The Asymmetry Term in Nuclear Incompressibility from the Giant Monopole Resonances

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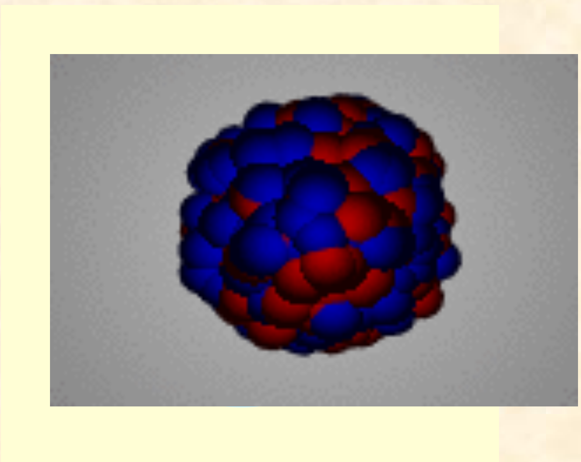
The Compressional Mode Giant Resonances

GMR

l = 0



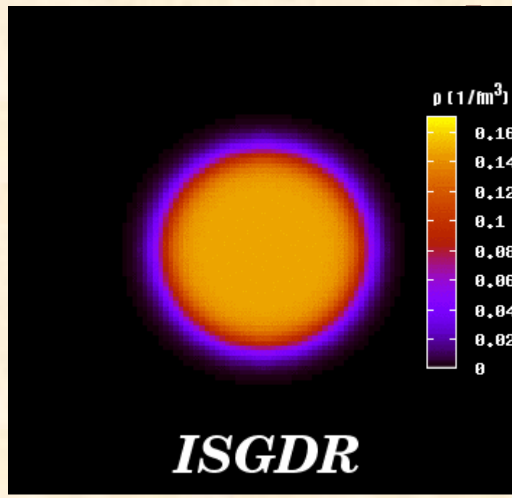
"Breathing Mode"

$$\sum r_i^2$$

$$2\hbar\omega$$

ISGDR

l = 1



"Squeezing Mode"

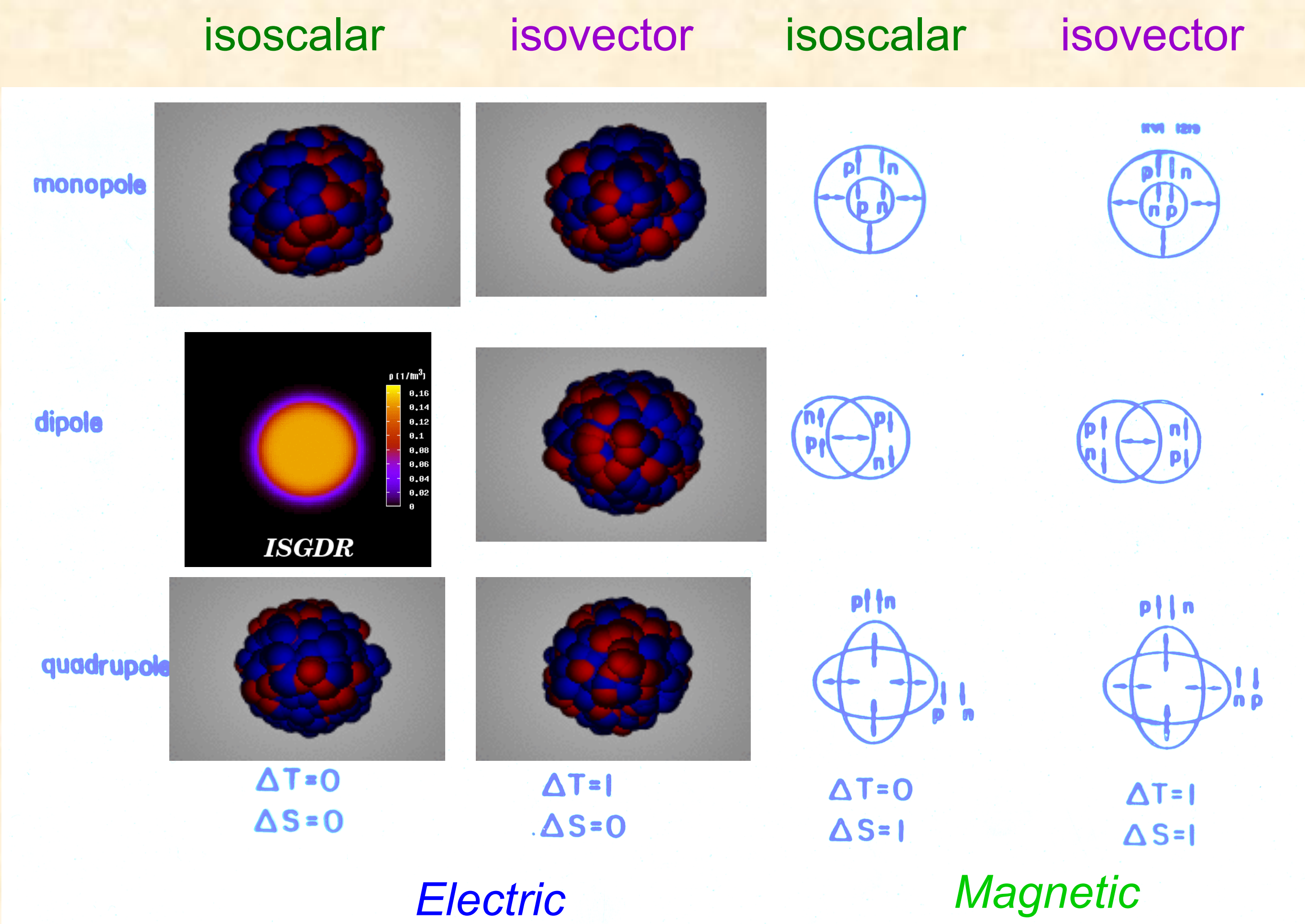
$$\sum r_i^3 Y_1$$

$$3\hbar\omega$$

The energies of both these resonances are directly related to Nuclear Incompressibility.

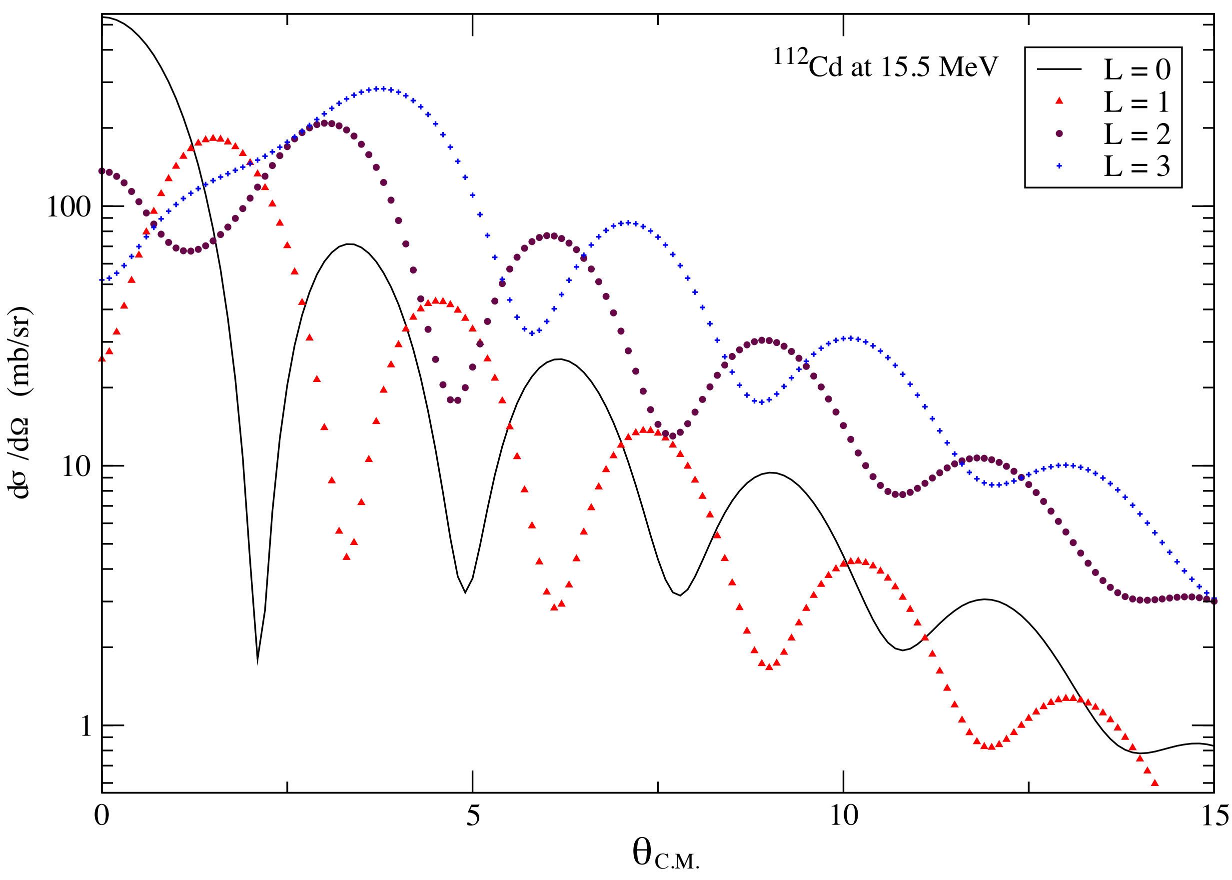
$$E_{GMR} = \hbar\sqrt{\frac{K_A}{m\langle r^2\rangle}}$$

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

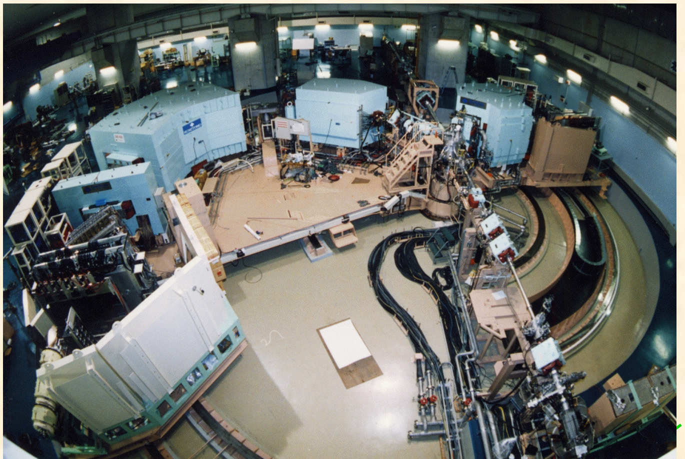


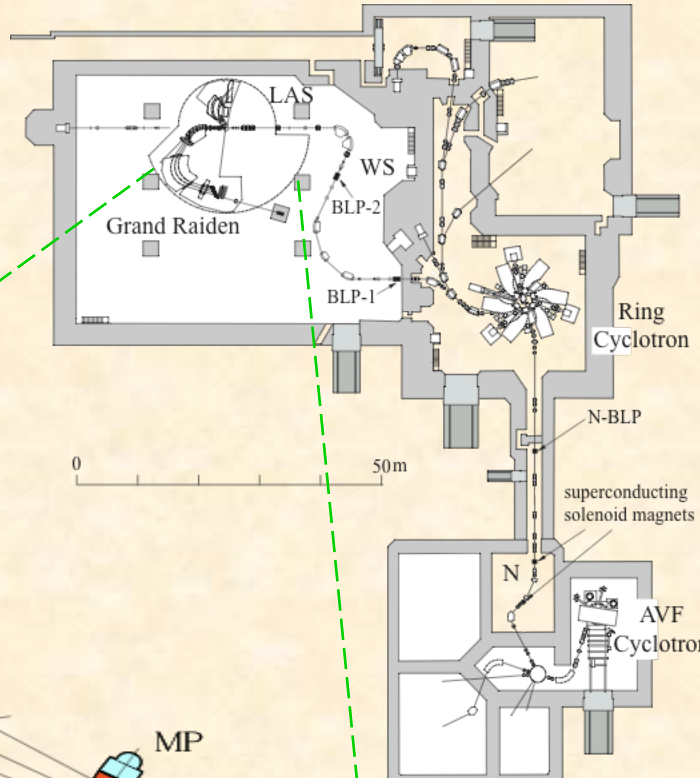
Selectivity of probes: (α,α'), (p,p'), (γ,γ'), (e,e')

