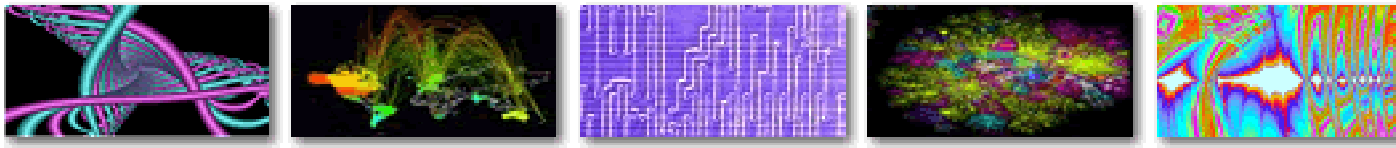
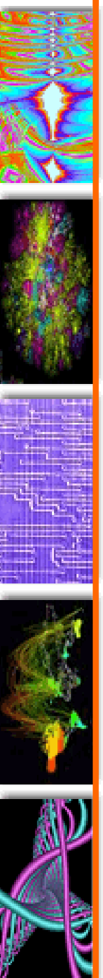




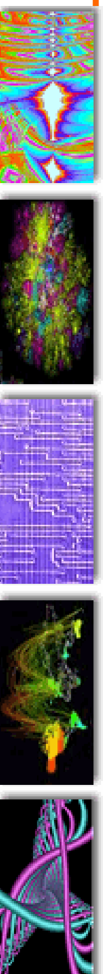
Isotopic dependence of the giant monopole resonance in the even-A $^{112-124}$Sn isotopes and the asymmetry term in nuclear incompressibility

Tao Li

Department of Physics

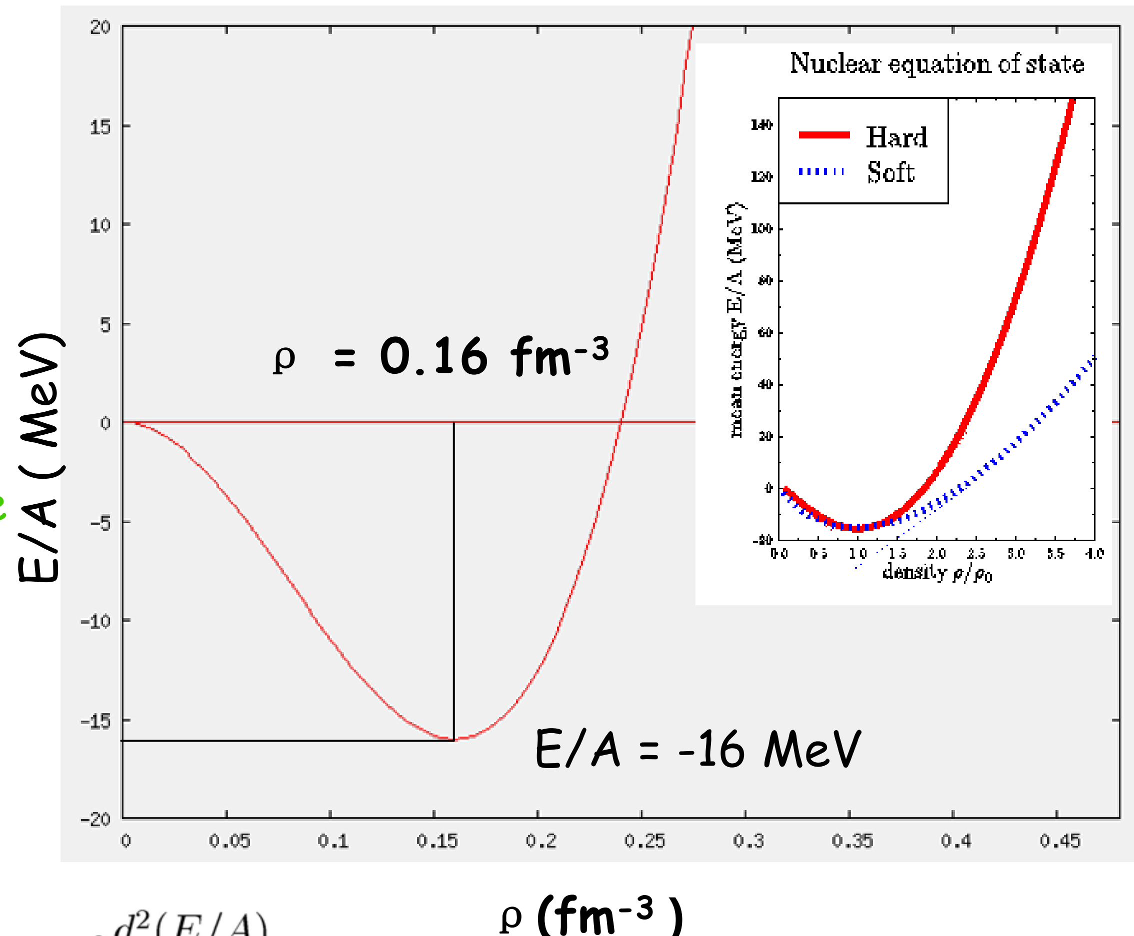
University of Notre Dame

Nuclear equation of State



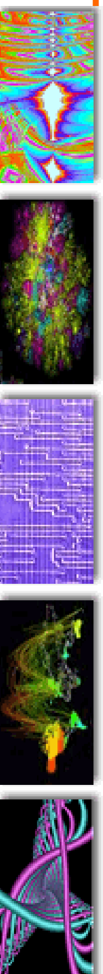
E/A, ρ_0, K_∞

- Neutron Star
- Stellar Collapse
- Supernovae

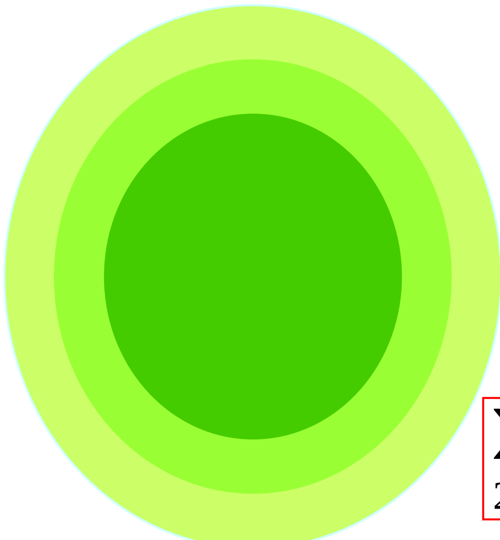


$$K_\infty = k_f^2 \frac{d^2(E/A)}{dk_f^2}\Big|_{k_{f0}} = 9\rho^2 \frac{d^2(E/A)}{d\rho^2}\Big|_{\rho_0}$$

