Parameters of EoS extracted from GMR measurements

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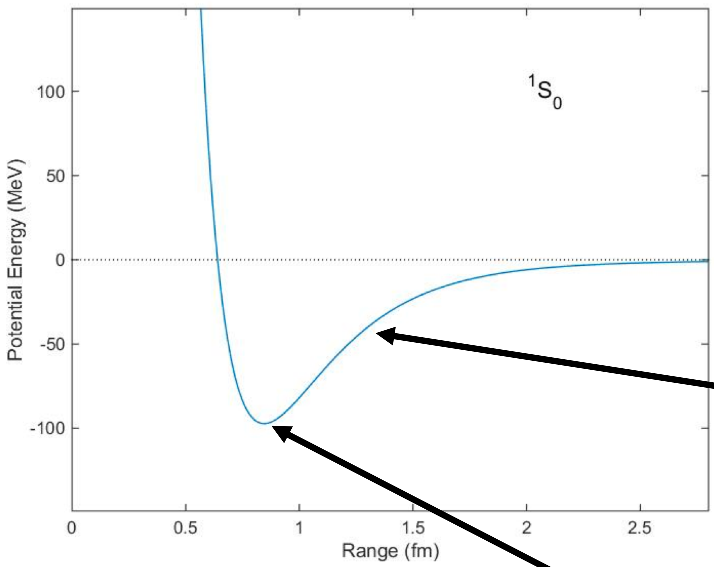
Origin of nuclear incompressibility

Bare nucleon-nucleon interaction



$$\rho = \left(\tfrac{4}{3}\pi r_0^3\right)^{-1}$$

r_0=1.2 fm from ρ_0=0.15 fm^{-3}

ρ_{pack}=0.45 fm^{-3}=3ρ_0 from r_{pack}=0.8 fm

- The hard-core of the nucleon-nucleon interaction shall not be driving the saturation density
- Contribution from quantum effects: zero point energy: $T_0 = \dfrac{\hbar^2}{m r_0^2} \simeq 30$ MeV
- Incompressibility of the **nucleus**: $K_A \equiv 4\langle r^2\rangle \left.\dfrac{d^2E/A}{d\langle r^2\rangle^2}\right|_{\mathrm{g.s.}} \approx 5T_0 \simeq 140$ MeV

E. Khan, N. Paar, D. Vretenar, Li-Gang Cao, H. Sagawa, G. Colò, Phys. Rev. C 87, 064311 (2013)

EoS: definitions

$$\frac{E}{A}(\rho) = \frac{E}{A}(\rho_0) + \frac{1}{2}K_0\frac{(\rho-\rho_0)^2}{9\rho_0^2} + \frac{1}{6}Q_0\frac{(\rho-\rho_0)^3}{27\rho_0^3} + \ldots \equiv \frac{E}{A}(\rho,0)$$

a.k.a: $a_V \simeq -23$ MeV

a.k.a: $K_\infty \simeq 240$ MeV(?)

Skewness

Generalisation to asymmetric nuclear matter: $\delta \equiv \frac{N-Z}{A}$

$$\Rightarrow \quad \frac{E}{A}(\rho,\delta) = \frac{E}{A}(\rho,0) + S(\rho)\delta^2 + \ldots$$

with $S(\rho) = S(\rho_0) + L\frac{(\rho-\rho_0)}{3\rho_0} + \frac{1}{2}K_{sym}\frac{(\rho-\rho_0)^2}{9\rho_0^2} + \frac{1}{6}Q_{sym}\frac{(\rho-\rho_0)^3}{27\rho_0^3} + ..$

a.k.a.: $J, E_{sym}, a_4, a_A \simeq 30$ MeV

Slope of the symmetry energy

a.k.a.: L_{sym}

Incompressibilities

- Incompressibility of symmetric nuclear matter:

$$K_0 = 9\rho_0^2 \left(\frac{\partial^2 E/A(\rho,0)}{\partial \rho^2} \right)_{\rho=\rho_0}$$

- Isospin dependence of the incompressibility of nuclear matter:

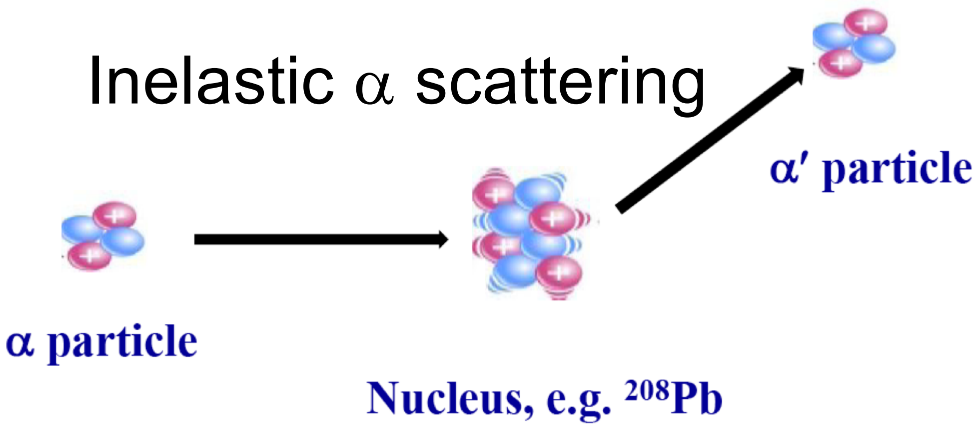
$K_0 + K_{sym}\delta^2$ with $K_{sym} = 9\rho_0^2 \left(\frac{\partial^2 S(\rho)}{\partial \rho^2} \right)_{\rho=\rho_0}$

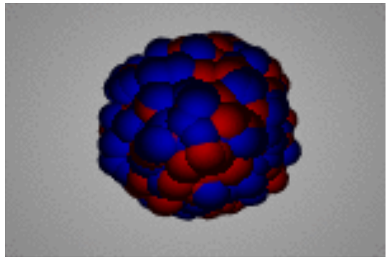
$$? \Big\updownarrow ?$$

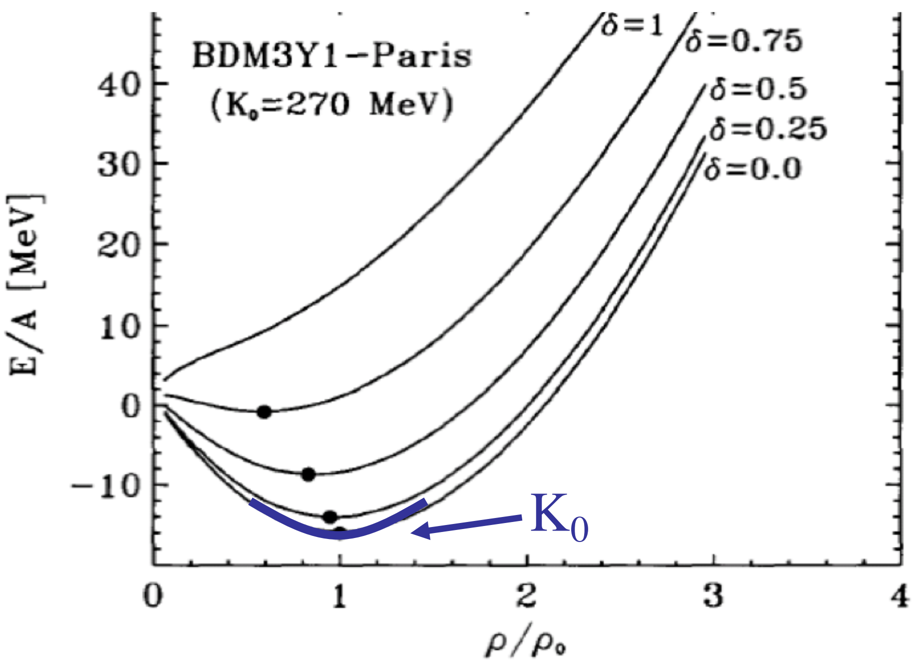
- Incompressibility of a nucleus: $K_A \equiv 4\langle r^2 \rangle \frac{d^2 E/A}{d\langle r^2 \rangle^2}\Big|_{\mathrm{g.s.}}$ and $E_{\mathrm{GMR}} = \sqrt{\frac{\hbar^2 K_A}{m\langle r^2 \rangle}}$