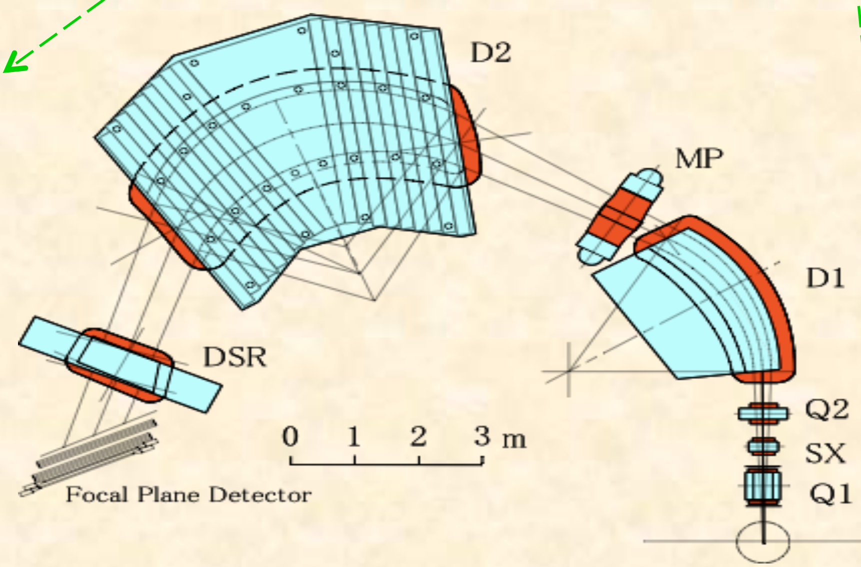
animations courtesy M. Itoh and T. Aumann



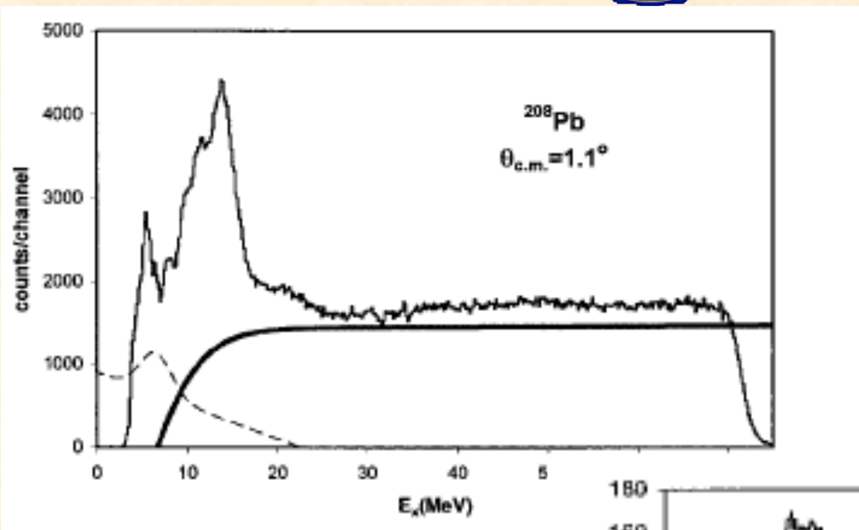
(α,α') at 400 MeV

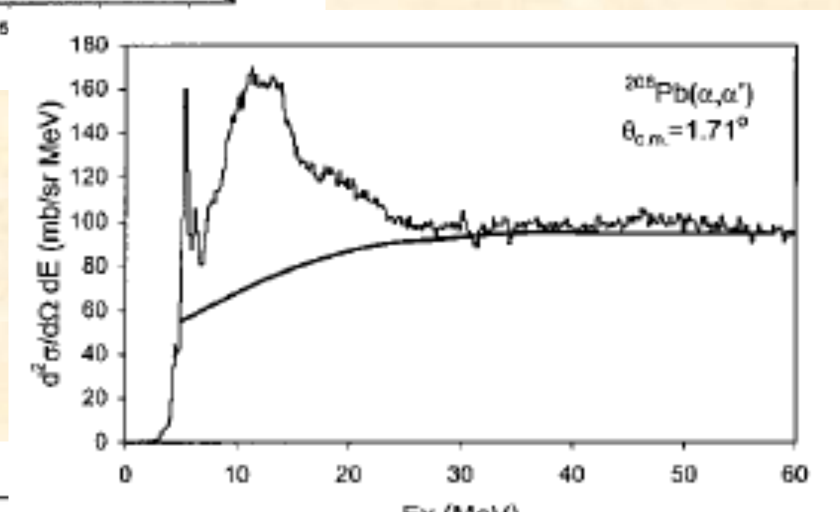


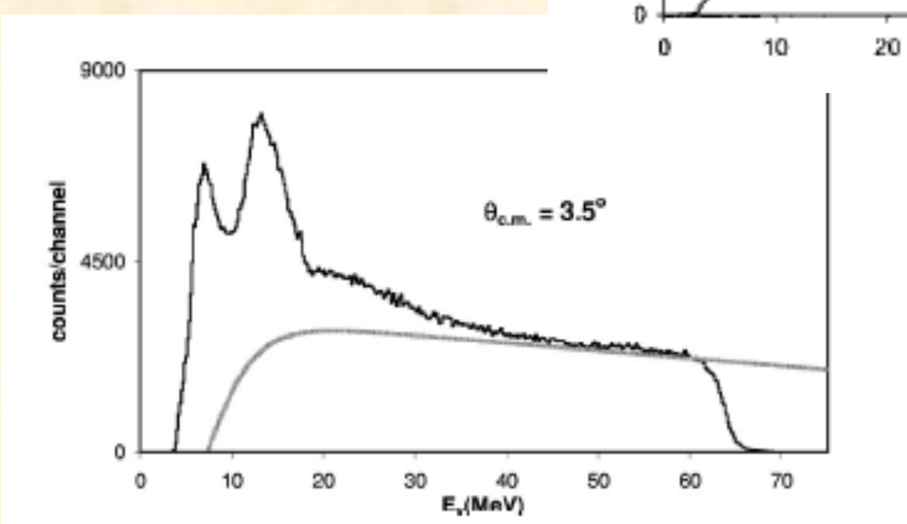




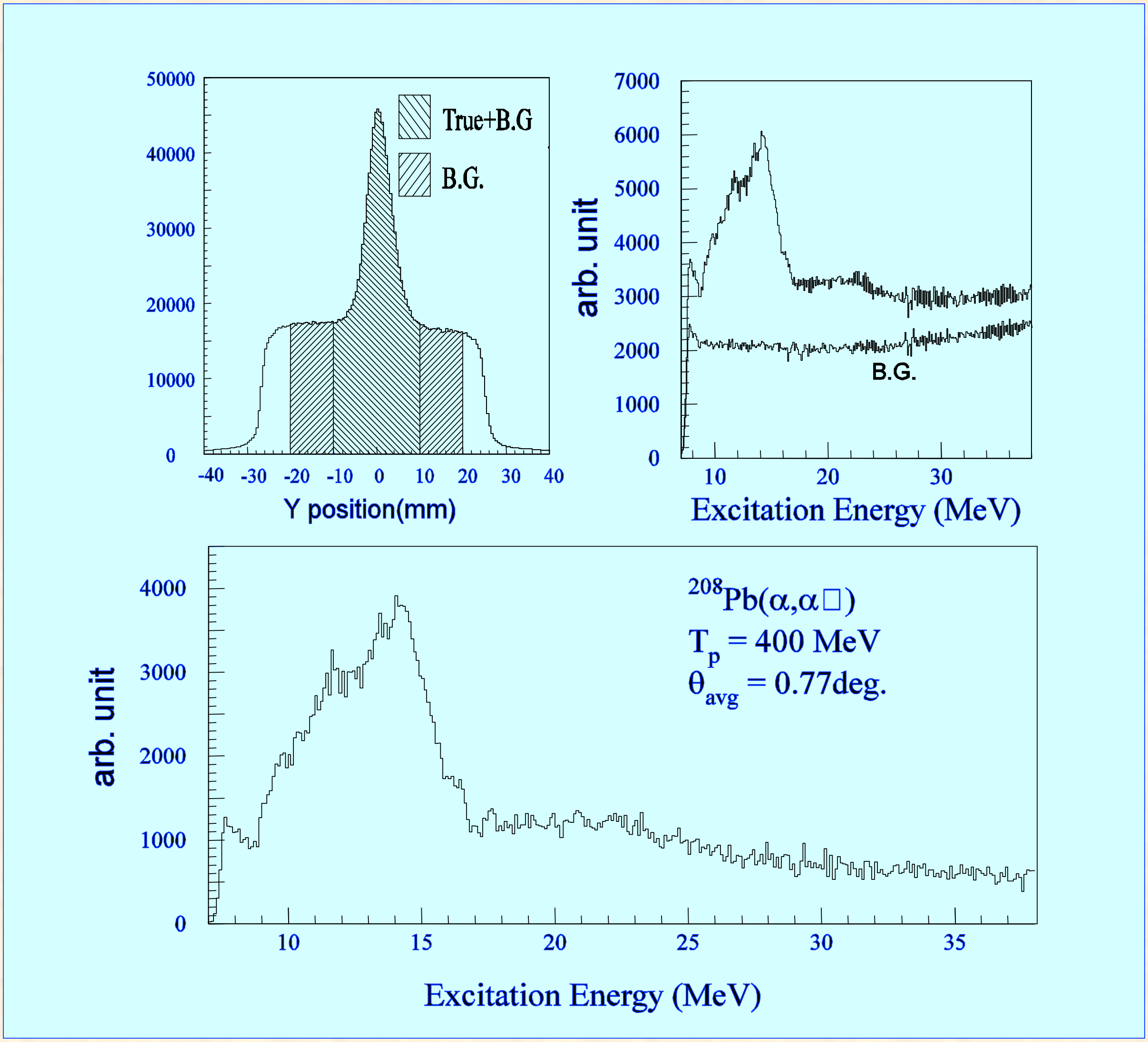
“Halos” and “Wings”