The compression mode of Giant resonaces



GMR L=0

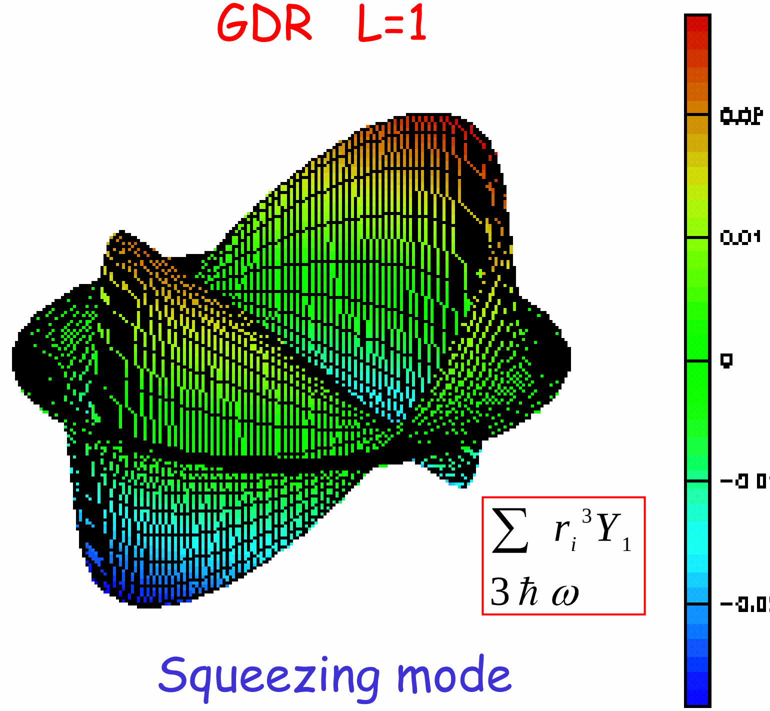


$\sum r_i^2$

$2\hbar\omega$

Breathing mode

GDR L=1



$\sum r_i^3 Y_1$

$3\hbar\omega$

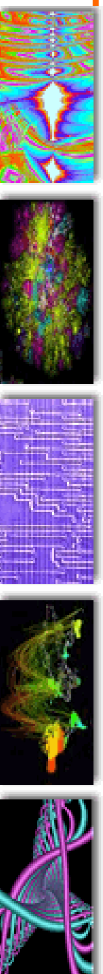
Squeezing mode

$$E_{GMR} = \hbar\sqrt{\frac{K_A}{m\langle r^2\rangle}}$$

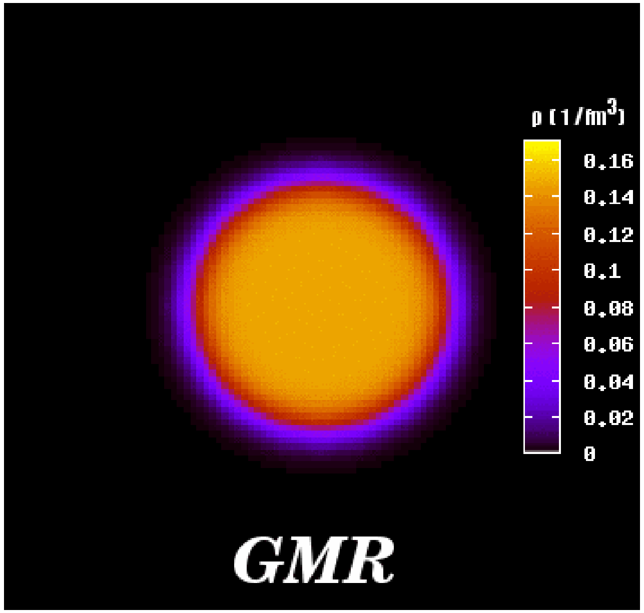
$$E_{ISGDR} = \hbar\sqrt{\frac{7}{3}\frac{K_A + \frac{27}{25}\varepsilon_F}{m\langle r^2\rangle}}$$

The energy of both of these resonances are directly related to the nuclear incompressibility.

The compression mode of Giant resonaces

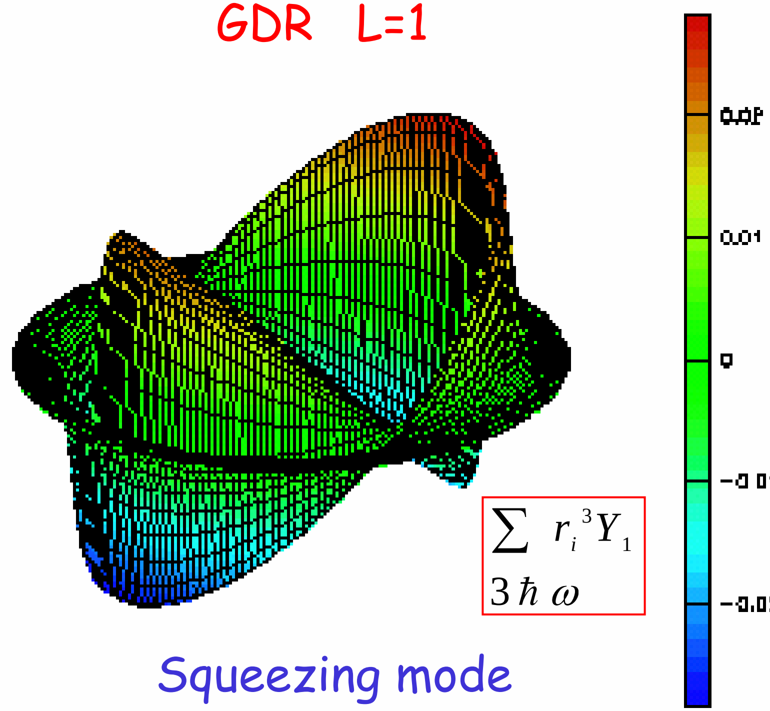


GMR L=0



Breathing mode

GDR L=1



Squeezing mode

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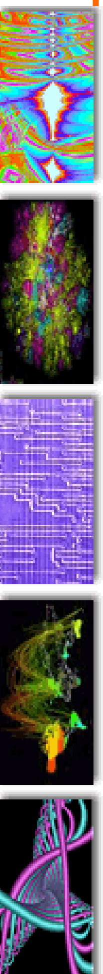
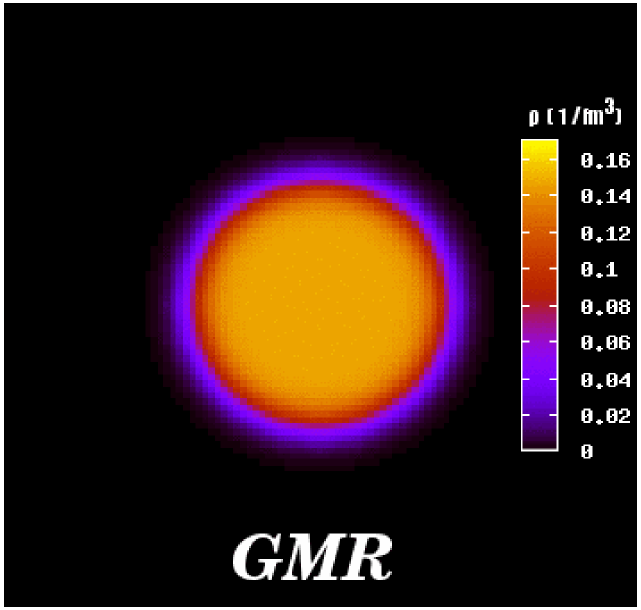


