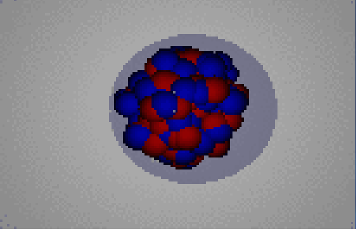
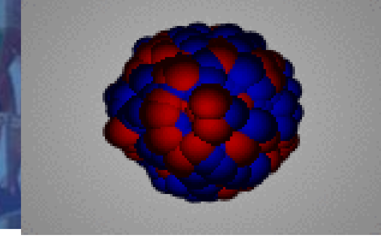
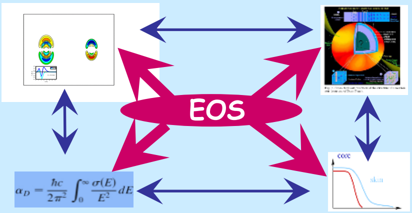


Experimental Studies of PDR and GDR in Exotic Nuclei

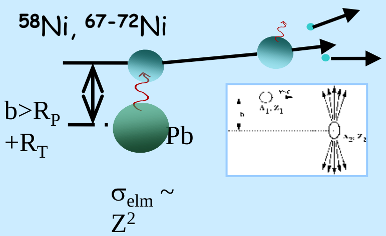


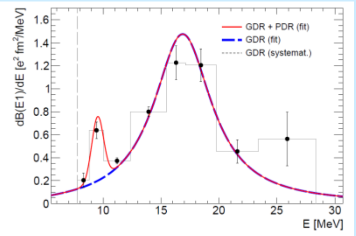
Konstanze Boretzky, GSI for the LAND-R³B Collaboration

- pygmy dipole resonance and dipole polarizability ←→ EOS

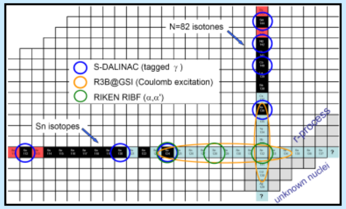


- dipole excitation in inverse kinematics



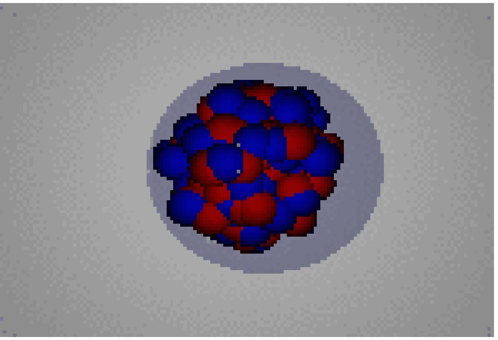


- dipole strength in neutron-rich Ni isotopes: ^{68}Ni



- experimental perspectives

Equation of State



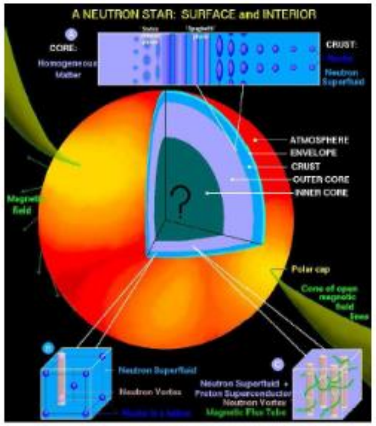


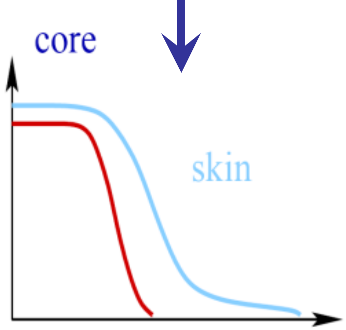
Fig. 3. State-of-the-art rendition of the structure of a neutron star (courtesy of Dany Page).

symmetry energy (ρ)

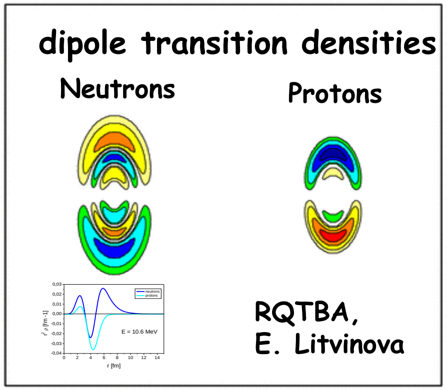
EQUATION OF STATE

symmetry energy (ρ)

$$\alpha_D = \frac{\hbar c}{2\pi^2} \int_0^\infty \frac{\sigma(E)}{E^2} dE$$



Equation of State



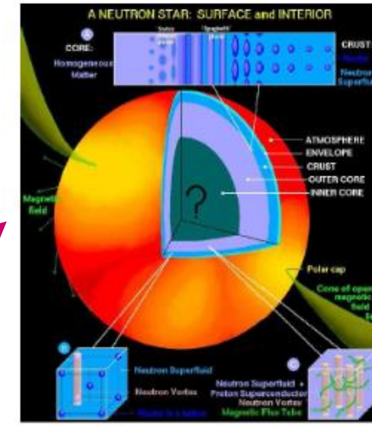


Fig. 3. State-of-the-art rendition of the structure of a neutron star (courtesy of Dany Page).

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EQUATION OF STATE

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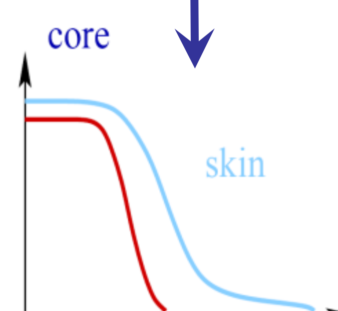
$$\alpha_D = \frac{\hbar c}{2\pi^2} \int_0^\infty \frac{\sigma(E)}{E^2} dE$$



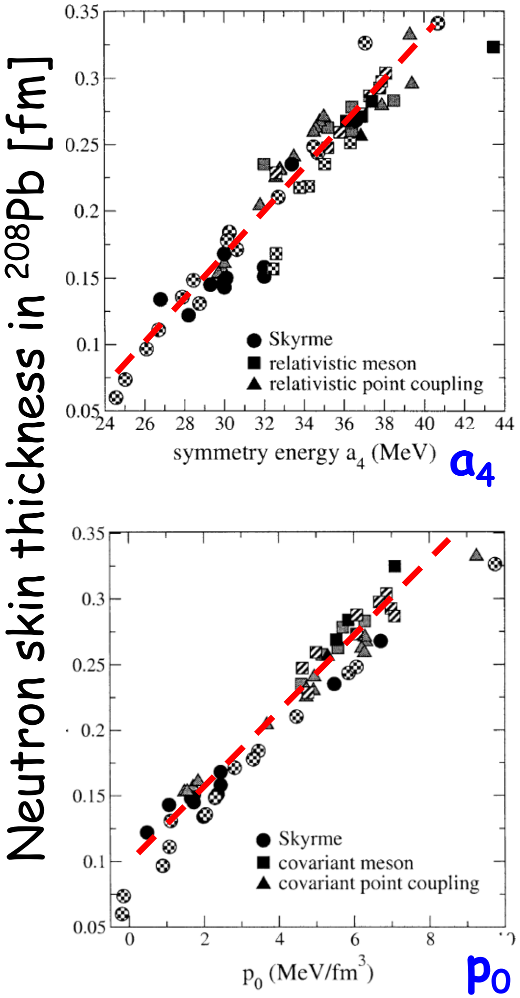
Symmetry Energy of Nuclear Matter

Taylor expansion per nucleon in nuclear matter: $E(\rho,\alpha) = E(\rho,0) + S_2(\rho)\alpha^2 + O(\alpha^4)\,,\ \alpha = \dfrac{N-Z}{A}$