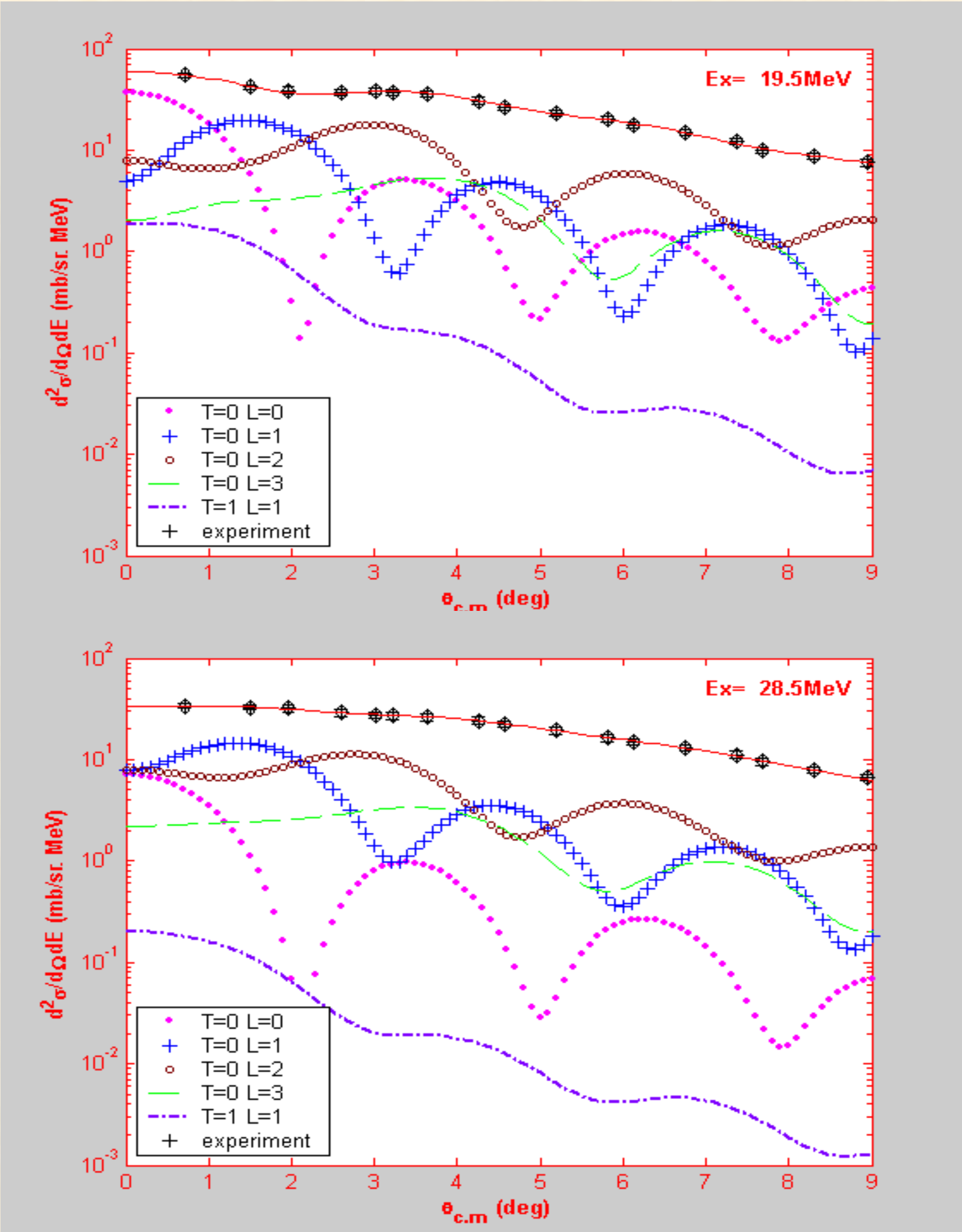


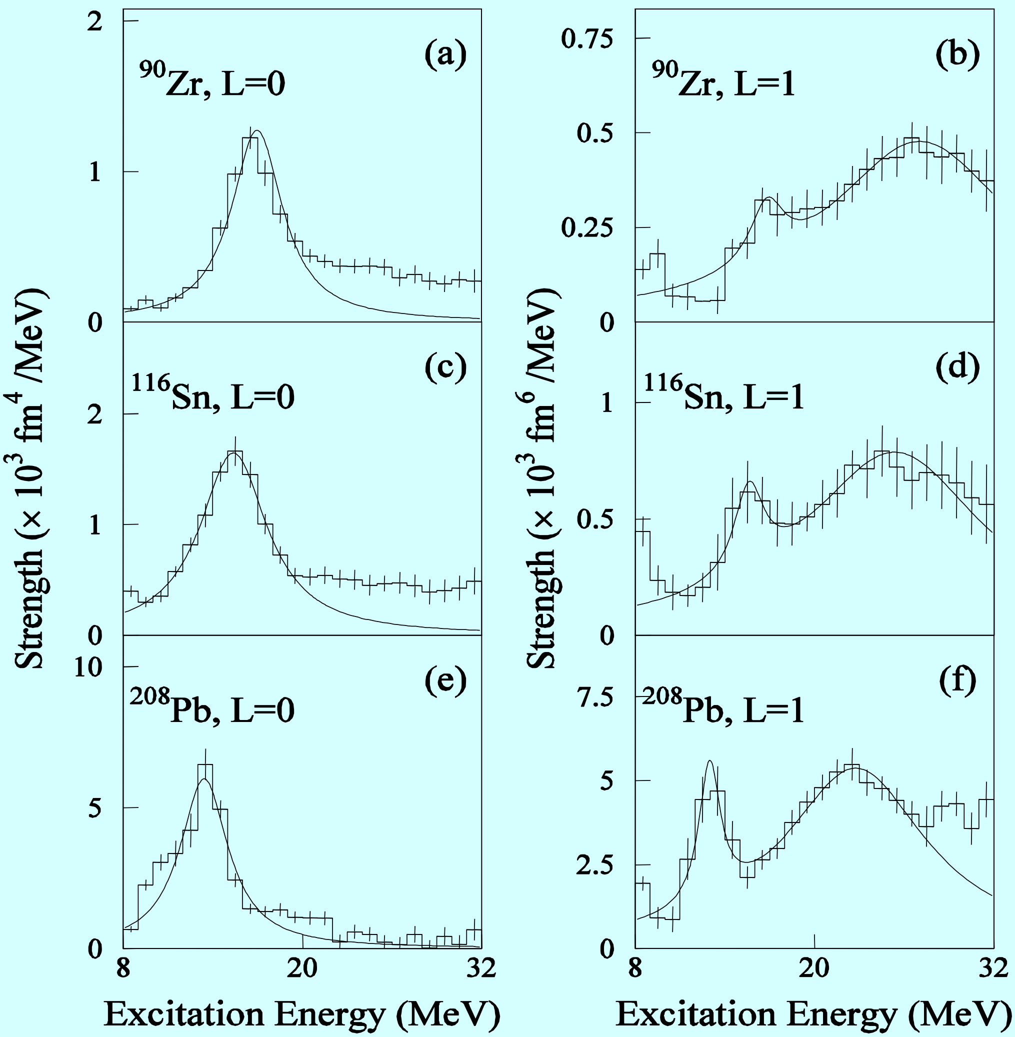
240 MeV (α,α') [Texas A & M]



True+B.G
B.G.
Y position(mm)
arb. unit
B.G.
Excitation Energy (MeV)
208Pb(α,α□)
Tp = 400 MeV
θavg = 0.77deg.
arb. unit
Excitation Energy (MeV)

^{112}Sn


Ex= 19.5MeV
T=0 L=0
T=0 L=1
T=0 L=2
T=0 L=3
T=1 L=1
experiment
d²σ/dΩdE (mb/sr. MeV)
θc.m (deg)
Ex= 28.5MeV
T=0 L=0
T=0 L=1
T=0 L=2
T=0 L=3
T=1 L=1
experiment
d²σ/dΩdE (mb/sr. MeV)
θc.m (deg)


(a)
^{90}Zr, L=0
(b)
^{90}Zr, L=1
(c)
^{116}Sn, L=0
(d)
^{116}Sn, L=1
(e)
^{208}Pb, L=0
(f)
^{208}Pb, L=1
Strength (× 10^3 fm^4 /MeV)
Strength (× 10^3 fm^6 /MeV)
Excitation Energy (MeV)
Excitation Energy (MeV)

From K_A to K_∞

Old Method:

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

Has many problems!

New Method:

- Build Energy Functionals $E(\rho)$

  Each such parameter set is characterized by a K_∞

- Obtain GMR strength distributions in a self-consistent RPA calculation
- The K_∞ value associated with the functional that best characterizes the observed GMR distributions is the "correct" K_∞.

From GMR data on ^{208}Pb and ^{90}Zr

$K_{\infty} = 240 \pm 20$ MeV

This number is consistent with both GMR and ISGDR data and with non-relativistic and relativistic calculations

We know K_A from E_{GMR}:

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

In an approximate way, K_A may be expressed as:

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

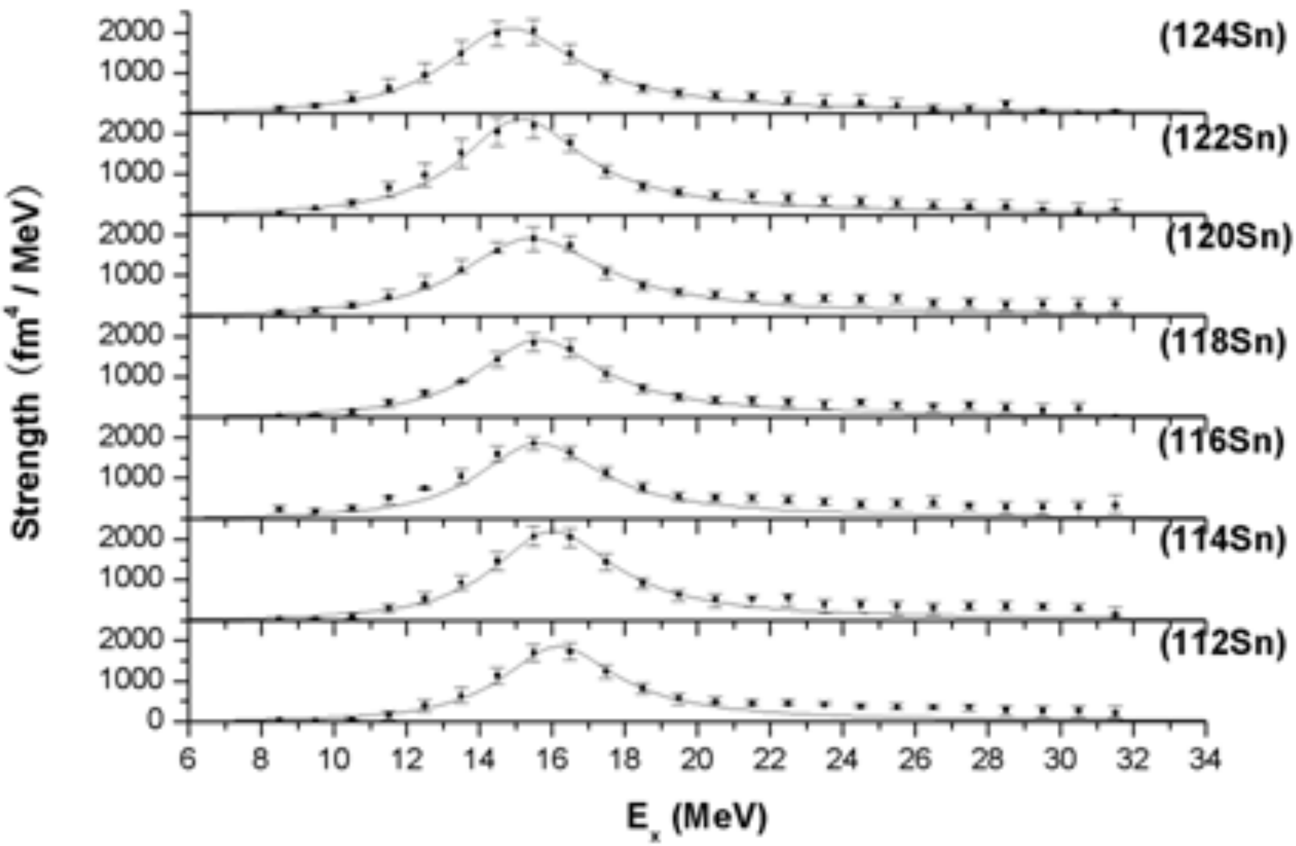
$c \sim -1$

K_{Coul} is, basically, model independent

K_τ ??

Measurements over a series of isotopes gives K_τ

K_τ is critical in our understanding the properties of neutron stars



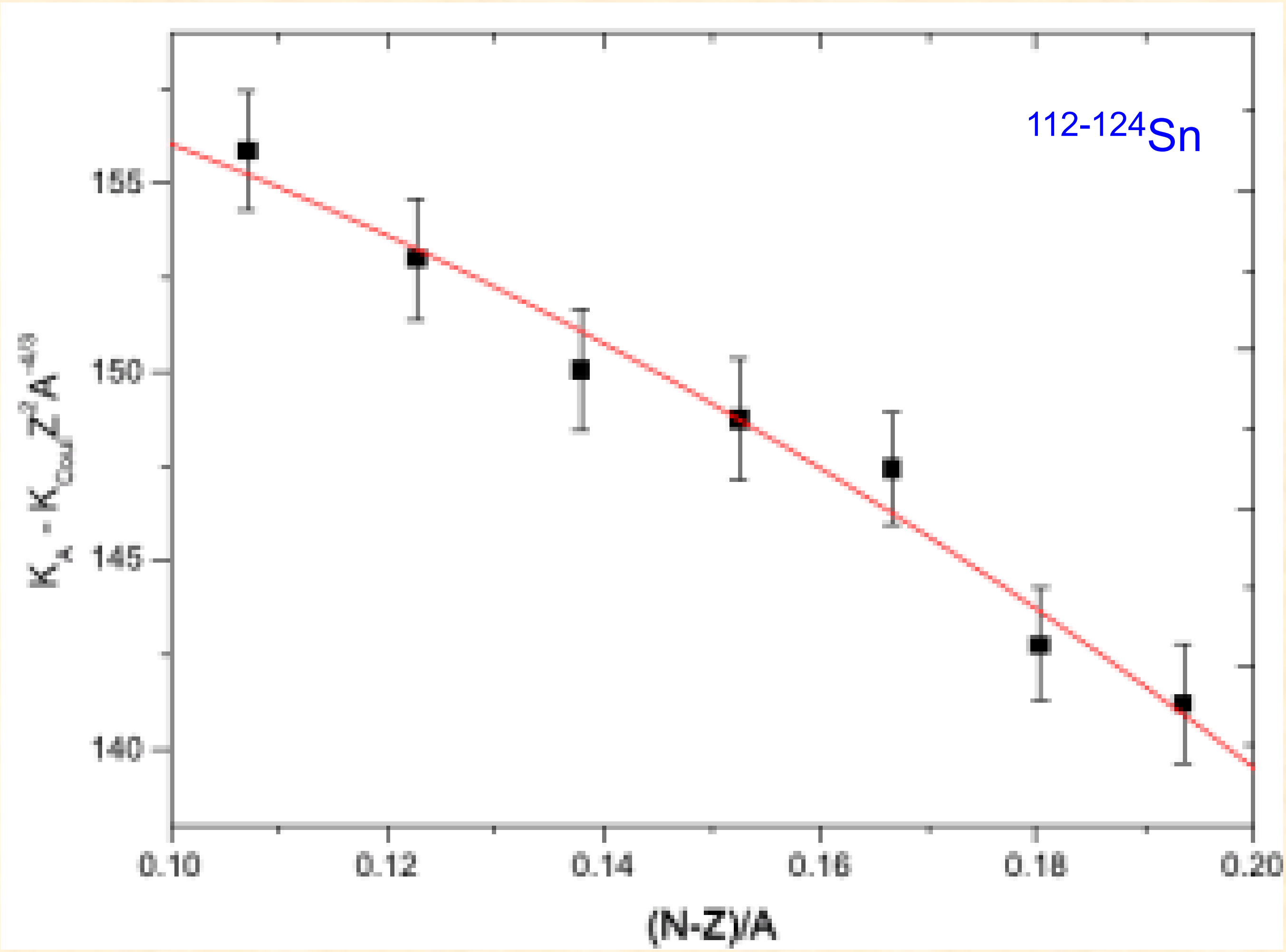
(124Sn)
(122Sn)
(120Sn)
(118Sn)
(116Sn)
(114Sn)
(112Sn)
Strength (fm^4 / MeV)
E_x (MeV)