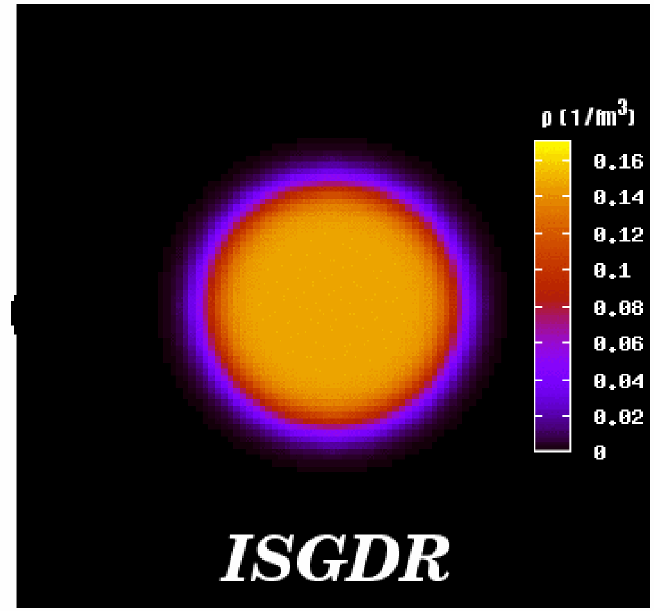
GMR L=0

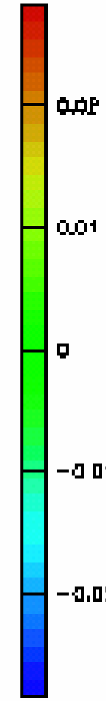


Breathing mode

$$E_{GMR} = \hbar \sqrt{\frac{K_A}{m \langle r^2 \rangle}}$$

GDR L=1



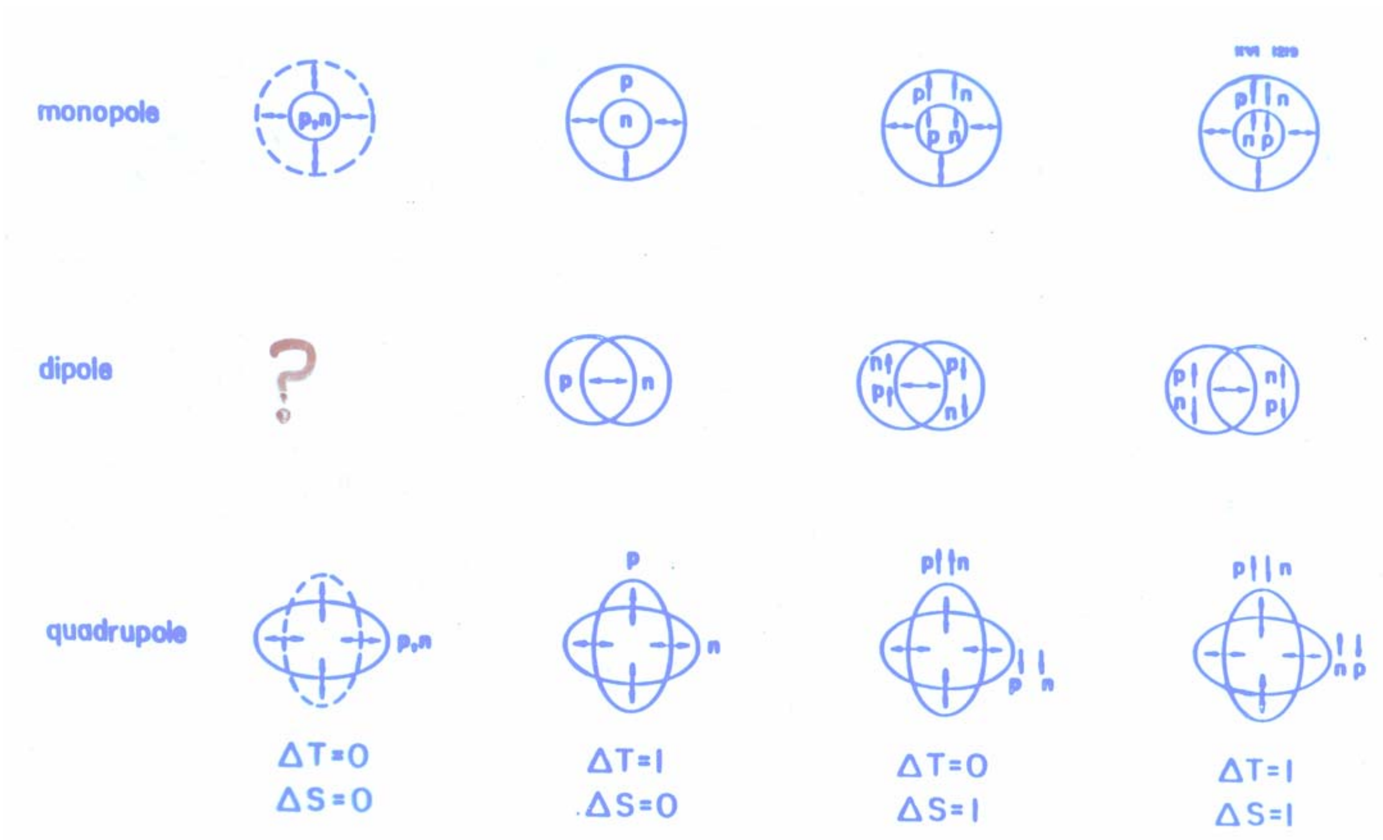


Squeezing mode

$$E_{ISGDR} = \hbar \sqrt{\frac{7}{3}\frac{K_A + \frac{27}{25}\varepsilon_F}{m \langle r^2 \rangle}}$$

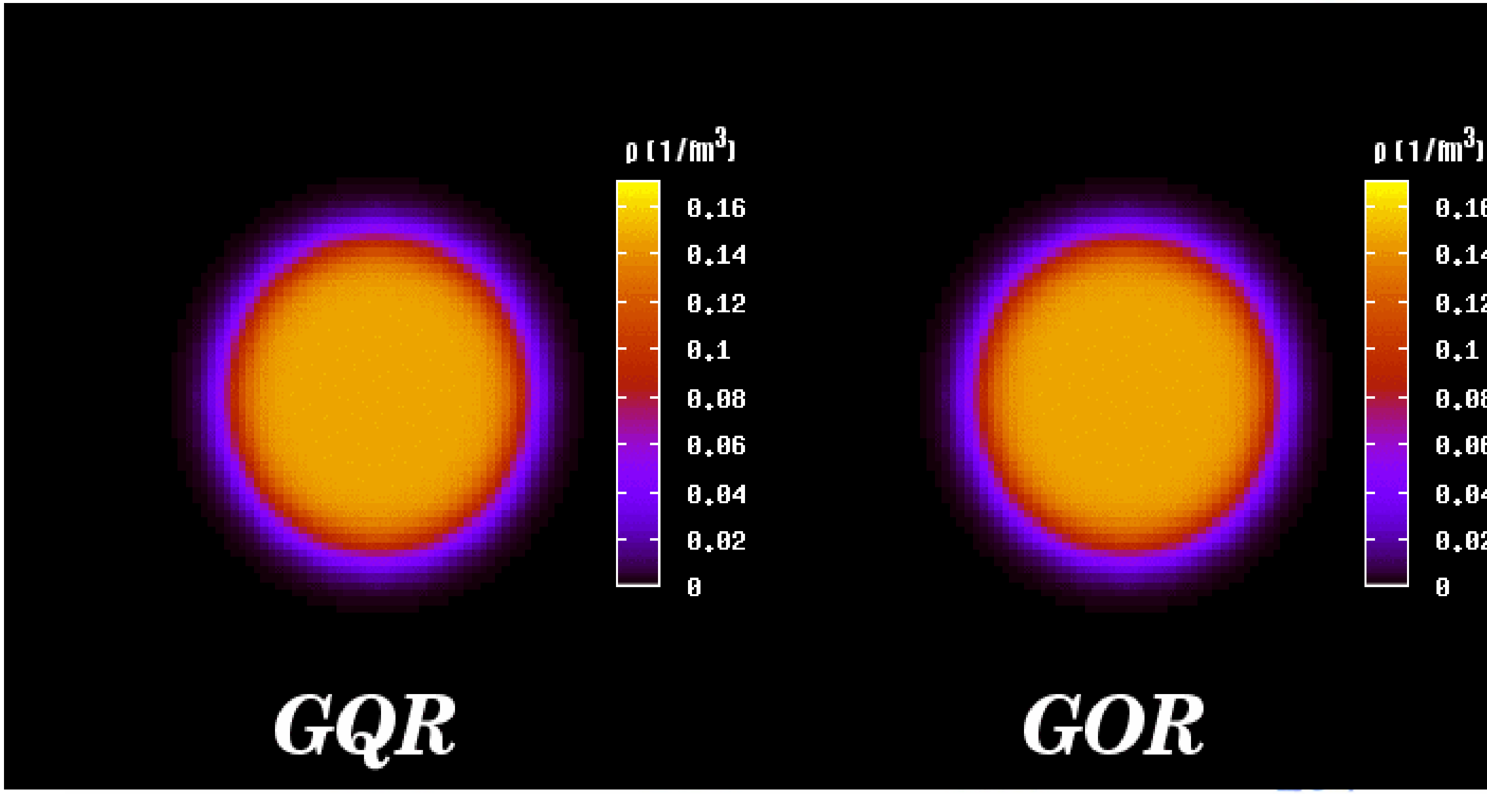
The energy of both of these resonances are directly related to the nuclear incompressibility.