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

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

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



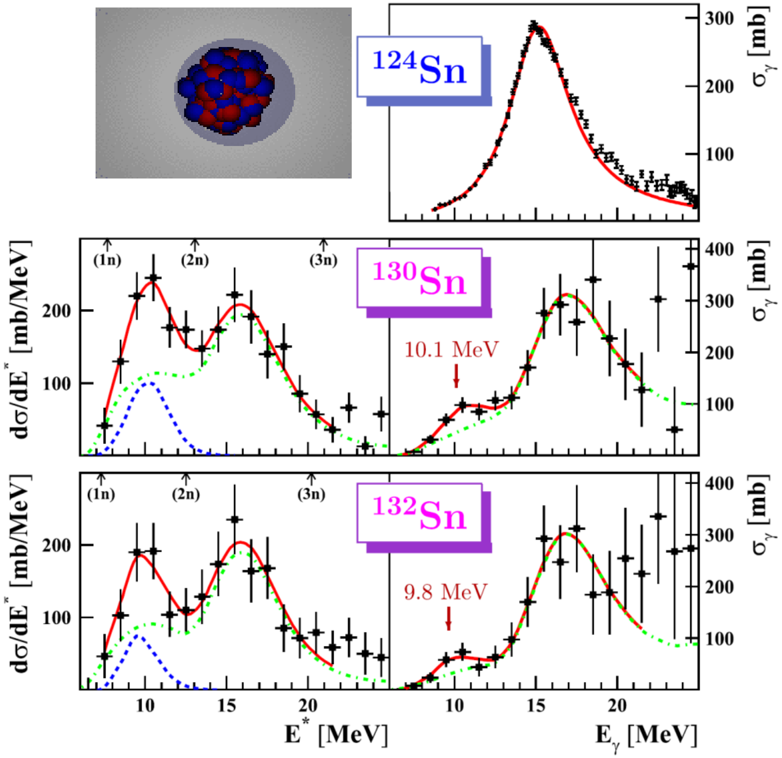
R.J.Furnstahl NPA 706(2002)85-110

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

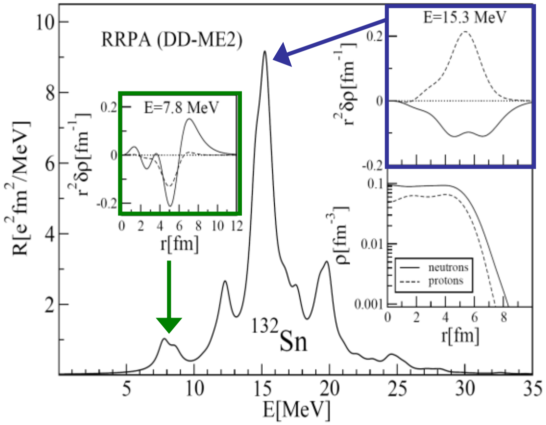
L ~ p_0: symmetry energy pressure

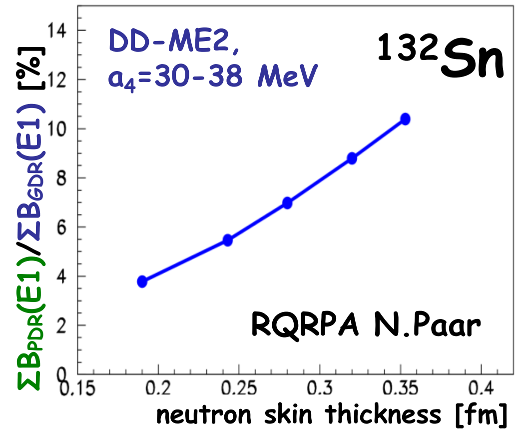
ΔK_0: correction to incompressibility

Reminder:
Pygmy and Neutron Skin in ^{132}Sn



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





GDR ➔ Breit-Wigner
PDR ➔ Gaussian

Analysis of $^{130,132}Sn$ data with respect to neutron skin thickness and symmetry energy parameters in

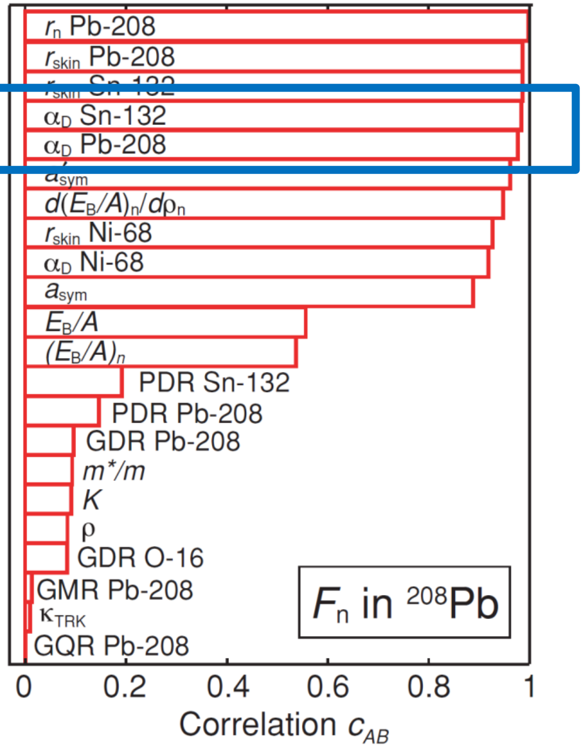
A. Klimkiewicz, N. Paar *et al.*, PRC **76** (2007) 051603(R)

Requires assumption of a specific line-shape of PDR and GDR

Dipole Polarizability and Neutron Skin

Covariance Analysis

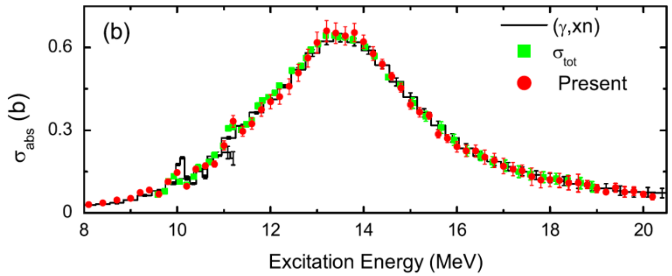
P-G. Reinhard and W. Nazarewicz, PRC **81** 051303(R) (2010)