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

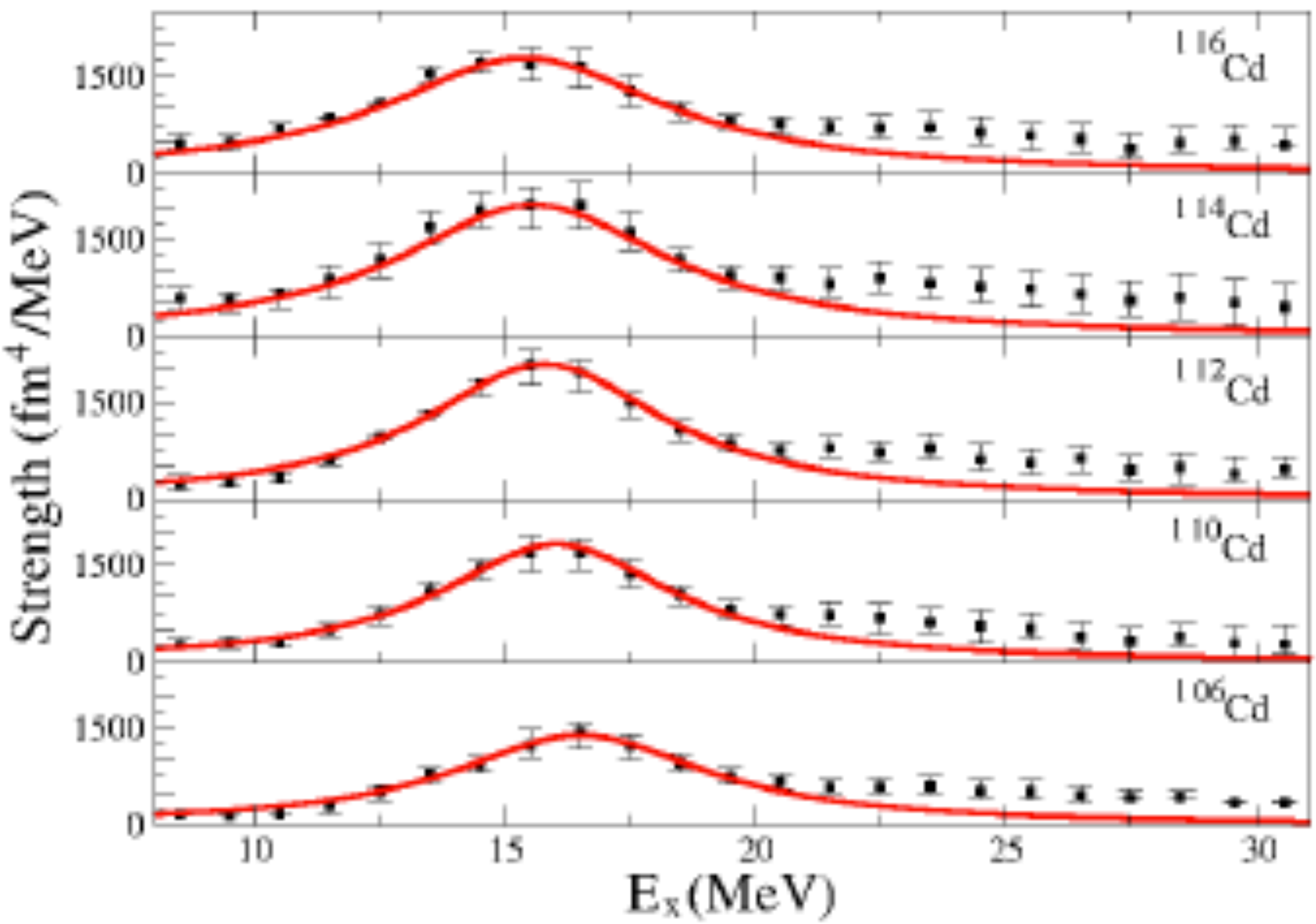
$$K_A - K_{Coul}\,Z^2A^{-4/3} \sim K_{vol}\,(1 + cA^{-1/3}) + K_\tau\,((N - Z)/A)^2$$

$$\sim \text{Constant} + K_\tau\,((N - Z)/A)^2$$

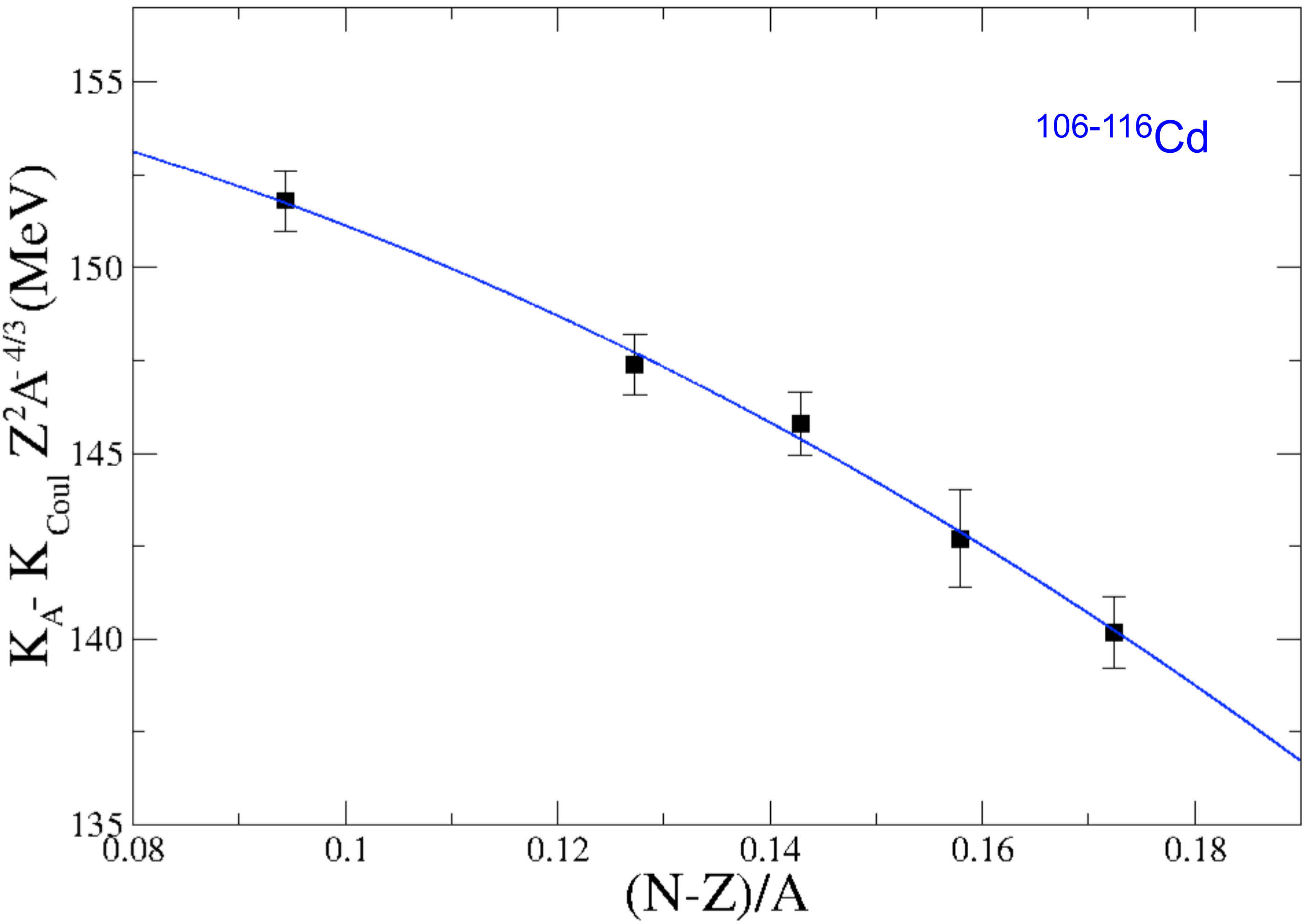
We use K_{Coul} = - 5.2 MeV (from Sagawa)



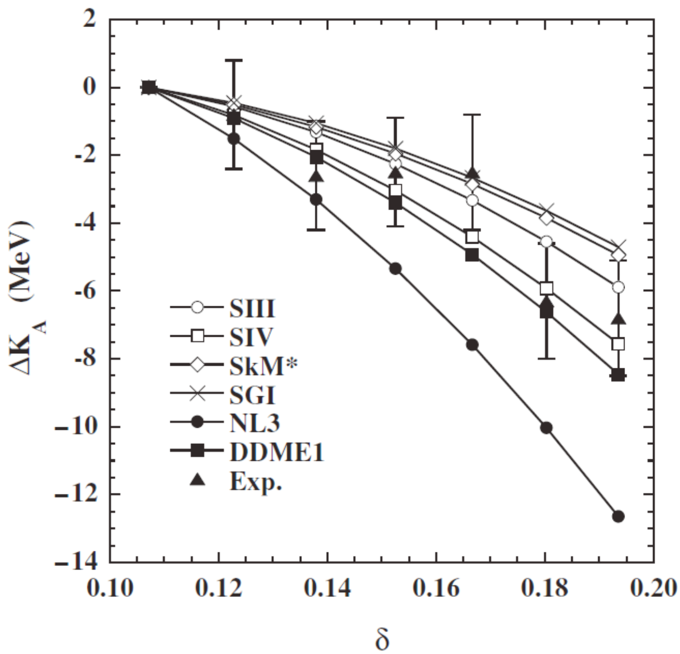
$$K_\tau = \text{-}550 \pm 100 \text{ MeV}$$



116Cd
114Cd
112Cd
110Cd
106Cd
1500
0
Strength (fm4/MeV)
10
15
20
25
30
Ex(MeV)