Method to determine EoS incompressibility

Inelastic α scattering







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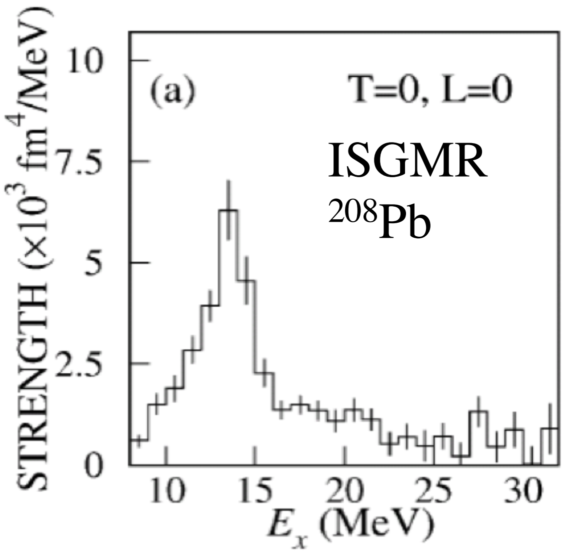
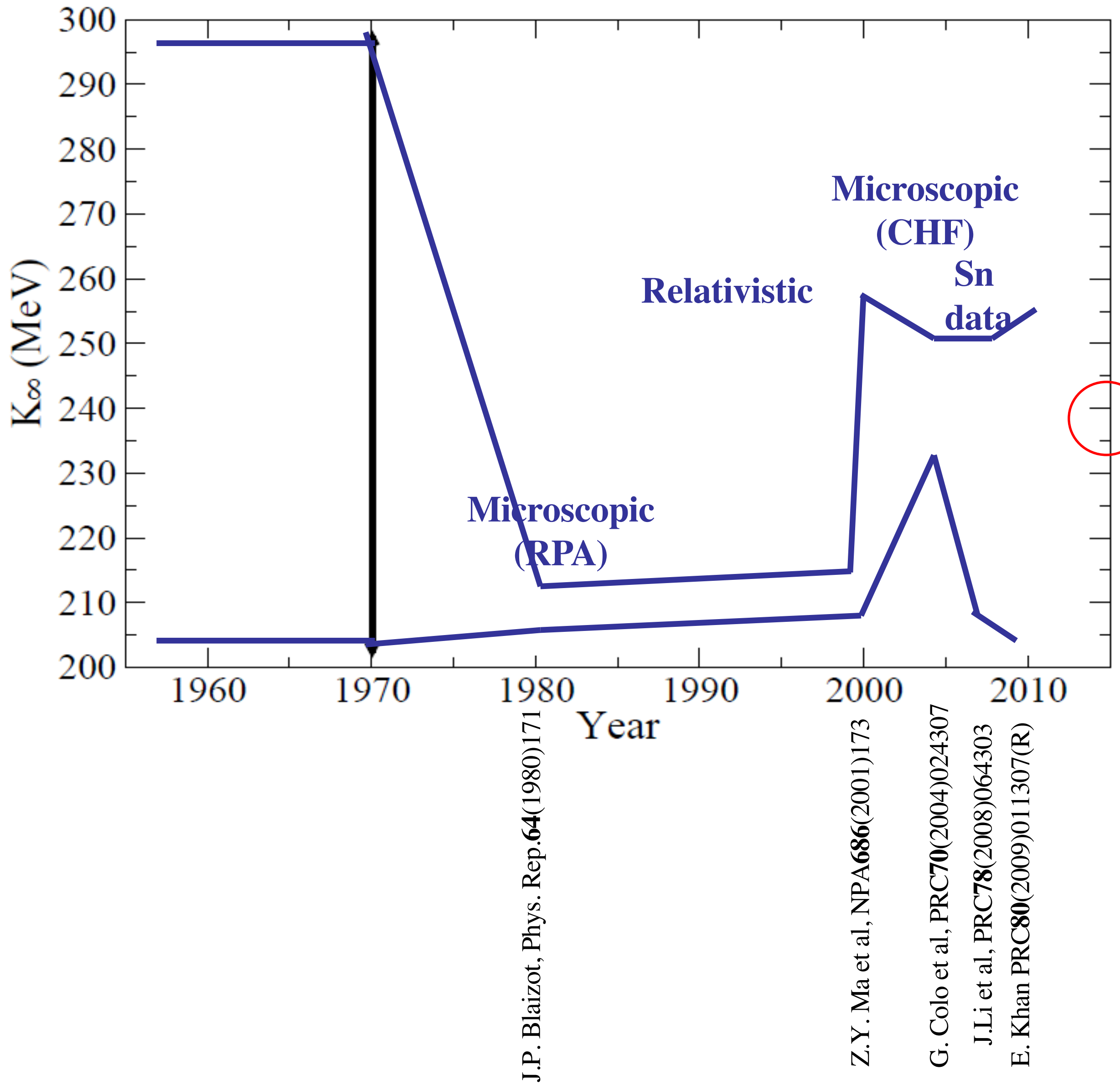


M. Uchida et al., PLB**557**(2003)12

The nucleus exhibits a compression mode (how lucky !): the Giant Monopole Resonance