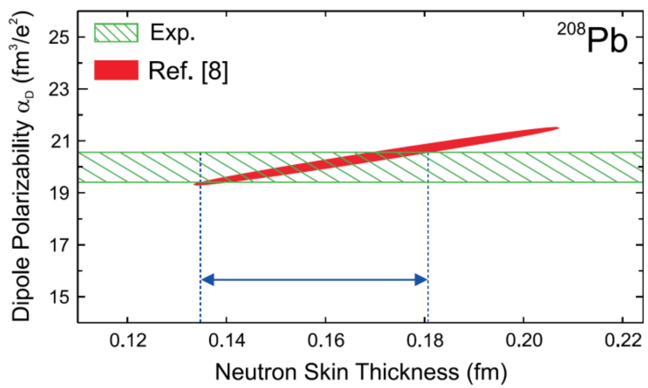


$$\alpha_D = \frac{\hbar c}{2\pi^2} \int_0^\infty \frac{\sigma(E)}{E^2} dE$$

Polarized Proton Scattering

A. Tamii et al., PRL **107** 062502 (2011)

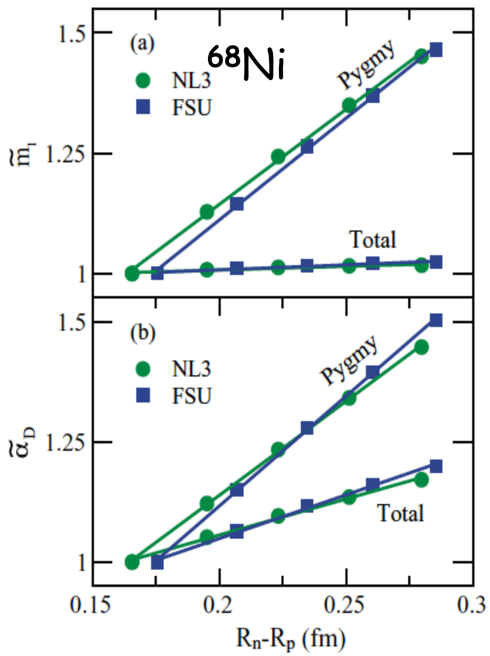




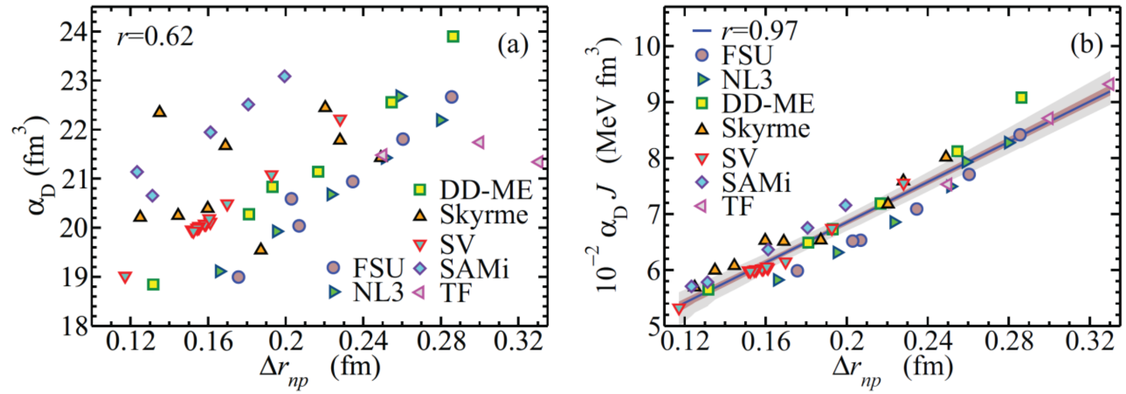
$$r_{\rm skin} = 0.156^{+0.025}_{-0.021}\ \text{fm}$$

Pygmy Strength and Dipole Polarizibility

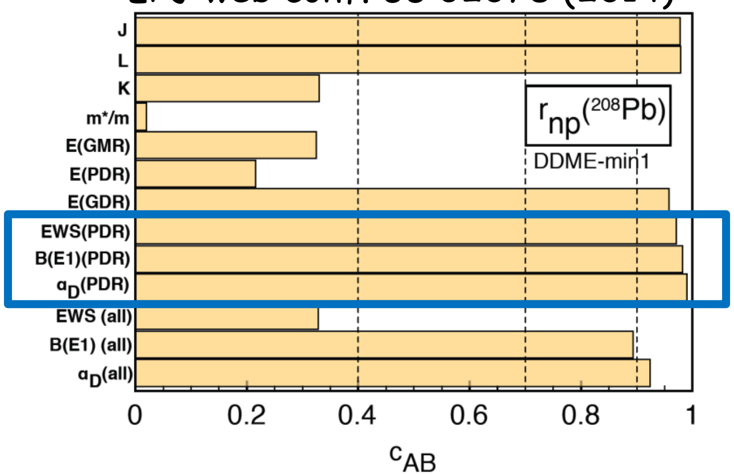
J. Piekarewicz,
PRC **83** 034319 (2011)



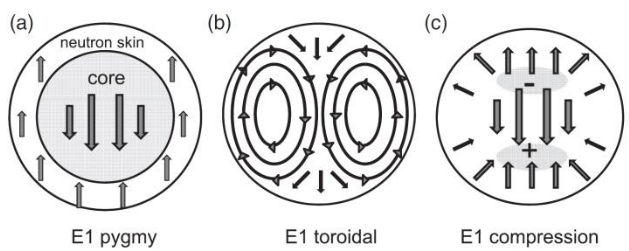
X. Roca-Maza *et al.*,
PRC **88**, 024316 (2013)



N. Paar and A. Horvat,
EPJ web conf. **66** 02078 (2014)

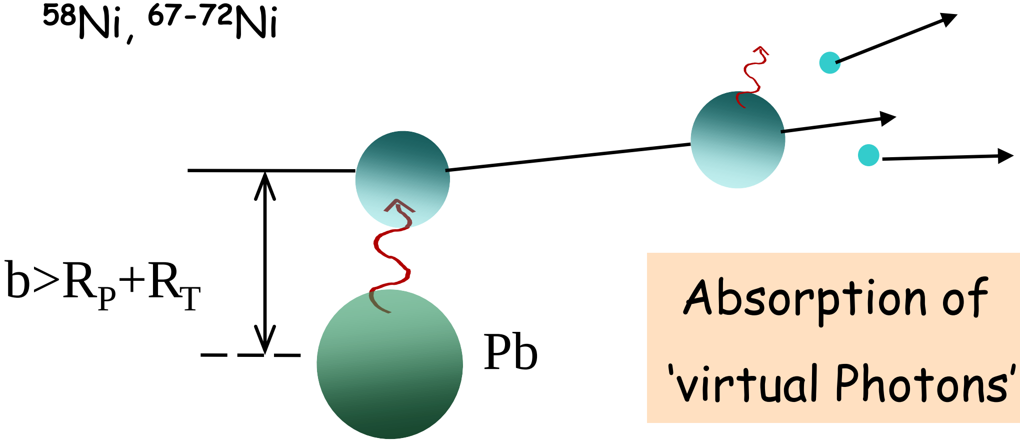


A. Repko et al.,
PRC **87**, 024305 (2013)



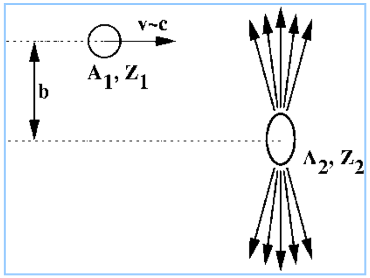
Experimental Approach: Electromagnetic Excitation at High Beam Energies