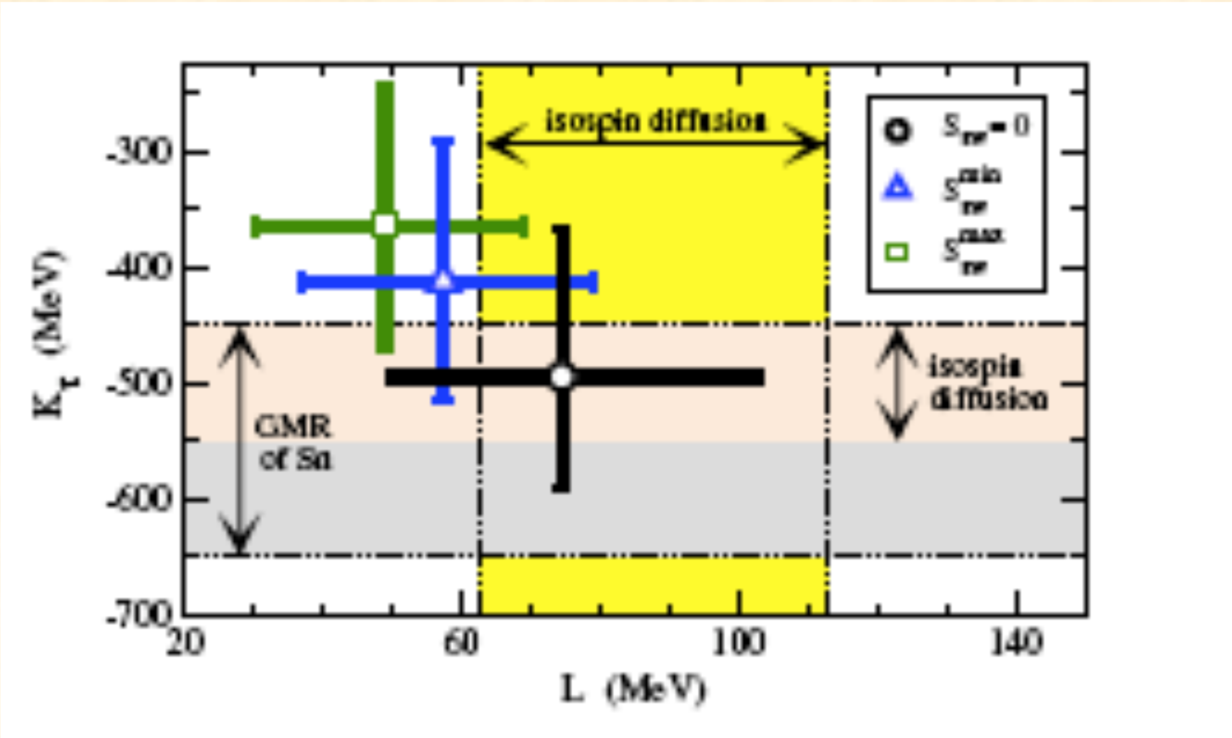
$K_\tau = -555 \pm 75$ MeV



H. Sagawa, et al.
PRC 76, 034327(2007)

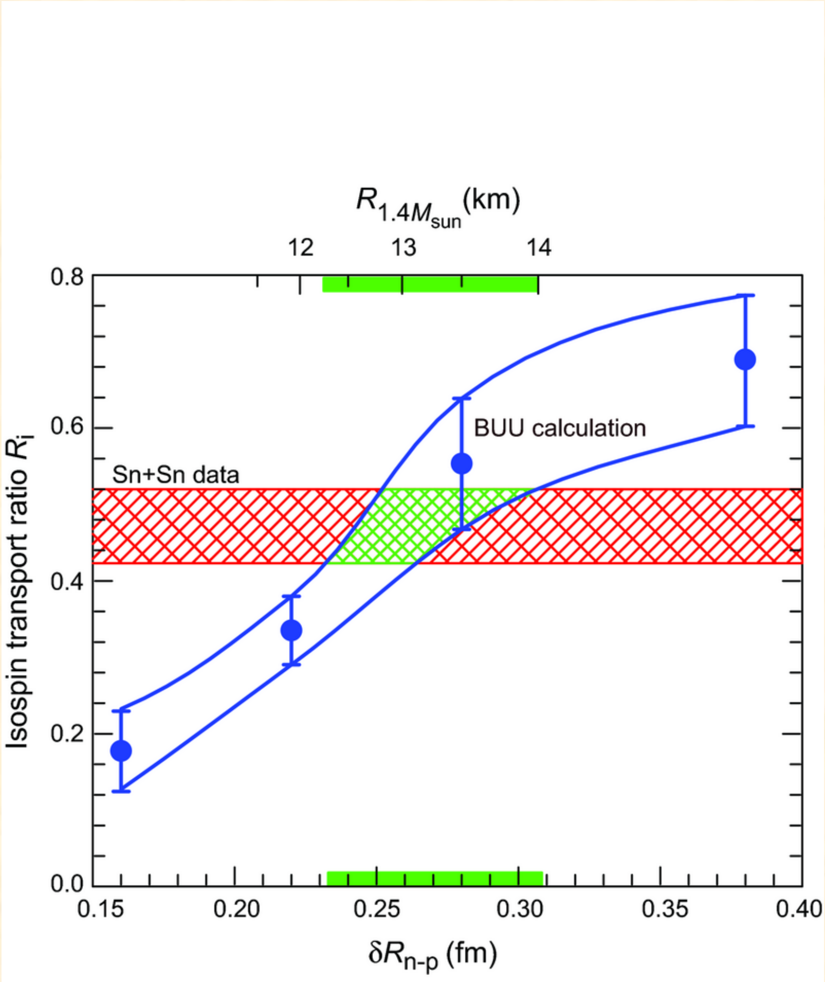
The difference of incompressibility $K = K_A - K_{A=112}$ as a function of $\delta = (N-Z)/A$. Experimental data are determined by using the excitation energies of ISGMR.

K_τ = -500 ± 50 MeV



$$K_\tau = -500^{+125}_{-100}\ \mathrm{MeV}$$

M. Centelles *et al*., Phys. Rev. Lett. **102**, 122502 (2009)



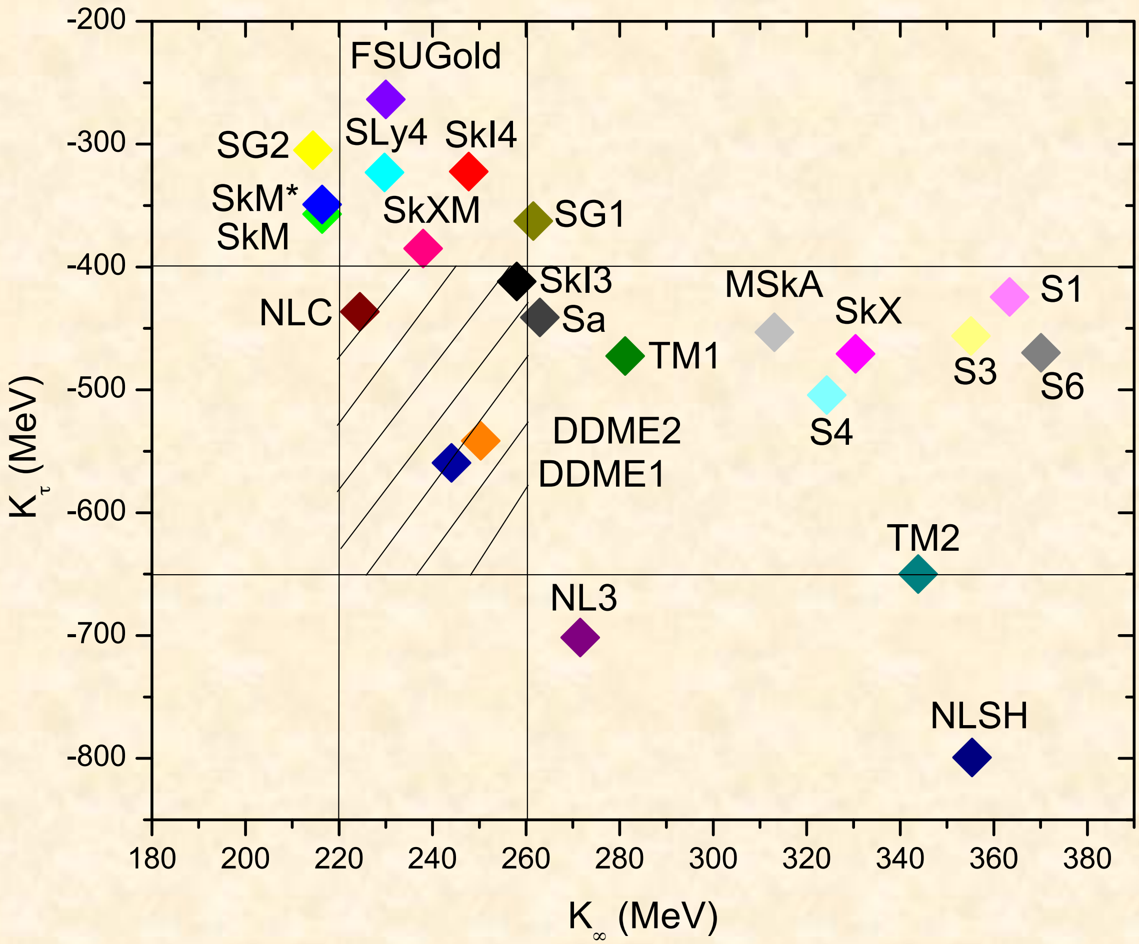
Conservative Conclusions:

$32(\rho/\rho_0)^{0.7} \leq E_{sym}(\rho) \leq 32(\rho/\rho_0)^{1.1}$

$K_{asy}(\rho_0) \approx -500 \pm 50$ MeV

for $\rho \leq 1.2\rho_0$

$K_\tau = -370 \pm 120$ MeV



$$K_\tau = K_{\tau,v} + K_{\tau,s}\, A^{-1/3}$$

Data from H. Sagawa *et al.*, Phys. Rev. C **76**, 034327 (2007)

Towards very neutron-rich nuclei

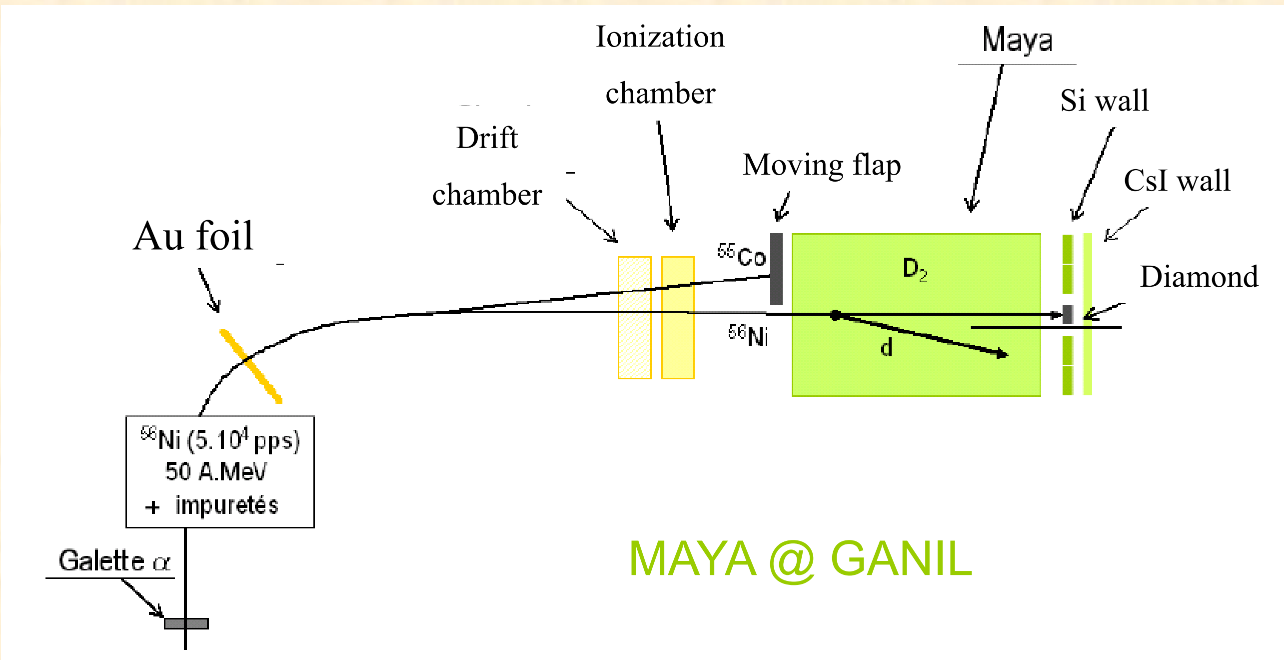
- K_τ
- K_{core} and K_{skin}

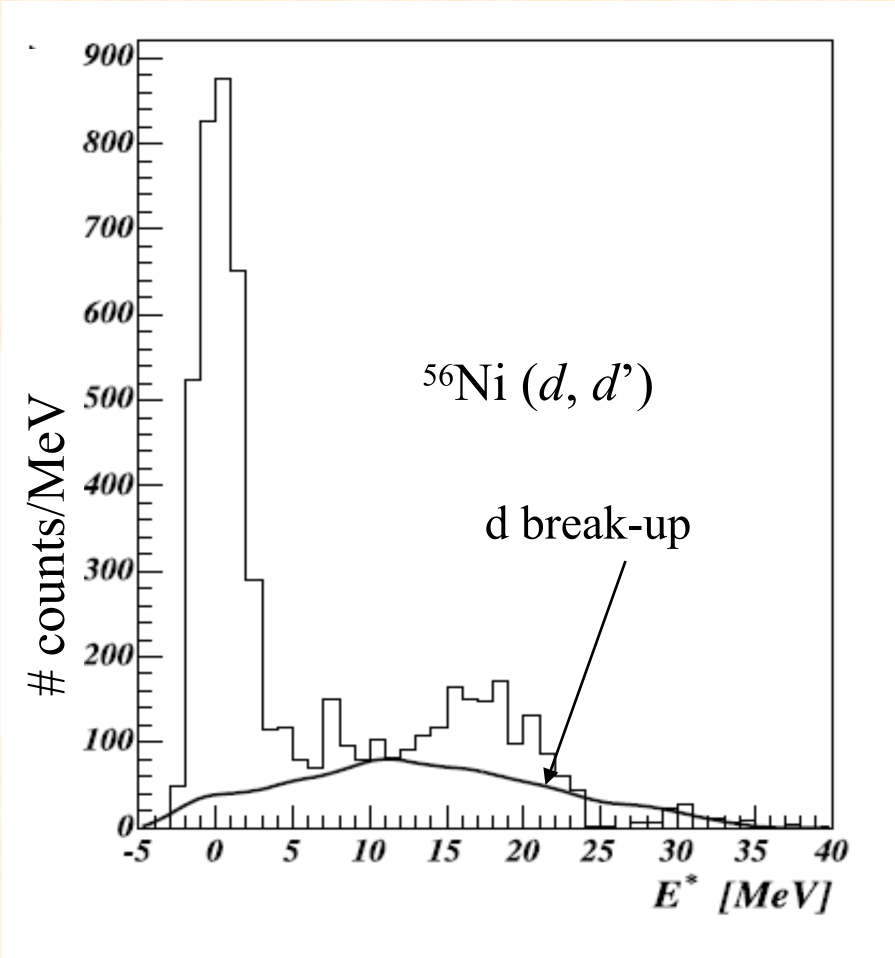
"soft GMR" akin to pigmy GDR's.