Classification of Giant resonances



Giant Resonance correspond to a collective motion involving all the particles in the nucleus. The occurrence of such a collective motion is a common feature of the many body quantum system.

Classification of Giant resonances



Giant Resonance correspond to a collective motion involving all the particles in the nucleus. The occurrence of such a collective motion is a common feature of the many body quantum system.

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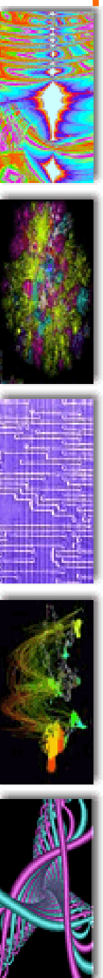
Recent result on nuclear incompressibility K_∞



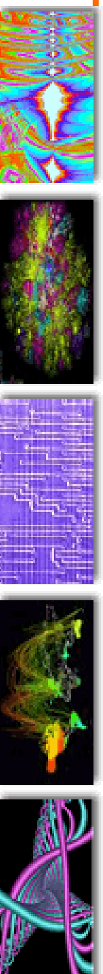
We now have a value of nuclear incompressibility $K_\infty = 240 \pm 10$ MeV, consistent with both the GMR and ISGDR data.

Previous results:

Non-relativistic calculation: 230--250 MeV
Cf. G. Colò, etc., Phys. Rev. C70 (2004) 024307.

Relativistic calculation: 250--270MeV
J.Piekarewicz, etc. PRC 66 (2002) 034305

There has been a claim that the different behaviour of relativistic and non-relativistic models has its origin in the different density dependence of the symmetry energy curve $S(\rho)$.



Experiment

- Reaction : $^{A}Sn\,(\alpha,\alpha')\,^{A}Sn$
- Target : Sn isotopes (A=112,114,116,118,120,122,124)

$$K_A \sim K_\infty(1+cA^{-1/3})+K_\tau((N-Z)/A)^2+K_{Coul}Z^2A^{-4/3}$$

- Beam : 400 MeV α -particle

  Resolution: 100 KeV
- Angle : 0 ~ 8 degrees

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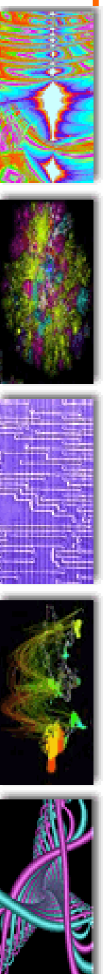
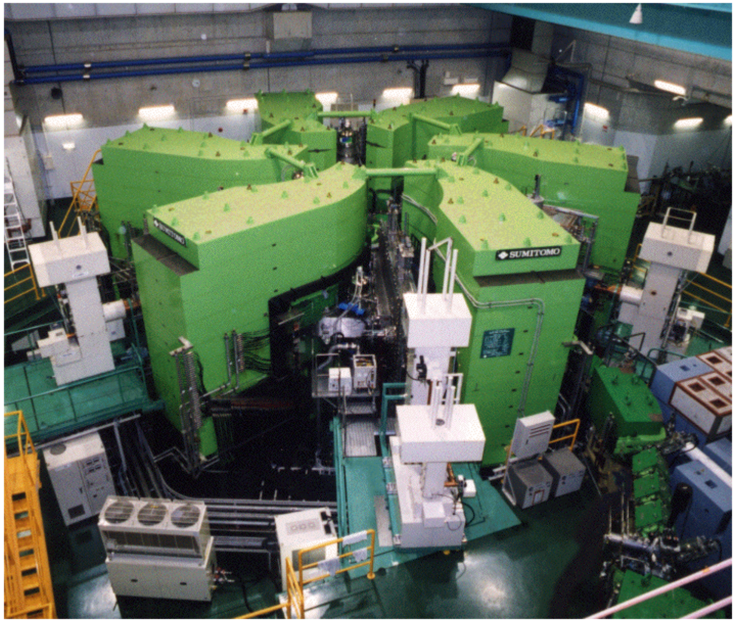
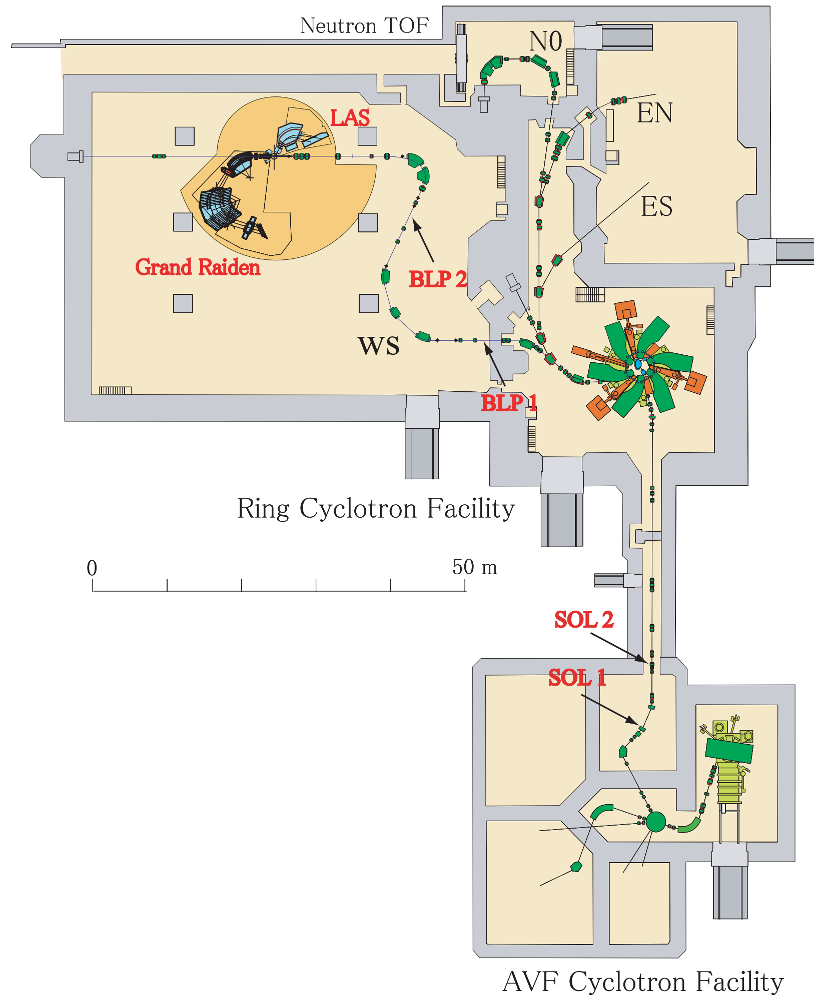
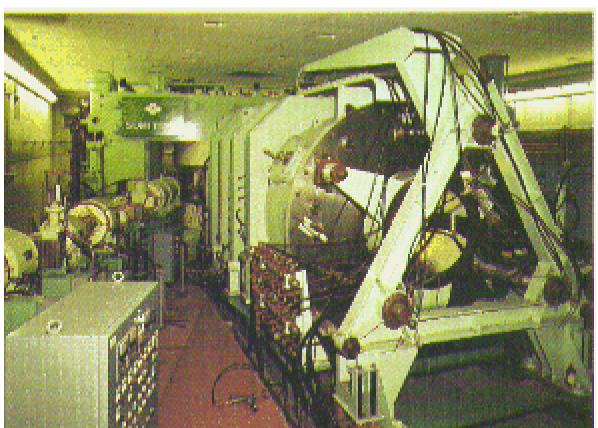
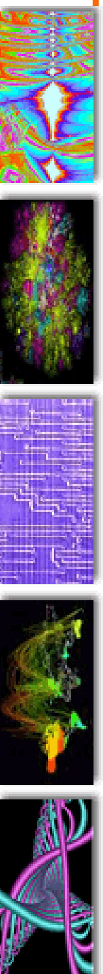