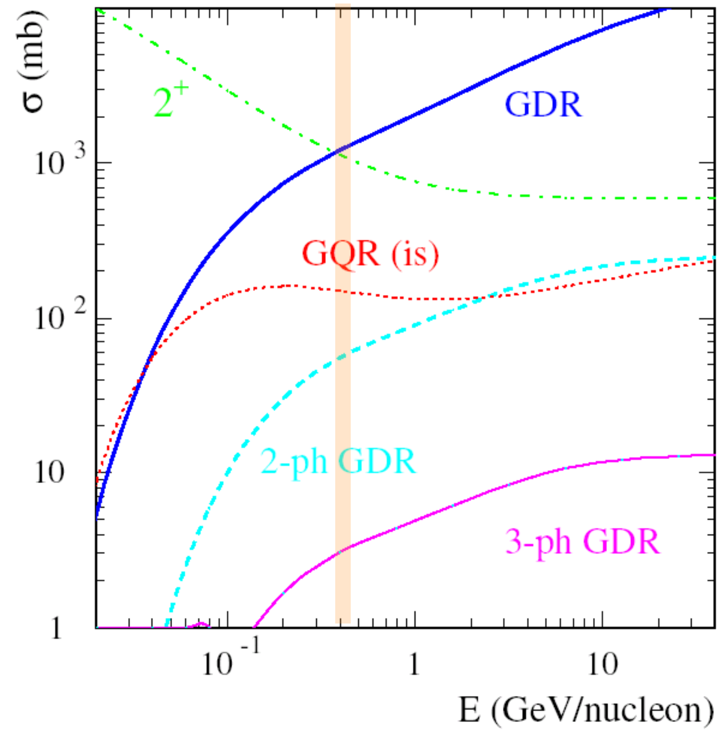
^{58}Ni, $^{67-72}$Ni



Absorption of 'virtual Photons'

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



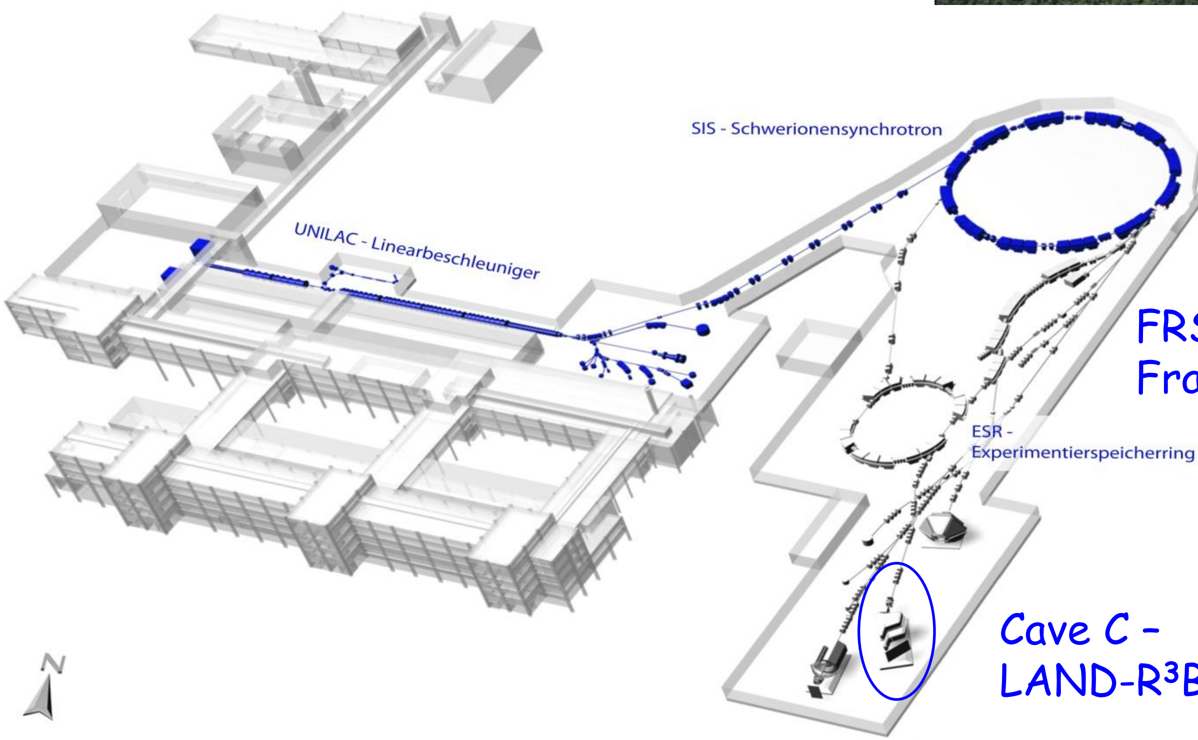


high velocities $\beta \approx 0.6$-0.9
⇒ high-frequency Fourier components
⇒ large excitation energies
⇒ large cross sections

1st order pertubation theory:

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

LAND-R^{3}B at GSI

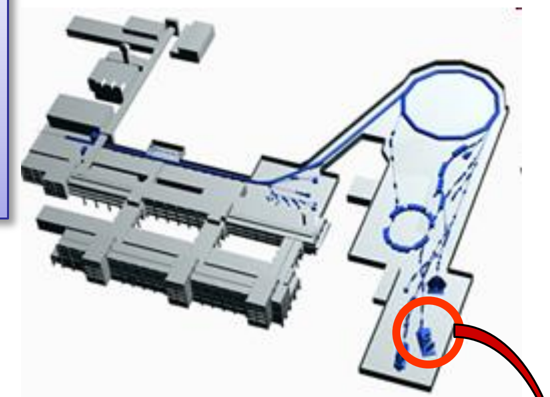


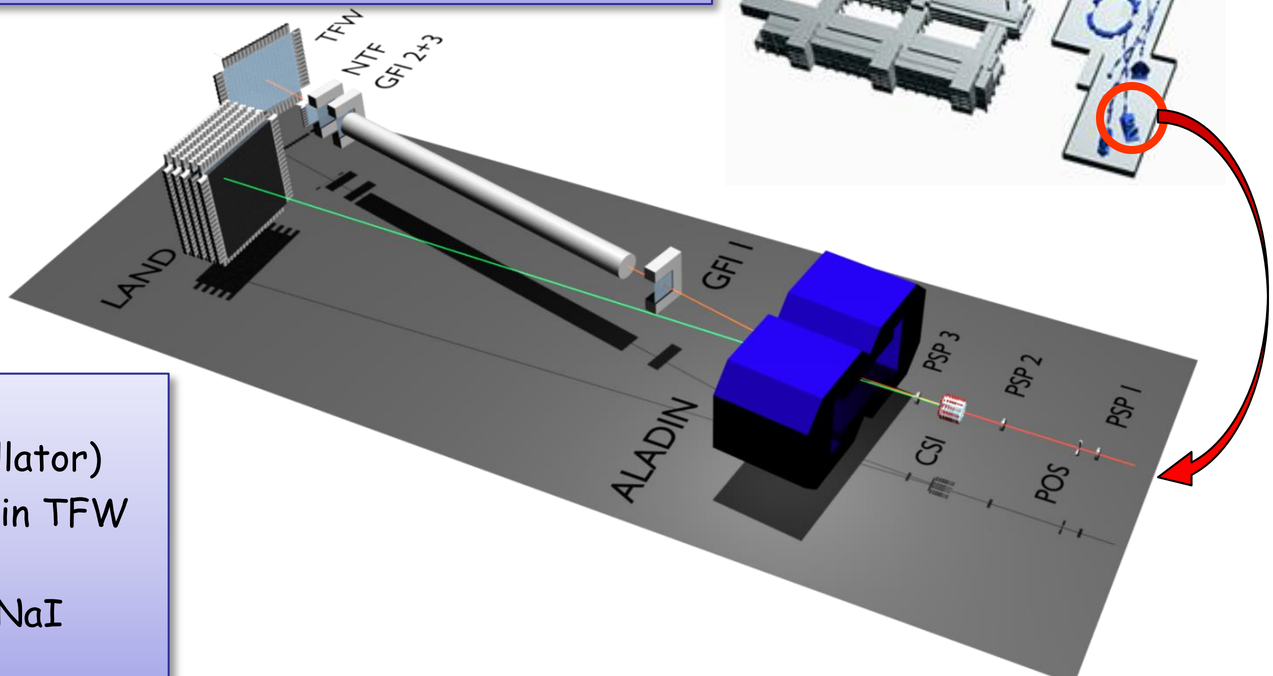
FRS -
Fragment Separator

Cave C -
LAND-R^{3}B setup

Experimental Setup of Nickel Experiment

- Beam tracking in Cave C: Si detectors (PSP) and scintillation detectors (POS, GFI, TFW)
- Kinematic forward-focusing (relativistic beam energies)
  → high-acceptance measurement (almost full coverage of solid angle)

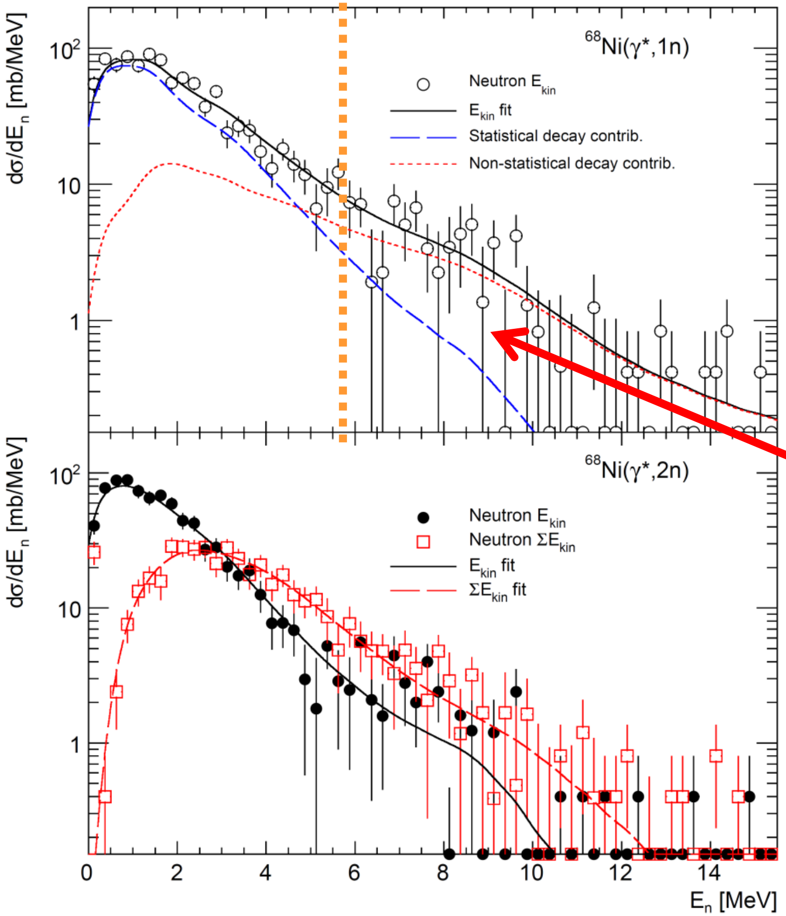




- Neutron detection with LAND
  (Fe converter + organic scintillator)
- Charged fragments detection in TFW (scintillation detector)
- Gamma detection with CsI or NaI detector

$$E^* = \sqrt{\sum_i m_i^2 + \sum_{i \neq j} \gamma_i \gamma_j m_i m_j \left(1 - \beta_i \beta_j \cos\vartheta_{ij}\right)} + E_\gamma - m_{proj}$$

$^{68}Ni(\gamma^*,n)$: Neutron Kinetic Energy

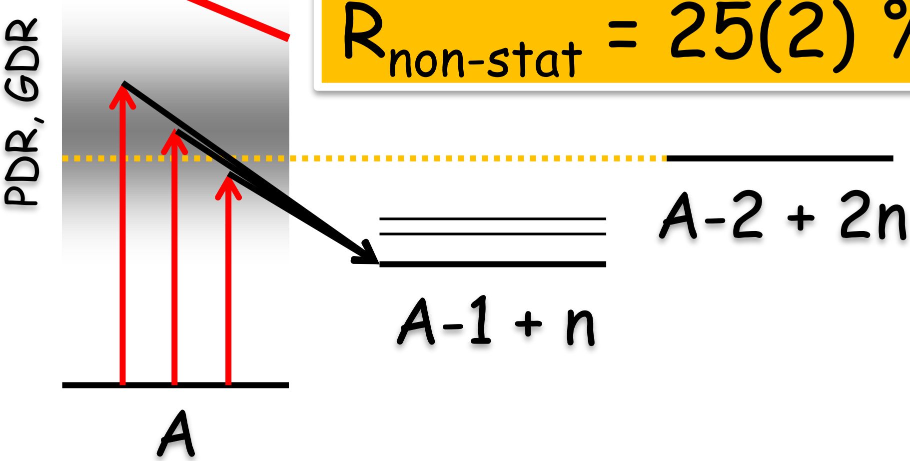


- Neutron kinetic energies reach well beyond the 2n threshold (dotted orange line)

→ Not expected with statistical decay

- Only decay to the vicinity of the A-1 ground state was considered
- Non-statistical decay branching ratio obtained from fit to neutron energies