- Need inverse reactions
  ^{2}H, ^{4}He, or ^{6}Li targets
  beams of 35-100 MeV/A
- First experiments performed at GANIL

^{56}Ni + ^{2}H, ^{68}Ni + ^{4}He

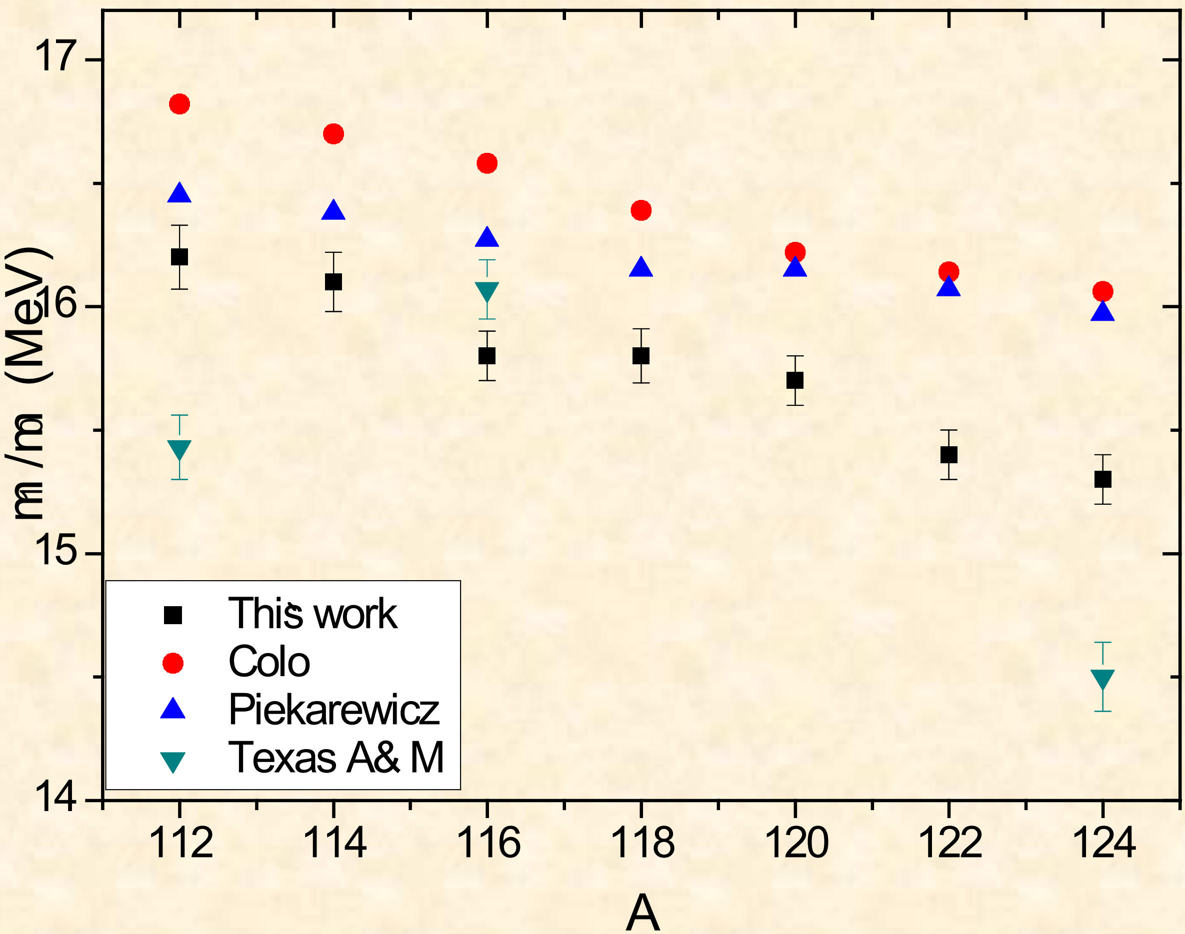
with active target MAYA


Ionization chamber
Maya
Si wall
Drift chamber
Moving flap
CsI wall
Au foil
55Co
D2
Diamond
56Ni
d
56Ni (5.10^4 pps)
50 A.MeV
+ impuretés
Galette α
MAYA @ GANIL

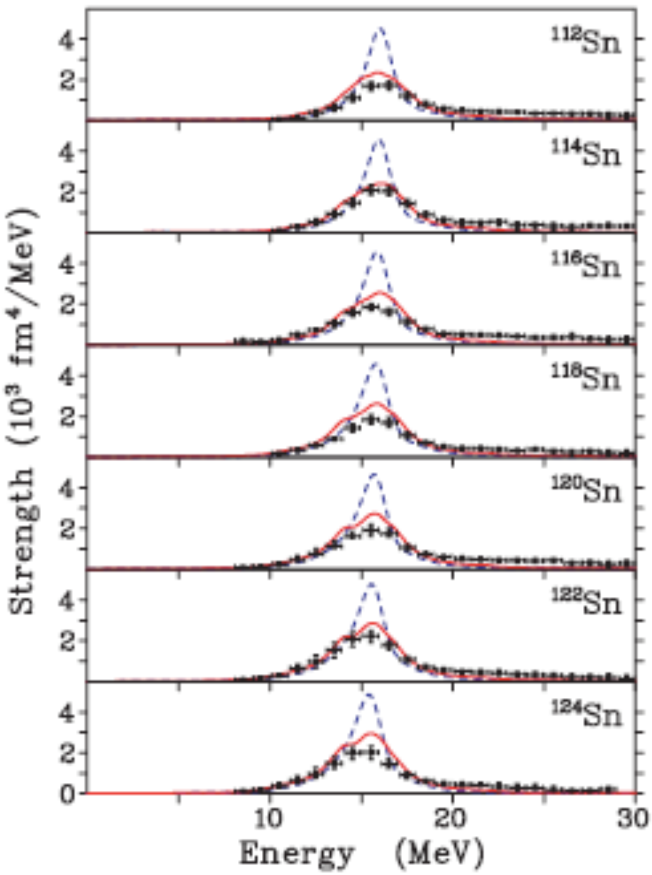


MAYA @ GANIL

C. Monrozeau *et al*., Phys. Rev. Lett. **100**, 042501 (2008)



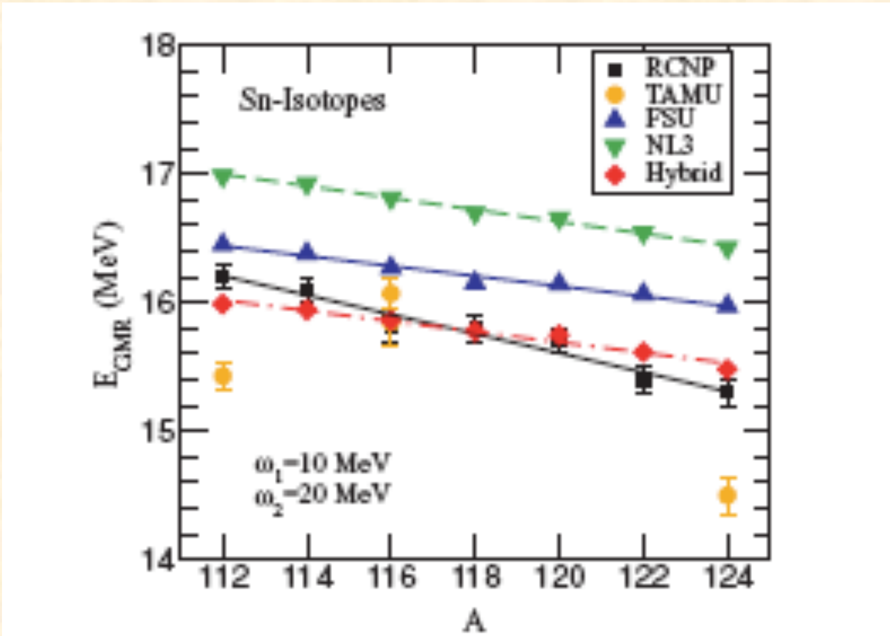
Why are tins so "Fluffy"?



V. Tselyaev *et al.*,
Phys. Rev. C **79**, 034309 (2009)

Self-consistent HF+BCS with T5 Skyrme Interaction;
K_∞ = 202 MeV

the experiment. On the whole, these results do not allow us to mbiguity in the value of K_∞ as compared with the previous known estimates. Note, however, that the main goal of our work is not to solve the problem of the nuclear matter incompressibility but to find under which conditions one can obtain reasonable description of the experimental data for the considered tin isotopes within the framework of the self-consistent approach including correlations beyond the QRPA.

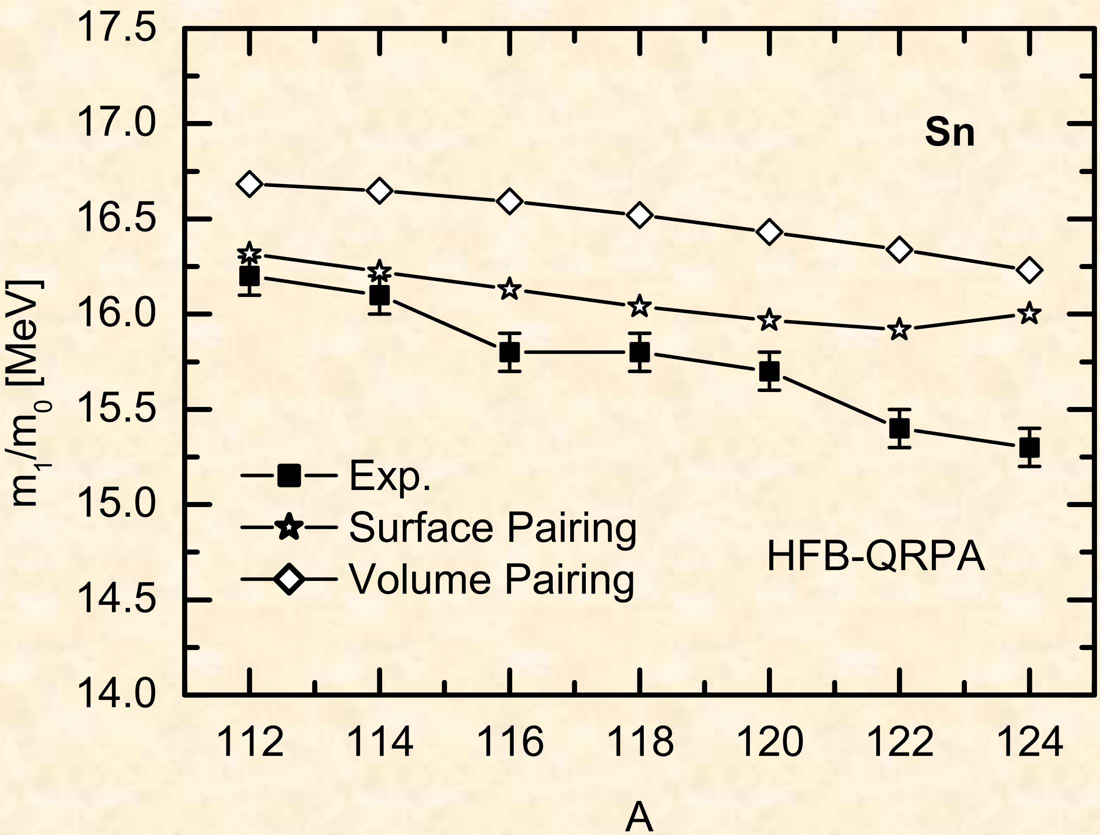


$K_\infty \sim 230$ MeV; $K_\tau = -532$ MeV

although the improvement in the case of the Sn isotopes is significant and unquestionable, an important problem remains: the hybrid model underestimates the GMR centroid energy in ^{208}Pb—the heaviest doubly magic nucleus—by almost 1 MeV. This suggests that the rapid softening with neutron excess predicted by the hybrid model may be unrealistic.