Overview of the RCNP Ring Cyclotron Facility

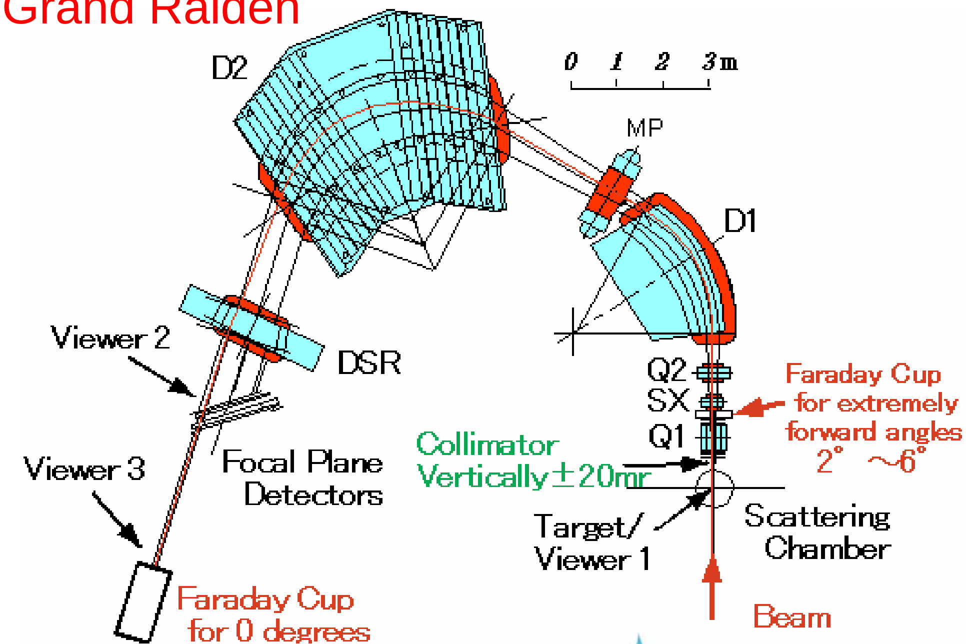


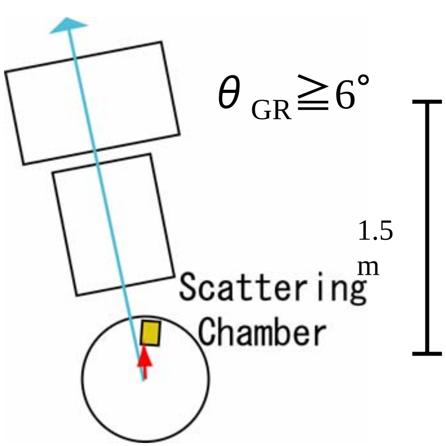


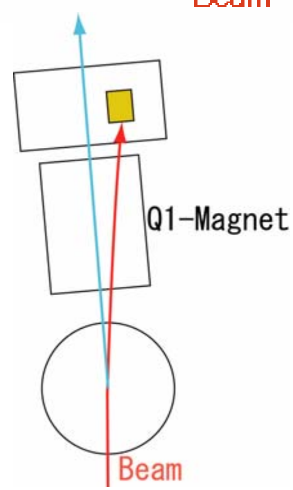


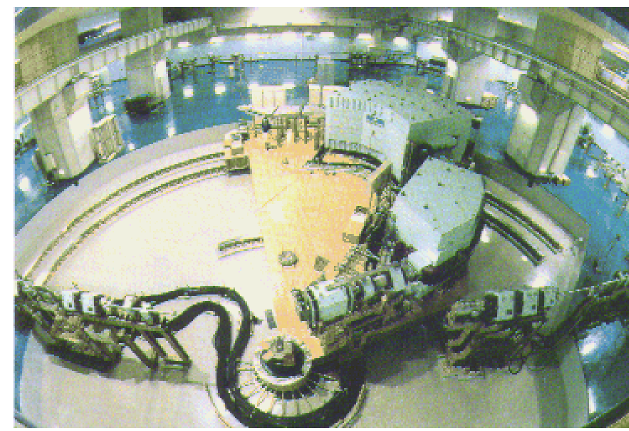


Grand Raiden

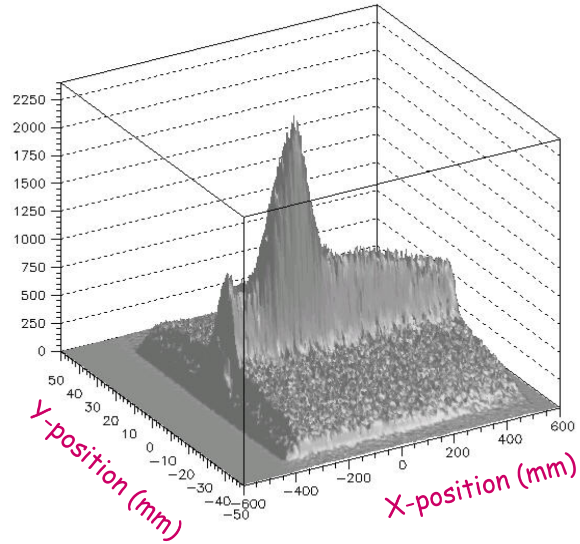


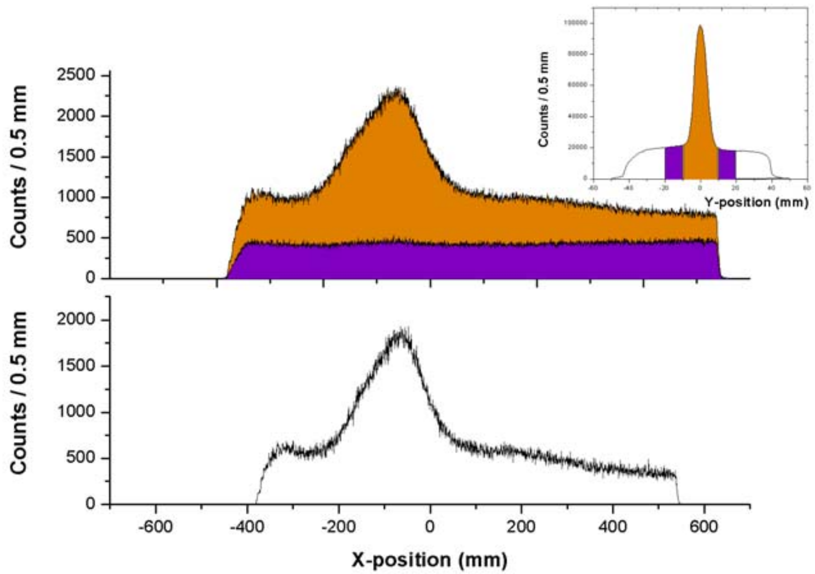


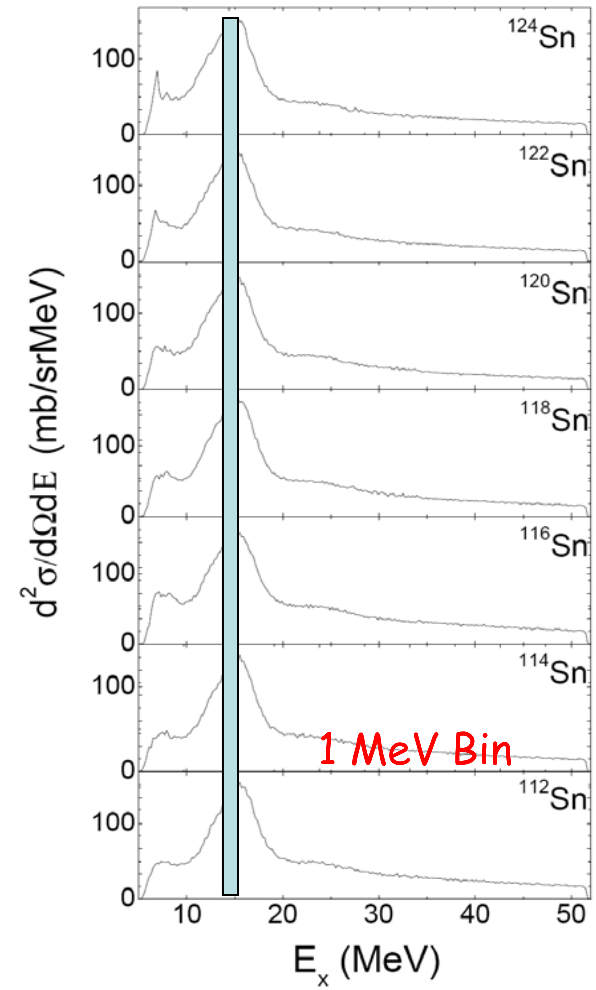




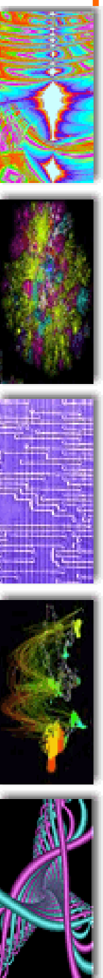
Background-free Spectrum at 0.69 deg







Multipole Decomposition method:



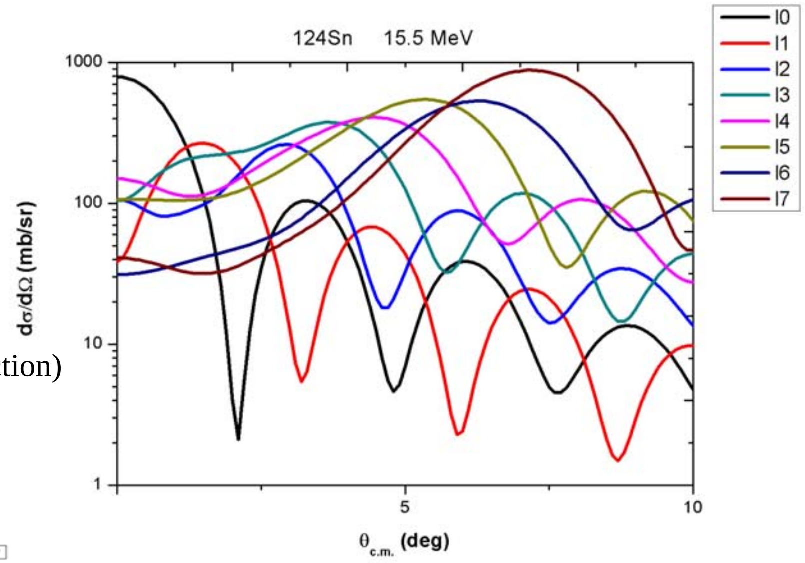
$$\left(\frac{d^2\sigma}{d\Omega dE}(\vartheta_{c.m.},E)\right)^{ex.} = \sum_L a_L(E)\left(\frac{d^2\sigma}{d\Omega dE}(\vartheta_{c.m.},E)\right)_L^{calc}$$

$$\left(\frac{d^2\sigma}{d\Omega dE}(\vartheta_{c.m.},E)\right)^{ex.} : \text{ Exprimental cross section}$$

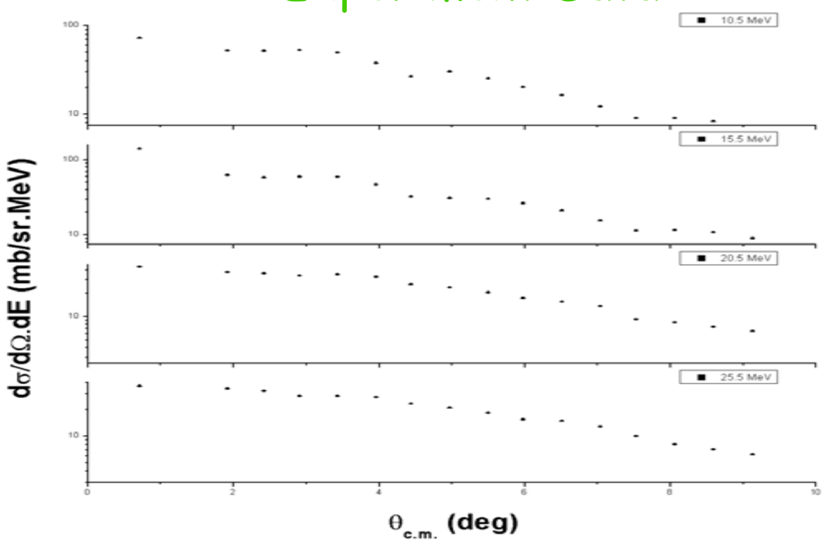
$$\left(\frac{d^2\sigma}{d\Omega dE}(\vartheta_{c.m.},E)\right)_L^{calc} : \text{ DWBA cross section (unit cross section)}$$

$a_L(E)$: EWSR factor

DWBA calculation



Experiment Data



A statistical measure of goodness-of-fit:

$$\chi^2(E_x) = \frac{1}{n - n_L - 1}\sum_{i=1}^{n}\left(\frac{\sigma^{exp}(\theta_i, E_x) - \sigma^{calc}(\theta_i, E_x)}{\Delta\sigma^{exp}(\theta_i, E_x)}\right)^2$$

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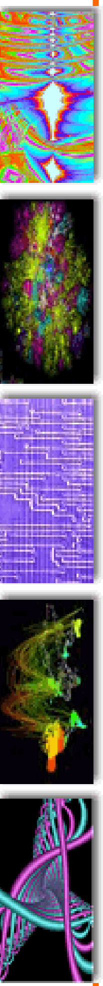
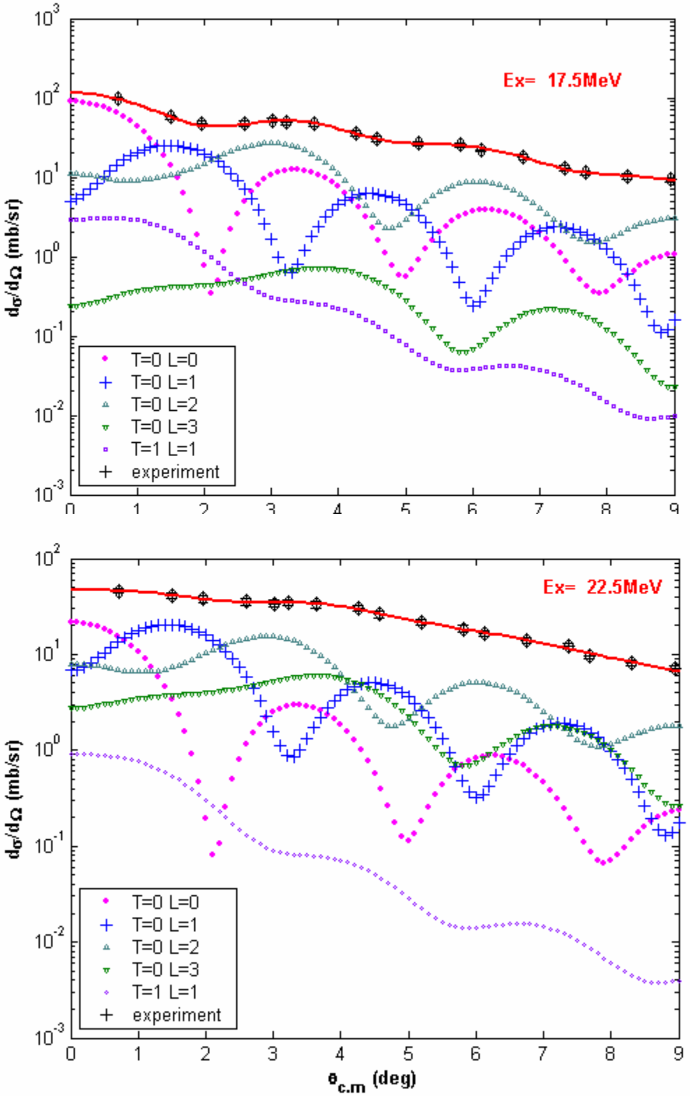
Angular distribution with MDA result