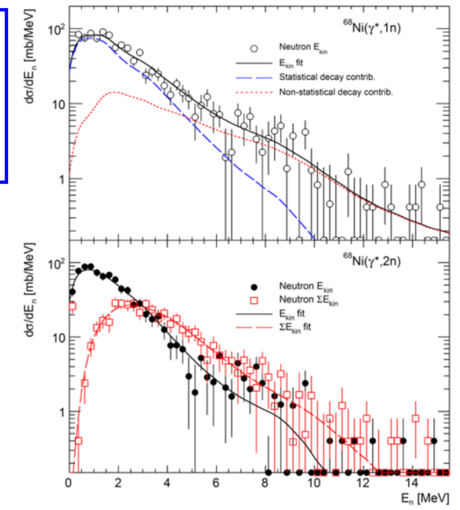
$R_{non\text{-}stat} = 25(2)$ %



GSI

Deconvolution of ^{68}Ni spectra

$$E^* = \sqrt{\sum_i m_i^2 + \sum_{i \neq j} \gamma_i \gamma_j m_i m_j \left(1 - \beta_i \beta_j \cos\vartheta_{ij}\right)} + E_\gamma - m_{proj}$$



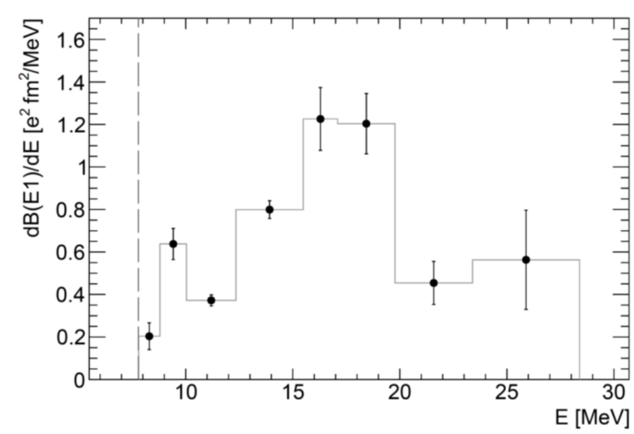
accounting for complex detector response:

- description of decay from n-spectra
- LAND neutron response from calibration data
- gamma response from GEANT4

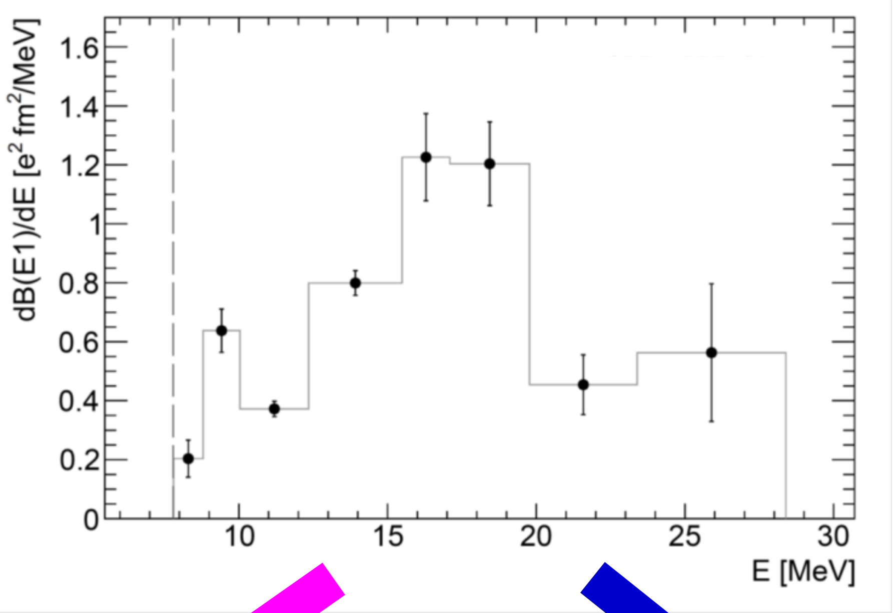
❖ simultaneous fit of E1 distribution and individual neutron spectra

❖ use of unbiased trial function for description of E1 spectrum
  - 8 independent bins running from 7.8 to 28.4 MeV
  - bin size according to experimental resolution
  - χ^2 minimization of bin strength to exp. data

→ "deconvoluted" E1 distribution



Dipole Strength measured in ^{68}Ni



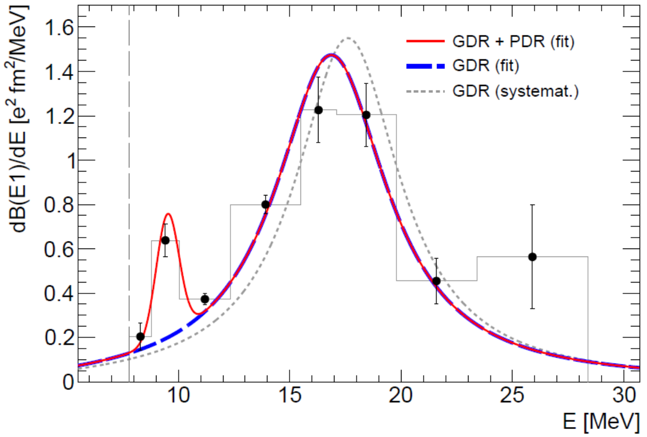
PDR and GDR parameters
comparison to RISING data