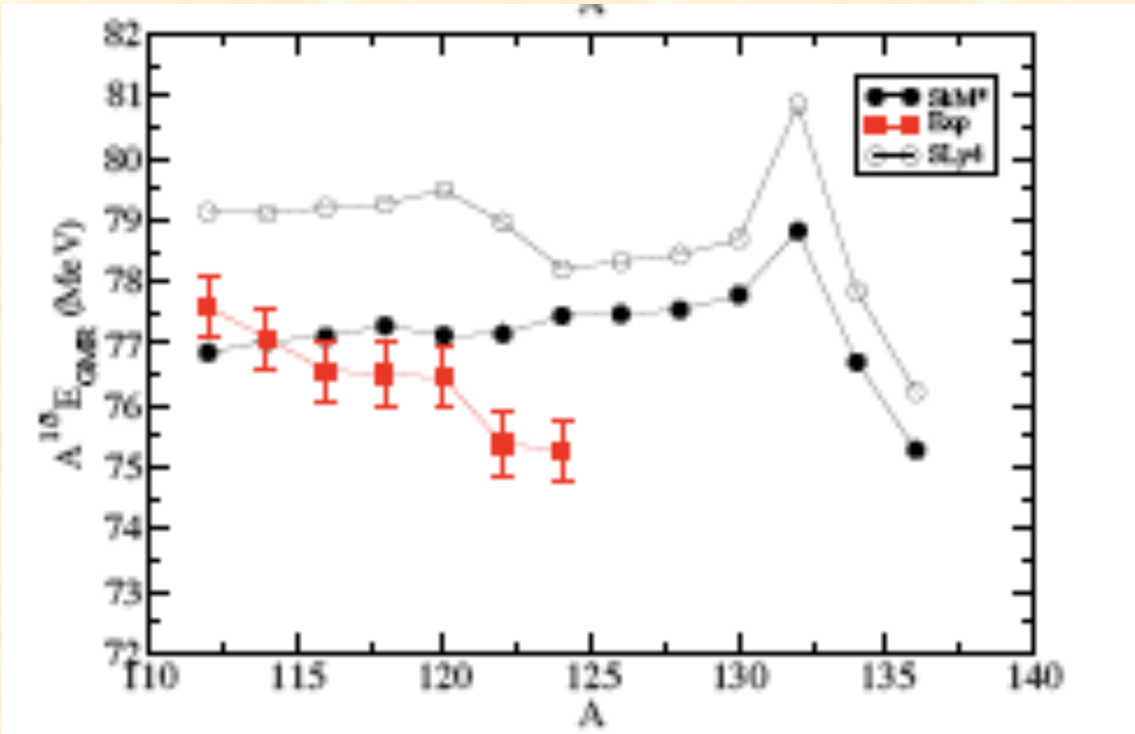
Thus, where does theory stand with respect to experiment? One possibility, given that FSUGold reproduces the centroid energy in both ^{90}Zr (with $\alpha = 0.11$) and ^{208}Pb (with $\alpha = 0.21$), is that its predictions for K_0 and K_τ are reliable, but that its failure to reproduce the GMR energies in tin is due to missing physics unrelated to the incompressibility of neutron-rich matter. We feel inclined to favor this possibility for two

J. Piekarewicz and M. Centelles, Phys. Rev. C **79**, 054311 (2009)



SkM* (K_∞ ~ 215 MeV)

Jun Li *et al.*, Phys. Rev. C 78, 064304 (2008)



In conclusion, it is shown that superfluidity favours the compressibility of nuclei, using a fully microscopic CHFB approach on the Tin isotopic chain. This may be the first evidence of a sizable effect of superfludity on the compressibility of a Fermionic system. Pairing effects should be described using a full microscopic HFB treatment. Doubly magic nuclei exhibit a specific increase of the GMR energy, due to the collapse of pairing. ^{208}Pb is therefore the "anomalous" data compared to the others. It is not possible to disentangle pairing interaction from the equation

E. Khan, Phys. Rev. C **80**, 011307 & 053702 (2009)

Nuclear Physics **A399** (1983) 11–50

MUTUAL SUPPORT OF MAGICITIES AND RESIDUAL EFFECTIVE INTERACTIONS NEAR ^{208}Pb

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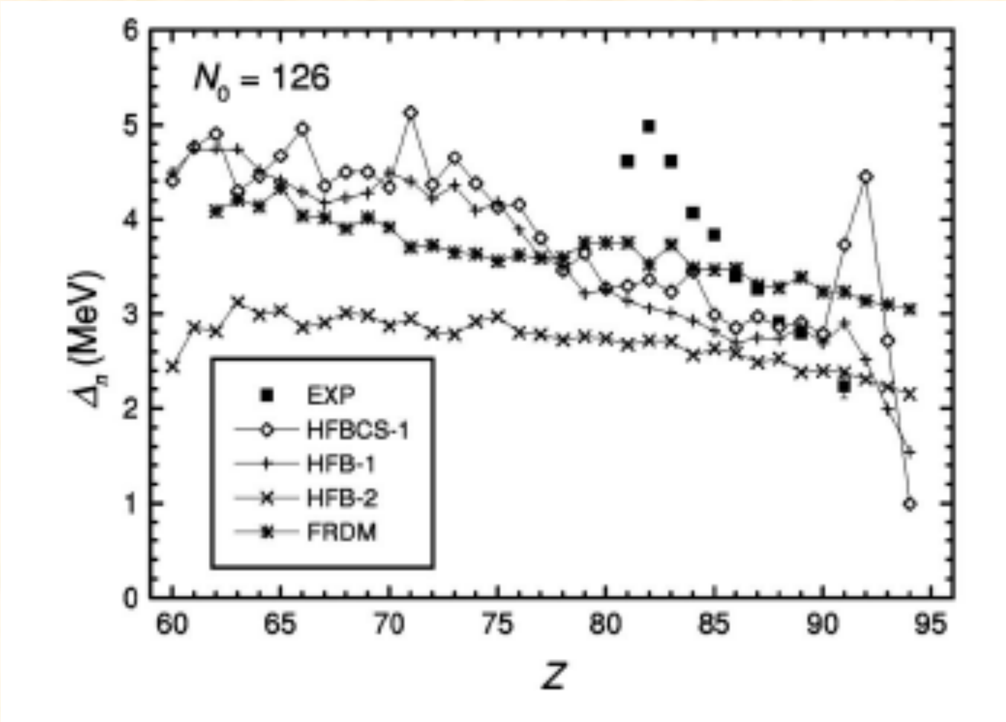
Niels Bohr Institute and Nordita, Blegdamsvej 17, DK-2100 Copenhagen Ø, Denmark

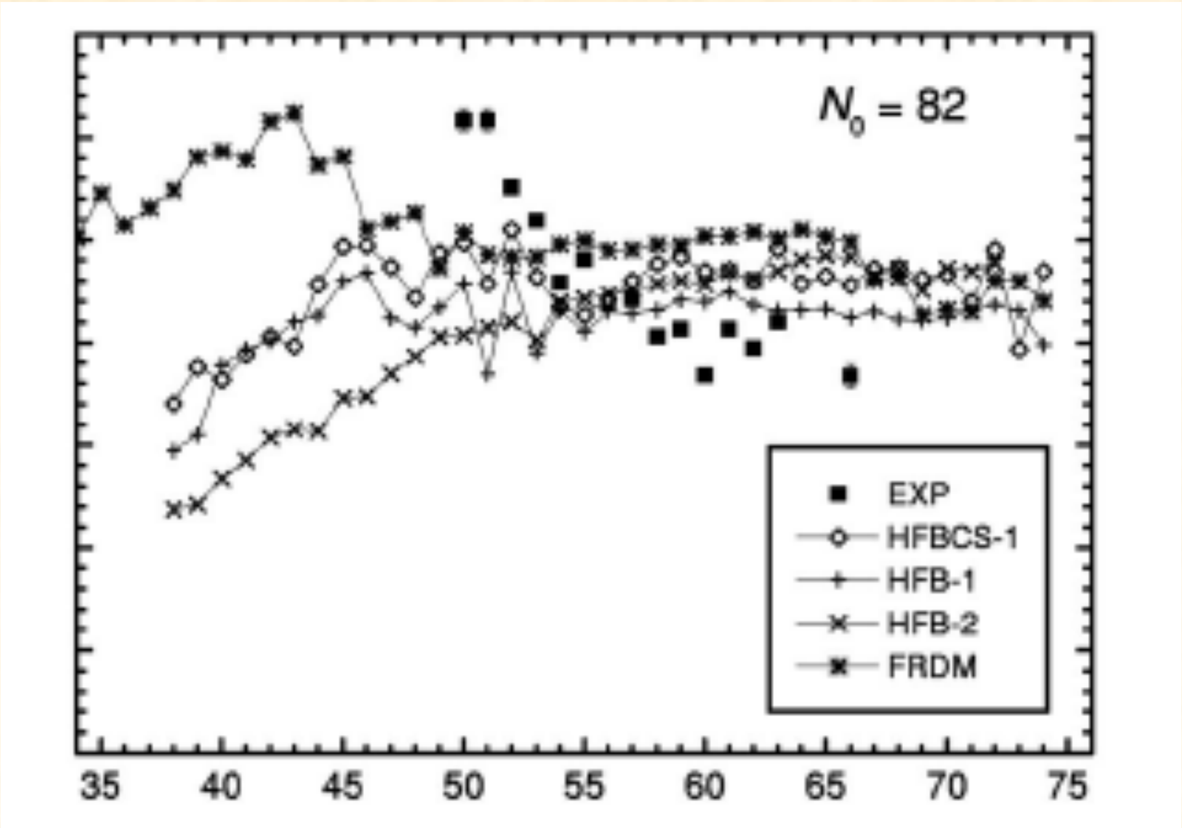
Received 1 November 1982

Abstract: We summarize experimental evidence in the lead region on the increased stability associated with neutron magic number when the proton number is magic, and vice versa. The effect is interpreted in the framework of the nuclear shell model with empirical effective interactions. Its relation to spherical Hartree-Fock calculations is pointed out and used to test Skyrme-type forces. None of the considered Skyrme interactions reproduce the effect.

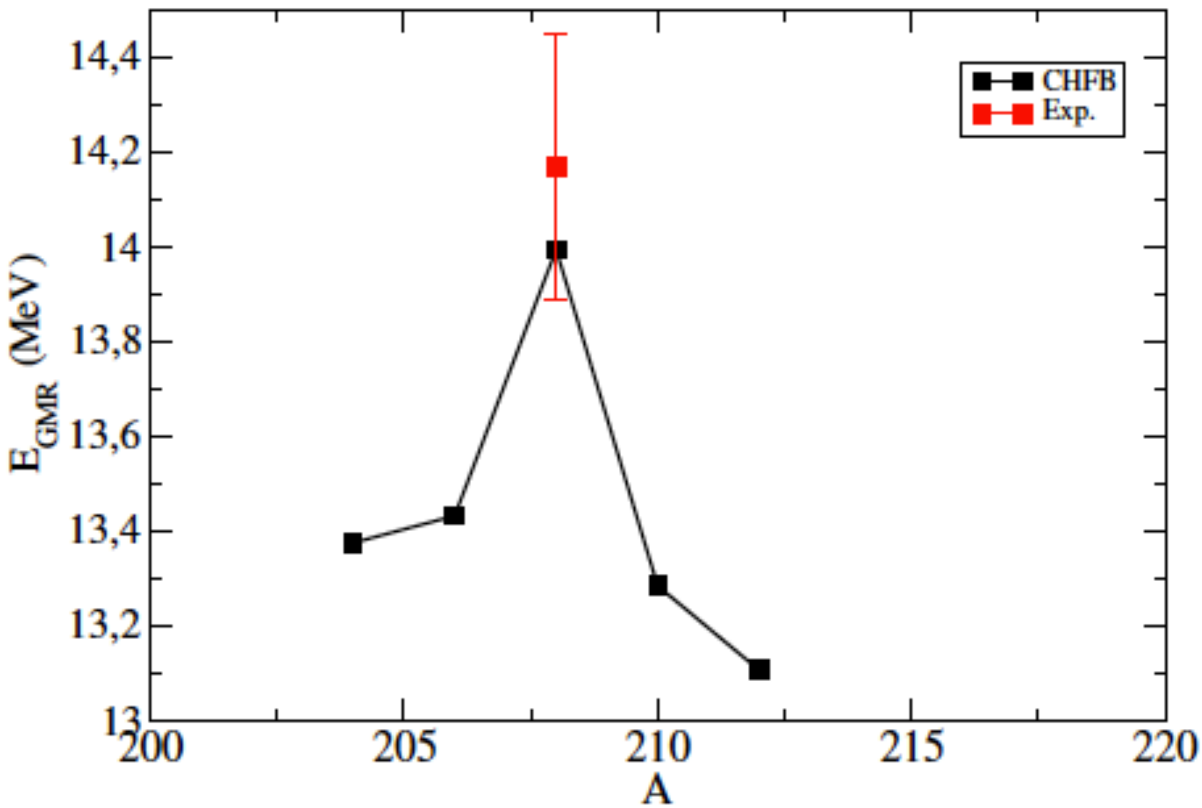



term). There are 27 such nuclei, and in the case of both HFB formulas their mean error (experiment −calculated) is −1.31 MeV, as compared to 0.040 MeV for the complete set of 1768 data points in the case of HFB-1 and 0.000 MeV (to three decimals) for the 2135 data points in the case of HFB-2. For HFBCS-1 the effect is smaller but still significant, the mean error for the 27 nuclei being −0.731 MeV, to be compared with 0.102 MeV for the complete fit.