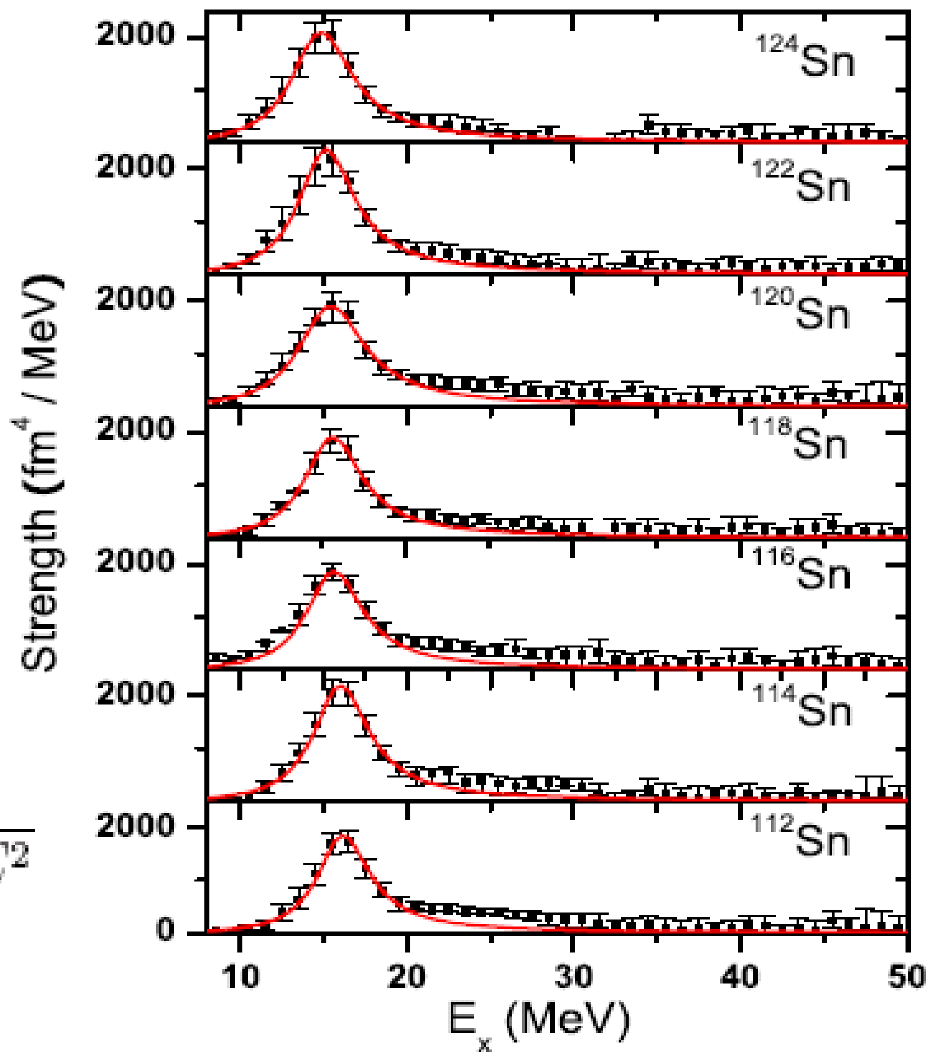




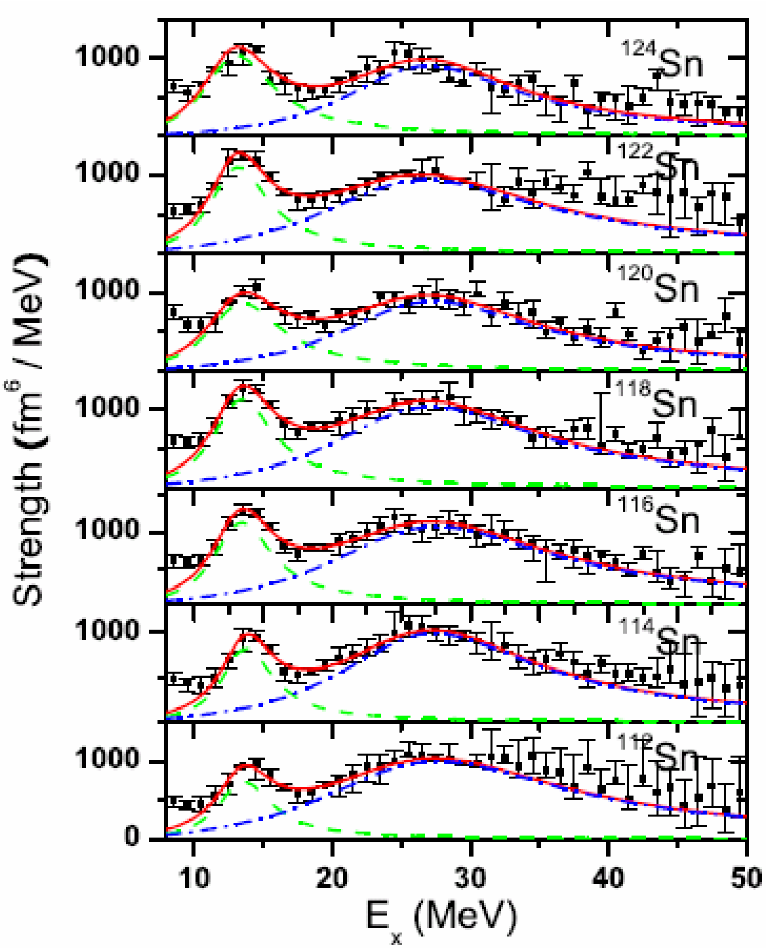
GMR

The strength distribution
with Lorentz fit

$$\sigma(E) = \frac{\sigma_m \Gamma_m^2 E^2}{(E^2 - E_m^2)^2 + \Gamma_m^2 E^2}$$

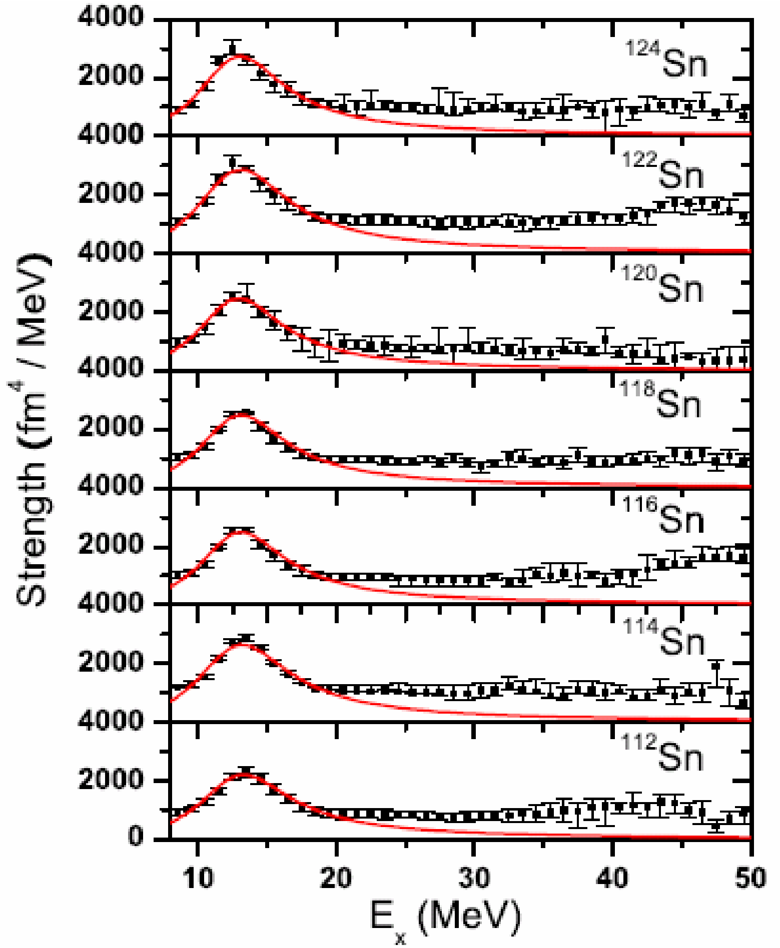


ISGDR



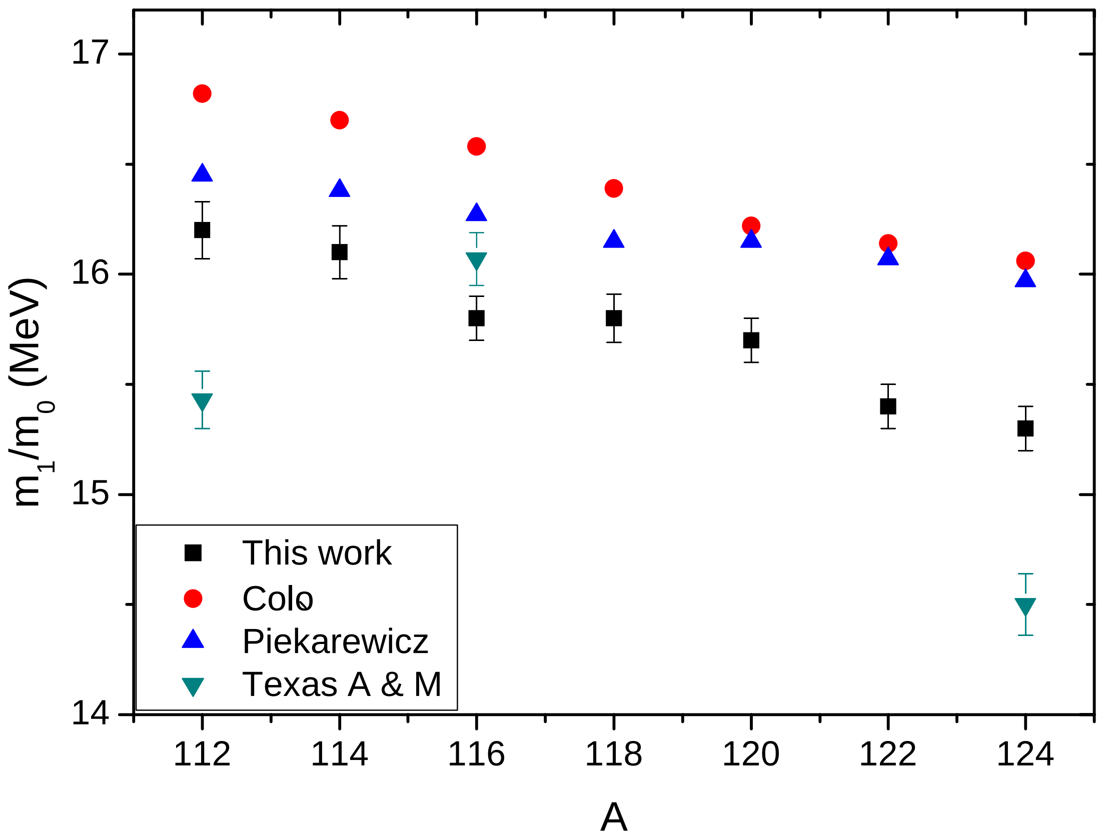
Strength (fm^6 / MeV)
1000
0
^{124}Sn
^{122}Sn
^{120}Sn
^{118}Sn
^{116}Sn
^{114}Sn
^{112}Sn
10
20
30
40
50
E_x (MeV)

GQR



Strength (fm^4 / MeV)
4000
2000
0
^{124}Sn
^{122}Sn
^{120}Sn
^{118}Sn
^{116}Sn
^{114}Sn
^{112}Sn
10
20
30
40
50
E_x (MeV)

Important Results from the Sn investigation:



Q. Why are Sn isotopes so "fluffy"?

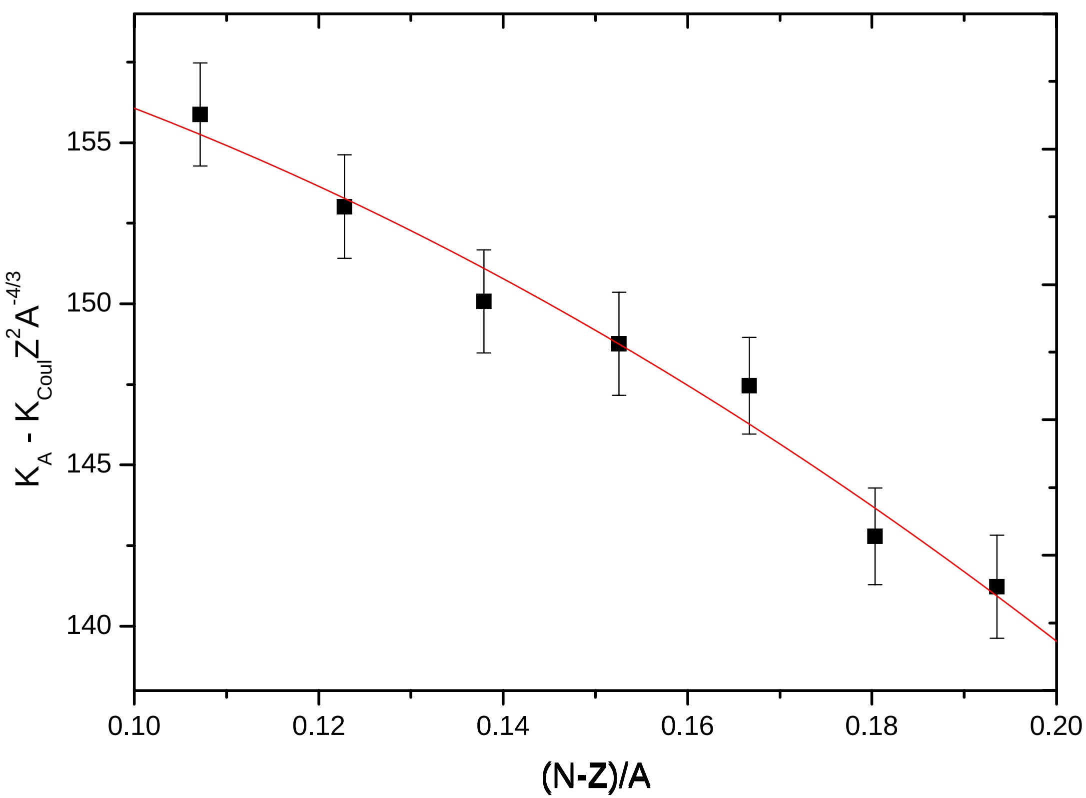
The GMR energies of the Sn isotopes are consistently lower than those predicted by theoretical calculations using the same parameters that reproduce the GMR energies in the standard test nuclei--^{90}Zr and ^{208}Pb.

- From the Sn GMR data, we have been able to extract a value for the "symmetry-energy" term, K_{τ}, in the expression for nuclear incompressibility.

- Determination of K_{τ} is extremely important in nuclear structure and astrophysical studies:
  - Reconciliation of relativistic and non-relativistic calculations for GMR
  - Constraints on radii of neutron stars

$$K_A \sim K_\infty(1+cA^{-1/3})+K_\tau((N-Z)/A)^2+K_{Coul}Z^2A^{-4/3}$$

Here c ~ -1 and K_{Coul} is, essentially, model-independent. One can approximate the difference [K_A - $K_{Coul}Z^2A^{-4/3}$] as having a quadratic relationship with the asymmetry parameter [(N-Z)/A]



K_τ = -550 ± 100 MeV

Consistent with the value (-500 ± 50 MeV) obtained indirectly from HI reactions data.

With the "experimental" values for K_∞ and K_τ, we can provide rather rigid constraints on interactions employed in nuclear structure and EOS calculations.

Collaborators

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