dipole polarizability
neutron skin thickness in ^{68}Ni

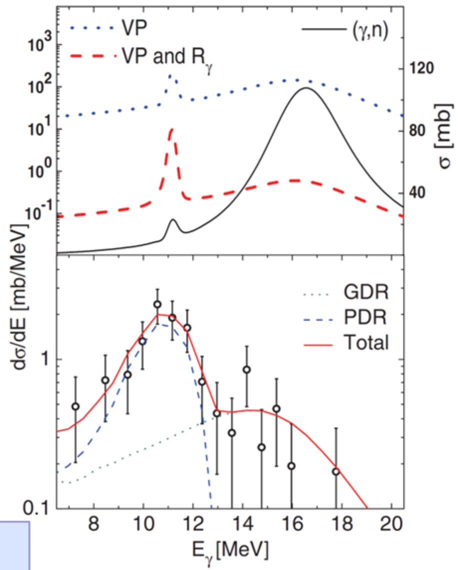
PDR and GDR parameters for ^{68}Ni

D. Rossi et al. ,
PRL 111, 242503 (2013)

O. Wieland et al.
PRL 102, 092502 (2009)



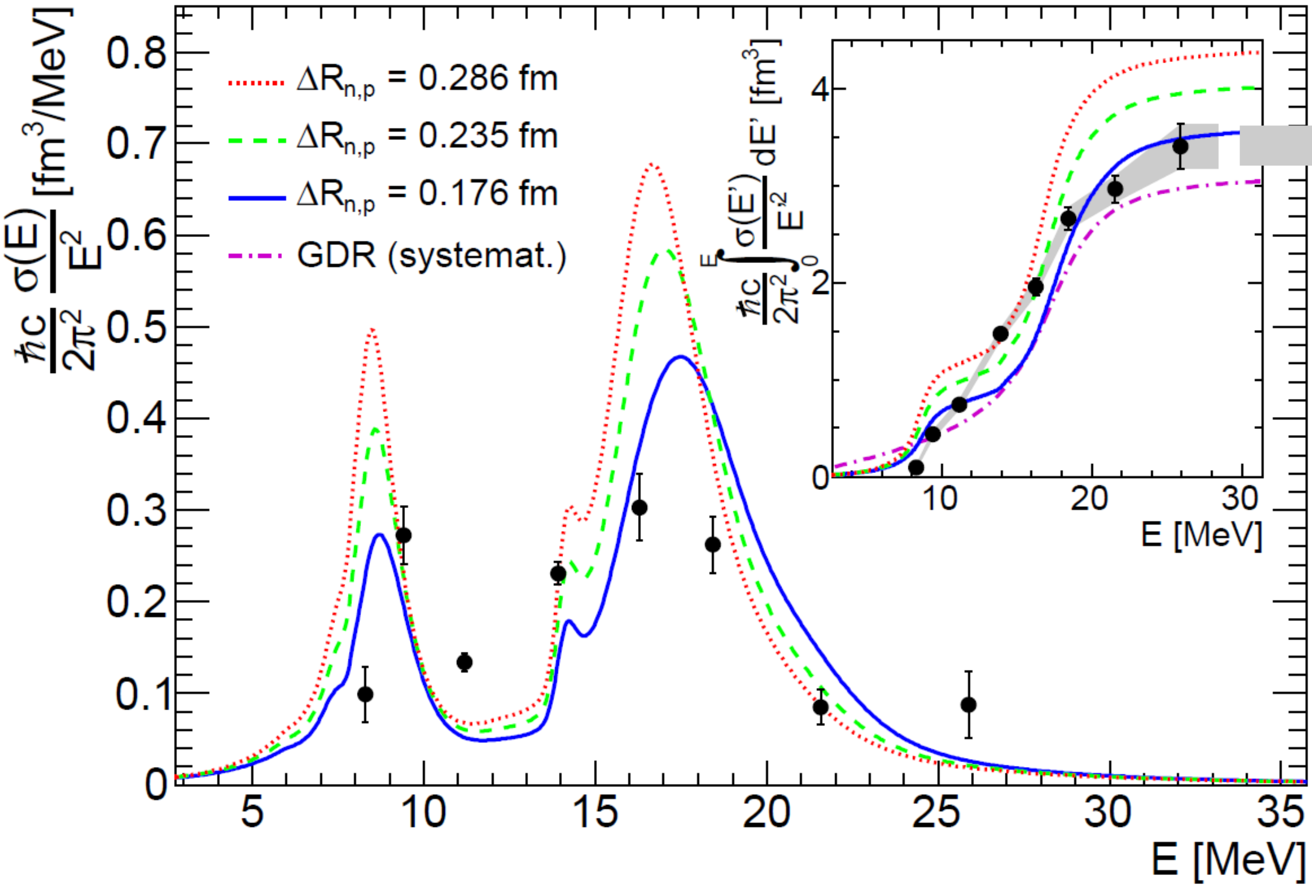
PDR in ^{68}Ni	(γ*,xn)	(γ*,γ')
E_m [MeV]	9.55(17)	11.0(5)
σ [MeV]	0.51(13)	< 1
S_{TRK} [%]	2.8(5)	0.2



GDR in ^{68}Ni	(γ *,xn)	Literature
E_m [MeV]	17.1(2)	17.84
Γ [MeV]	6.1(5)	5.69
S_{TRK} [%]	98(7)	100

γ-branching ratio:
Γ_0/Γ=7(2)%

Inverse Energy-Weighted Dipole Strength and Dipole Polarizability in ^{68}Ni

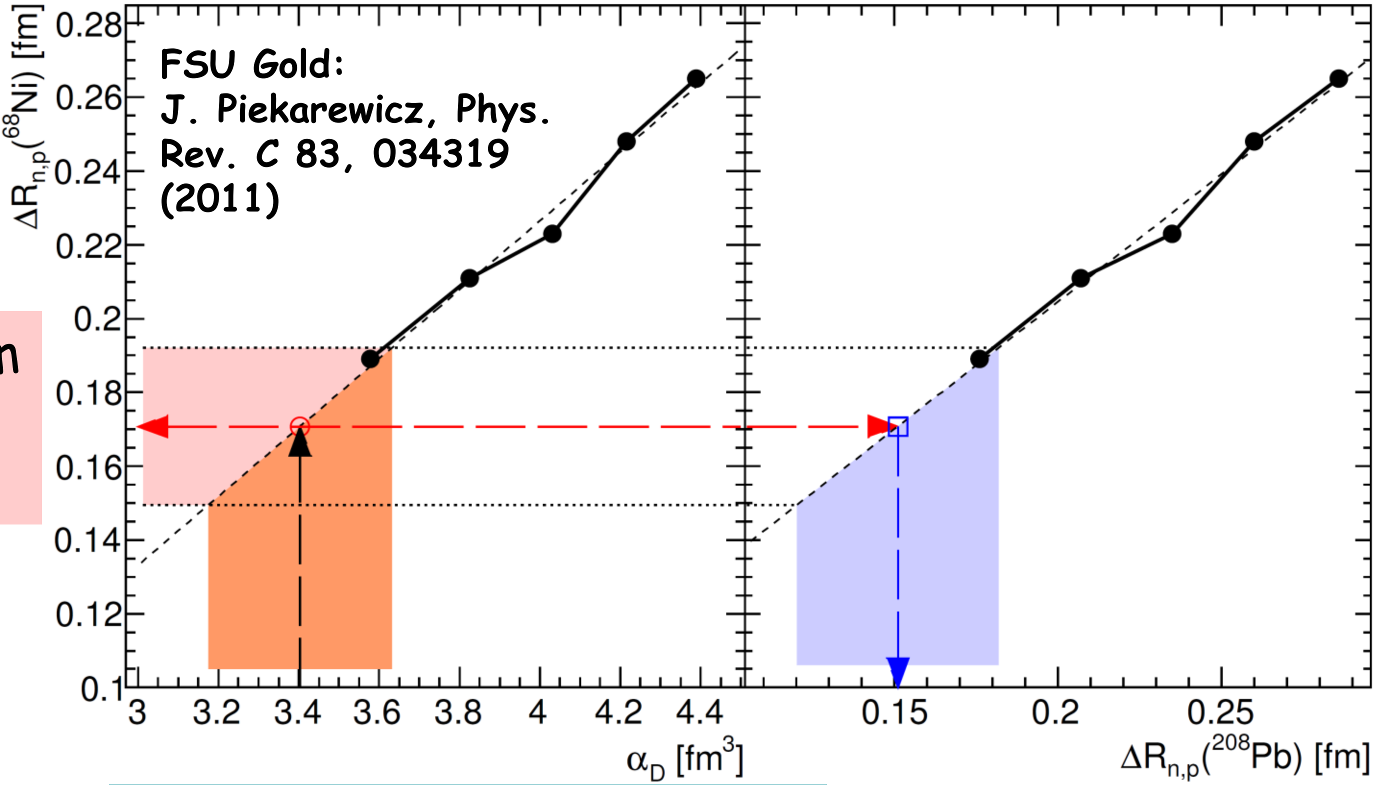


α_D^{exp} = 3.40(23) fm^3

FSU Gold: J. Piekarewicz, Phys. Rev. C 83, 034319 (2011)

Dipole Polarizability and Neutron Skin Thickness in ^{68}Ni

$\Delta R_{n,p}$ = 0.17(2) fm in ^{68}Ni from exp.



