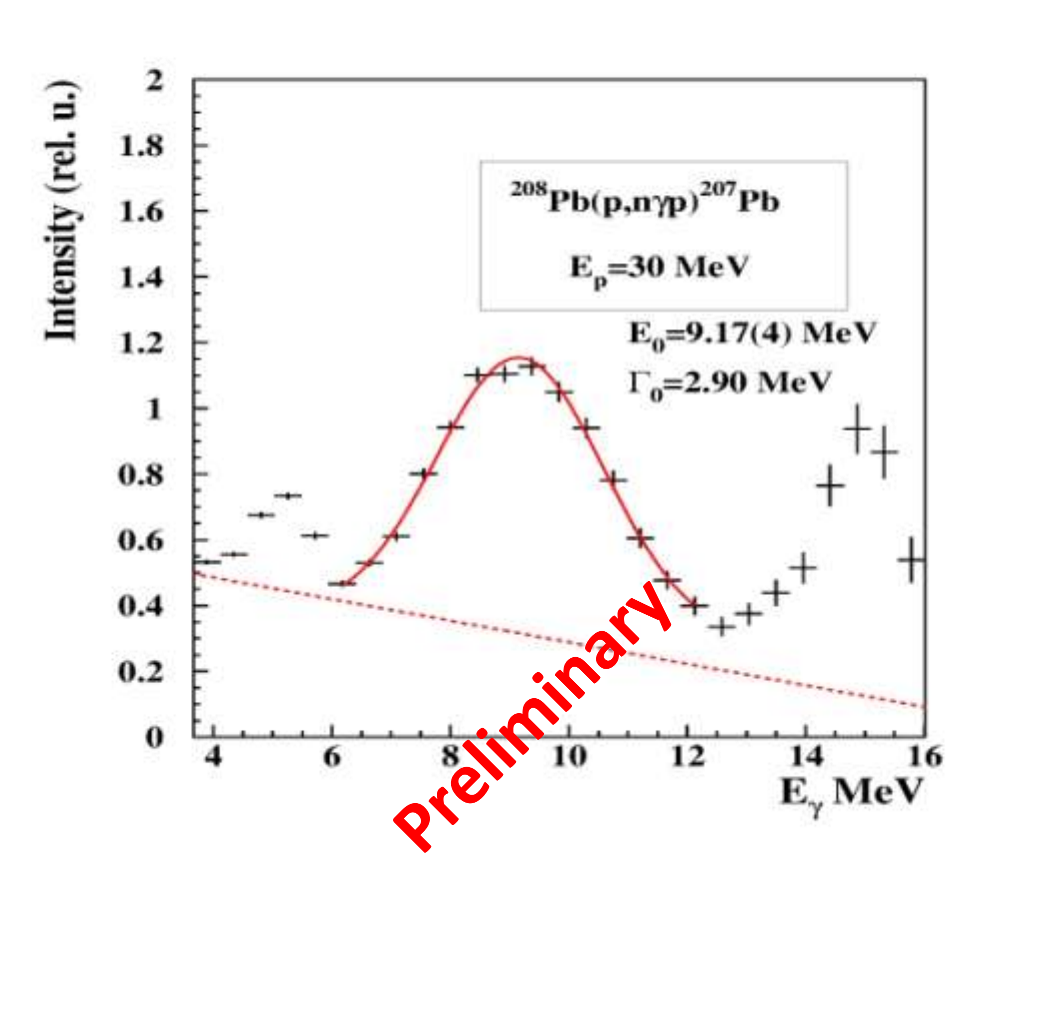




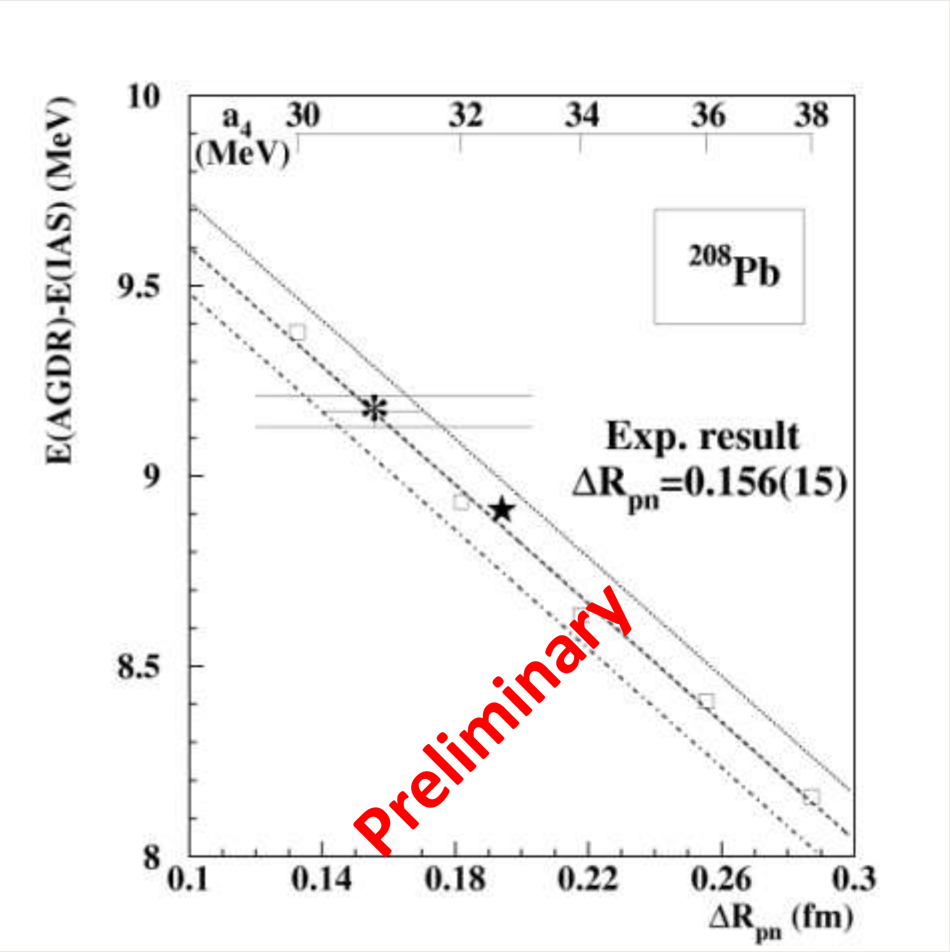
γ-energy spectrum measured in coincidence with the protons