D. Lunney *et al.*, Rev. Mod. Phys. **75**, 1021 (2003)

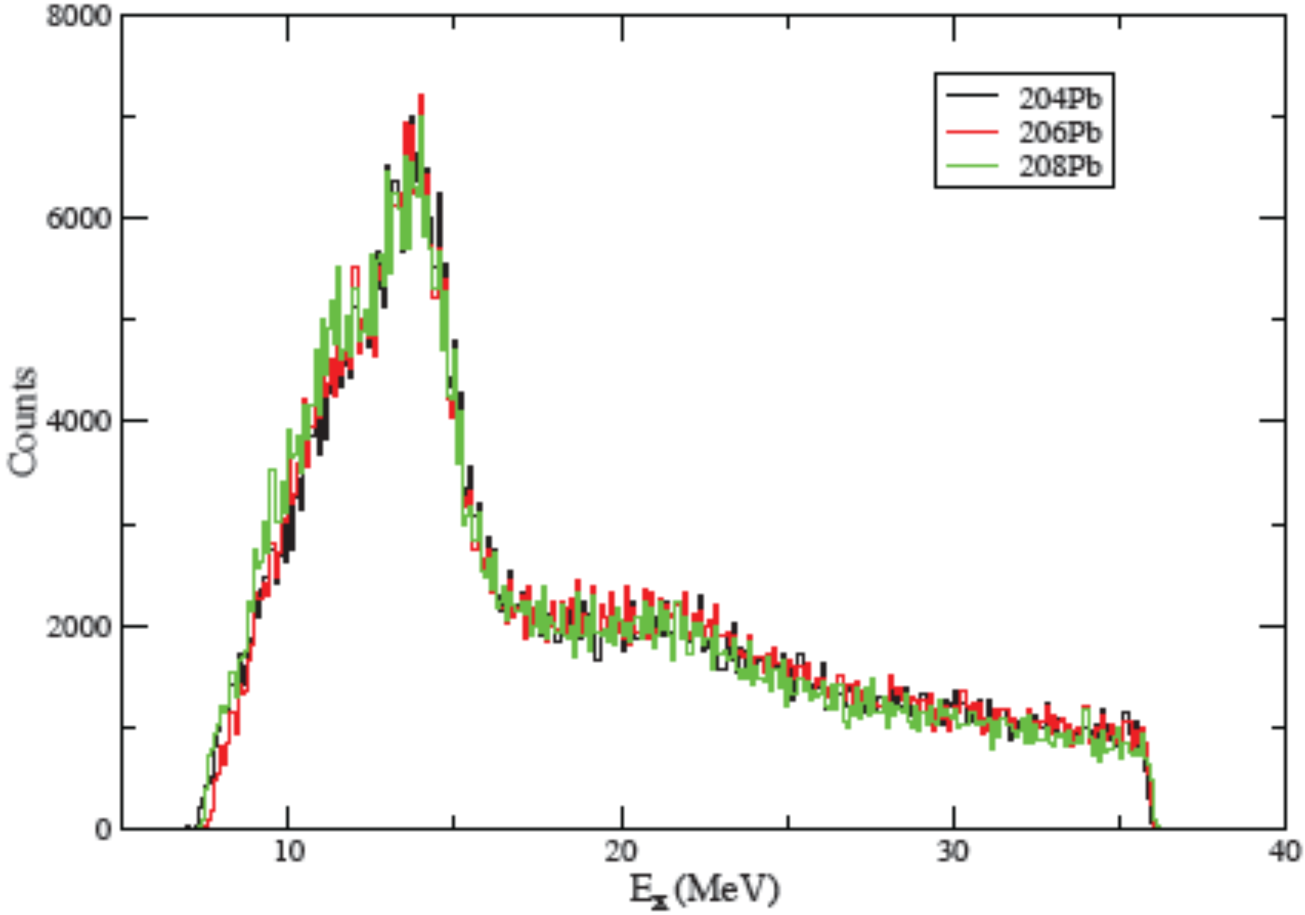


N_0 = 82
EXP
HFBCS-1
HFB-1
HFB-2
FRDM
35
40
45
50
55
60
65
70
75

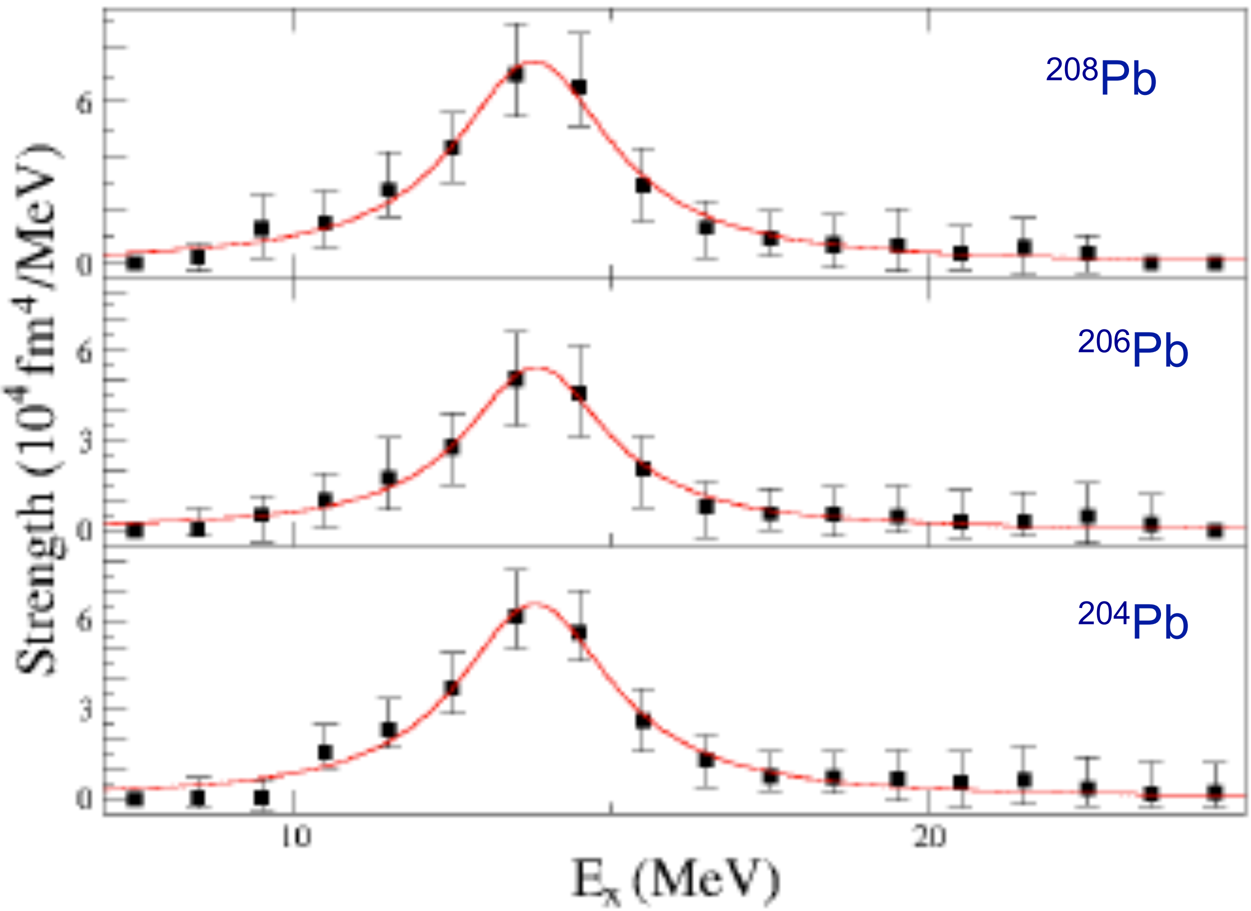


E. Khan, Phys. Rev. C **80**, 053702 (2009)

0° spectra



204Pb
206Pb
208Pb
Counts
8000
6000
4000
2000
0
10
20
30
40
E_x (MeV)



Strength (10^4 fm^4/MeV)
^{208}Pb
^{206}Pb
^{204}Pb
0
3
6
10
20
E_x (MeV)

- From compressional-mode giant resonances, we have an "experimental" value for **K_∞= 240 ± 20 MeV.**
- From GMR in the Sn and Cd isotopes, we get an "experimental" value for **K_τ = -550 ± 100 MeV.**
- The combination of these two values provides a constraint on the standard interactions used in EOS and nuclear structure calculations.
- Pairing effects ("superfluidity") are critical in our understanding of GMR's in "off-shell" nuclei.
- Mutually-Enhanced-Magicity (MEM) was suggested as one explanation. Doesn't appear to hold.
- "Why are Tin nuclei so "fluffy"? OR

What is "missing in theory ???

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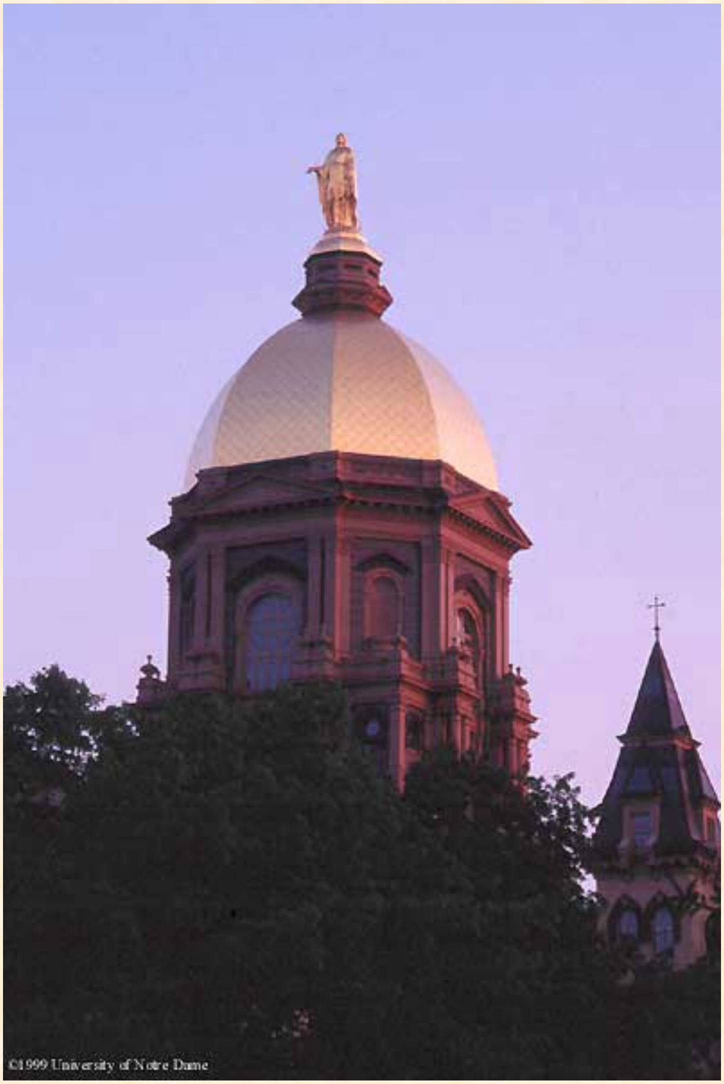
I S N A P

J I N A

धन्यवाद

Thanks!

The Question Kitten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