$\Delta R_{n,p}$ = 0.15(3) fm in ^{208}Pb from same parametrization

Agrees with (p,p') measurement on ^{208}Pb (Tamii *et al.*)

preliminary results

several slides removed...

Dipole Summary

dipole strength distribution in ^{68}Ni measured for 7.8 to 28.4 MeV

- dipole polarizability of α_D^{exp} = 3.40(23) fm^3 found
- neutron skin thickness deduced using FSU Gold parametrization
- . PRELIMINARY
- discussion of model dependencies, $\alpha_D J$ and possible constraints for J

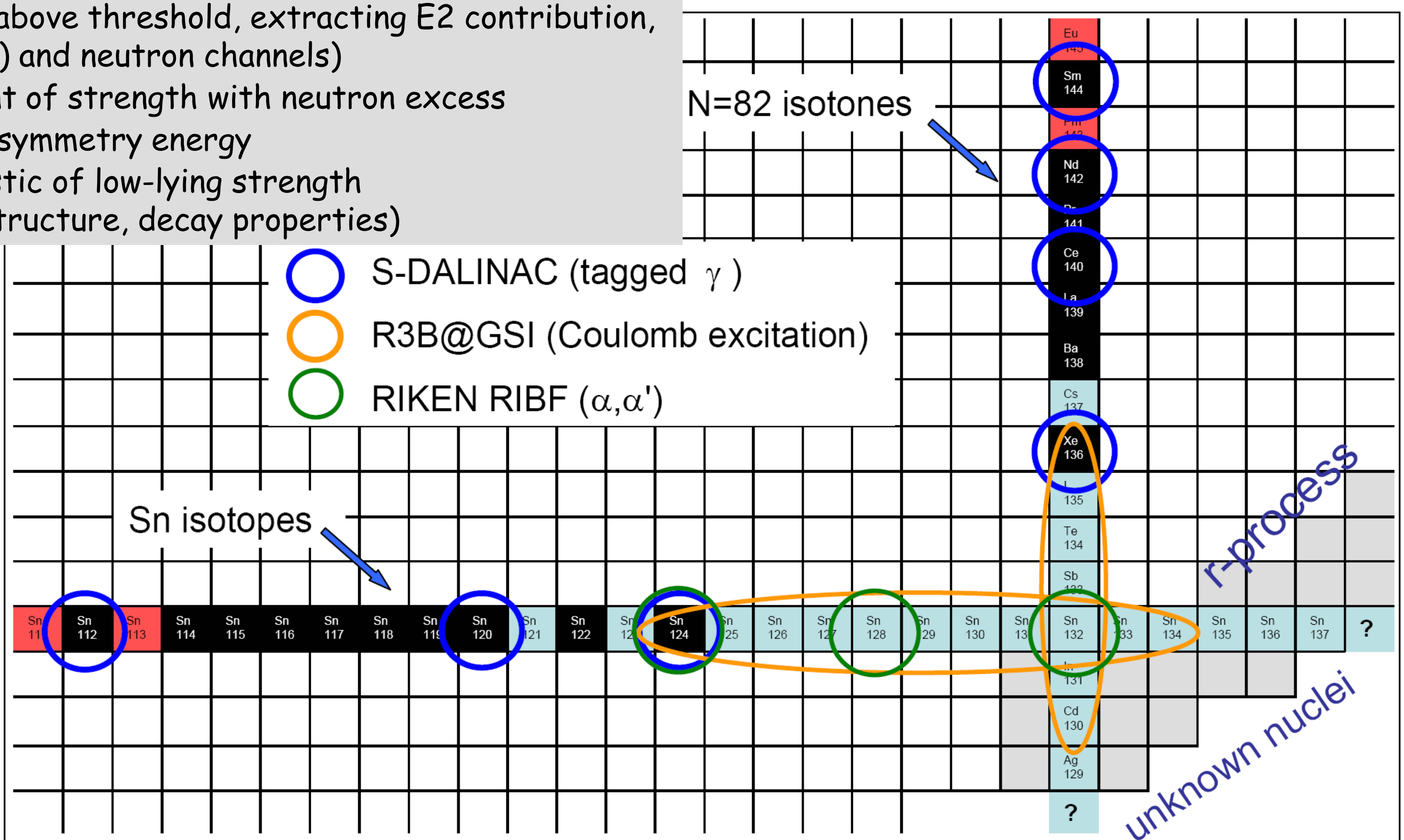
- E1 distribution in ^{68}Ni exhibits pronounced low-lying strength
- GDR found close to systematics, E_{mean} slightly lower
- additional strength at low energies →PDR parameters extracted
  3% TRK sum rule at 9.5 MeV
- decay properties investigated

dipole strength in exotic nuclei delivers valuable input to fundamental quantities → more, systematic data needed!

Experimental Program

Next-generation experiments – Goals:

- extraction of full dipole strength function (below and above threshold, extracting E2 contribution, γ(-cacade) and neutron channels)
- development of strength with neutron excess
- relation to symmetry energy
- characteristic of low-lying strength (isospin structure, decay properties)



Collaboration

analysis:
Dominic Rossi
PhD Thesis
Univ. Mainz,
PostDoc GSI,
now PostDoc
MSU

D. M. Rossi,[1,2,*] P. Adrich,[1] F. Aksouh,[1,†] H. Alvarez-Pol,[3] T. Aumann,[4,1,‡] J. Benlliure,[3] M. Böhmer,[5] K. Boretzky,[1] E. Casarejos,[6] M. Chartier,[7] A. Chatillon,[1] D. Cortina-Gil,[3] U. Datta Pramanik,[8] H. Emling,[1] O. Ershova,[9] B. Fernandez-Dominguez,[3,7] H. Geissel,[1] M. Gorska,[1] M. Heil,[1] H. T. Johansson,[10,1] A. Junghans,[11] A. Kelic-Heil,[1] O. Kiselev,[1,2] A. Klimkiewicz,[1,12] J. V. Kratz,[2] R. Krücken,[5] N. Kurz,[1] M. Labiche,[13,14] T. Le Bleis,[1,9,15] R. Lemmon,[14] Yu. A. Litvinov,[1] K. Mahata,[1,16] P. Maierbeck,[5] A. Movsesyan,[4] T. Nilsson,[10] C. Nociforo,[1] R. Palit,[17] S. Paschalis,[4,7] R. Plag,[9,1] R. Reifarth,[9,1] D. Savran,[18,19] H. Scheit,[4] H. Simon,[1] K. Sümmerer,[1] A. Wagner,[11] W. Waluś,[12] H. Weick,[1] and M. Winkler[1]

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