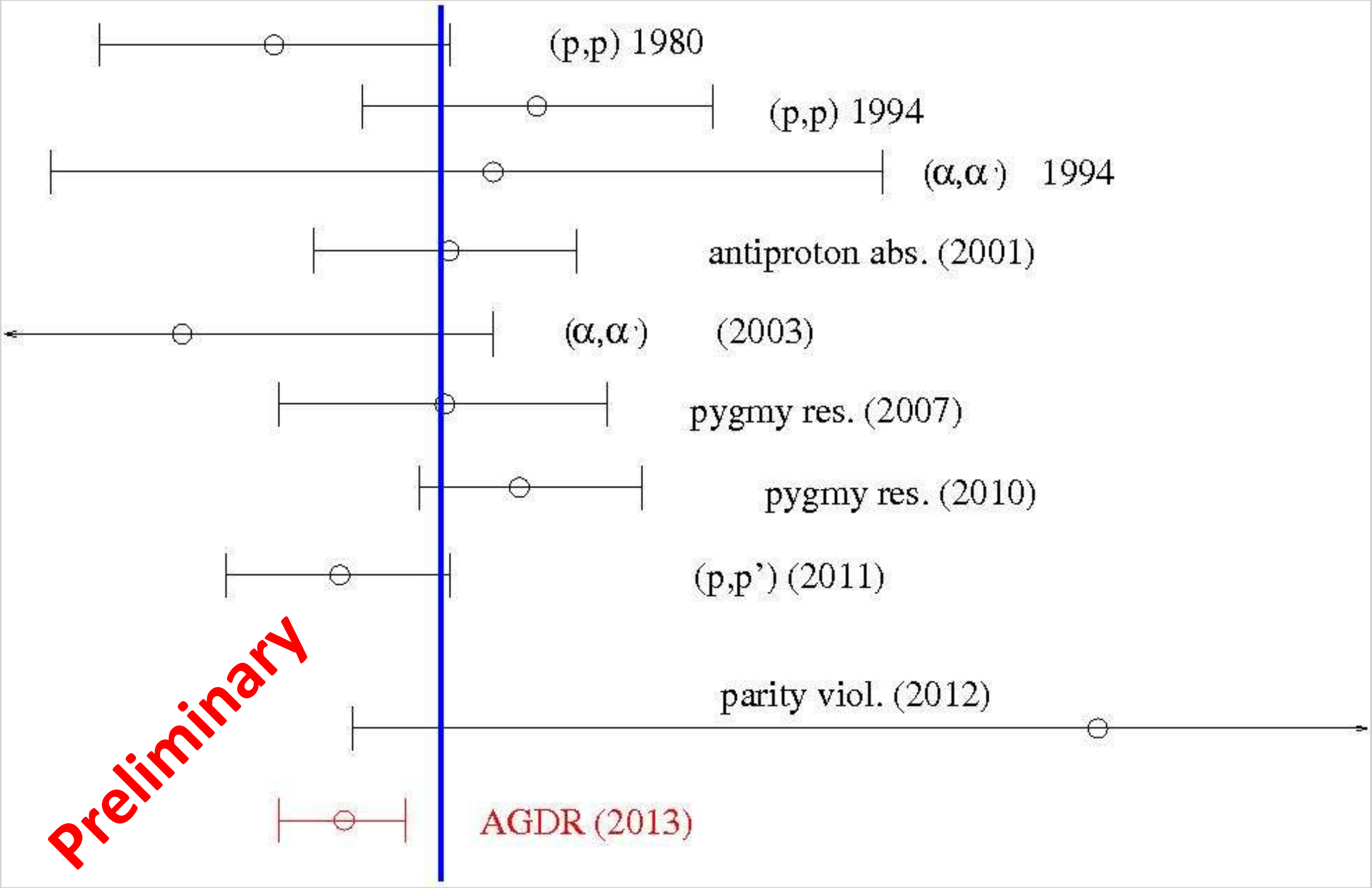
Determination of the energy of the AGDR



Determination of the neutron-skin thickness



Comparison of the neutron-skin thicknesses



V. Conclusions

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

Acknowledgements

- N. Paar, D. Vretenar, M.N. Harakeh
- A. Algora, M. Csatlós, L. Csige, J. Gulyás, L. Stuhl, J. Tímár, T. Tornyi
- A. Bracco, S. Brambilla, N. Blasi, F. Camera, A. Giaz, B. Million, L. Pellegri, S. Riboldi, O. Wieland
- For the whole EXL and R3B collaborations
- S. Siem, A. Görgen, P. Koehler, F. Giacoppo, T.W. Hagen,
- R. Julin