Uncertainties on K_0

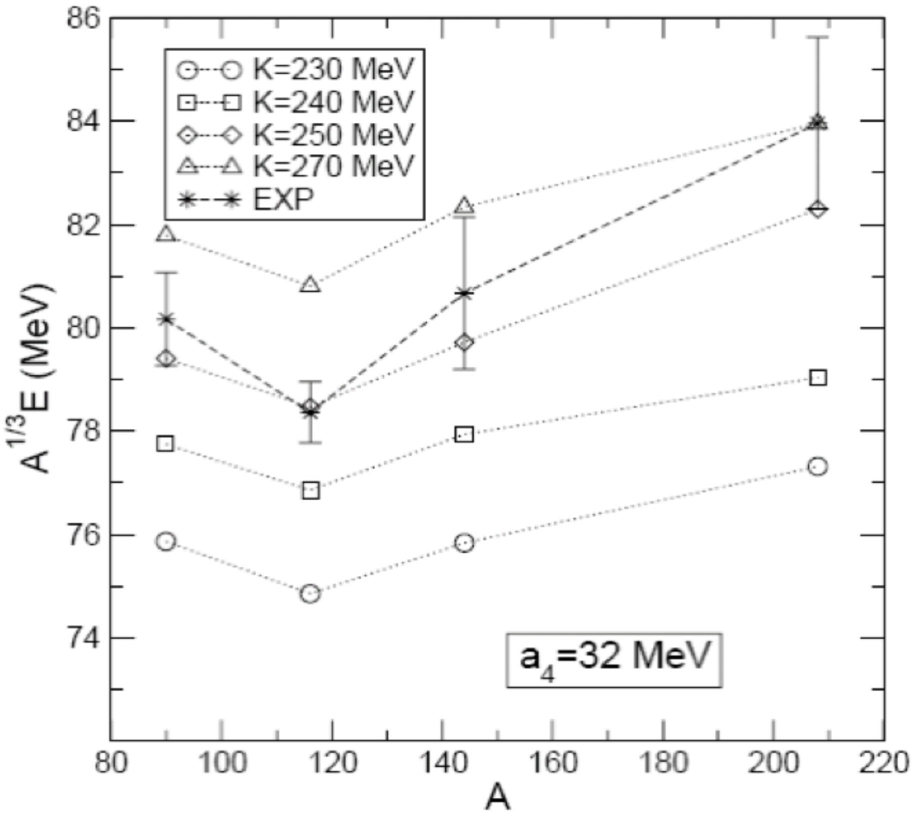


Is the method well defined ?

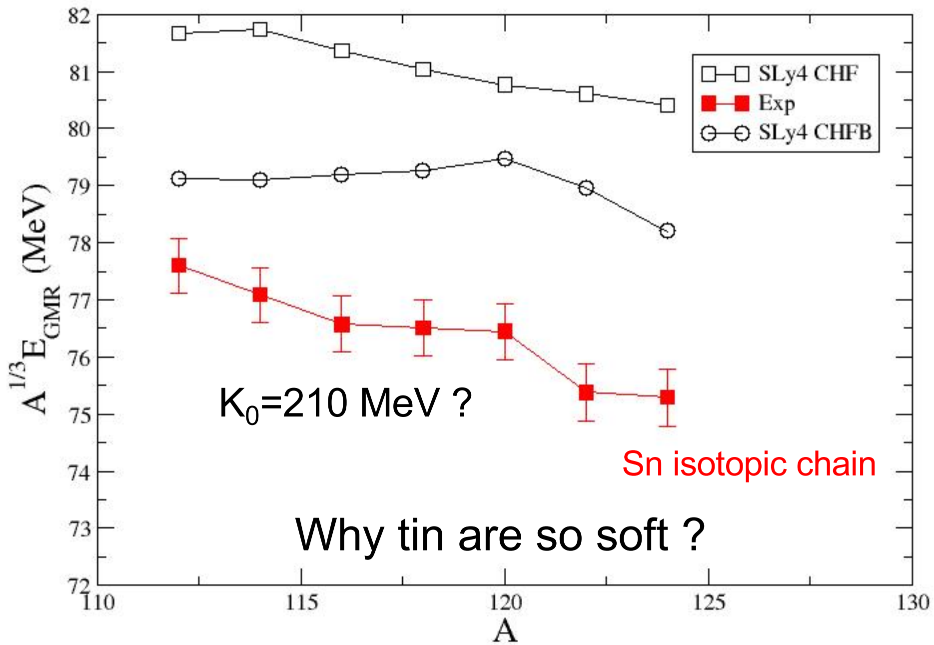
Admitted value (?)

Determination of K_0

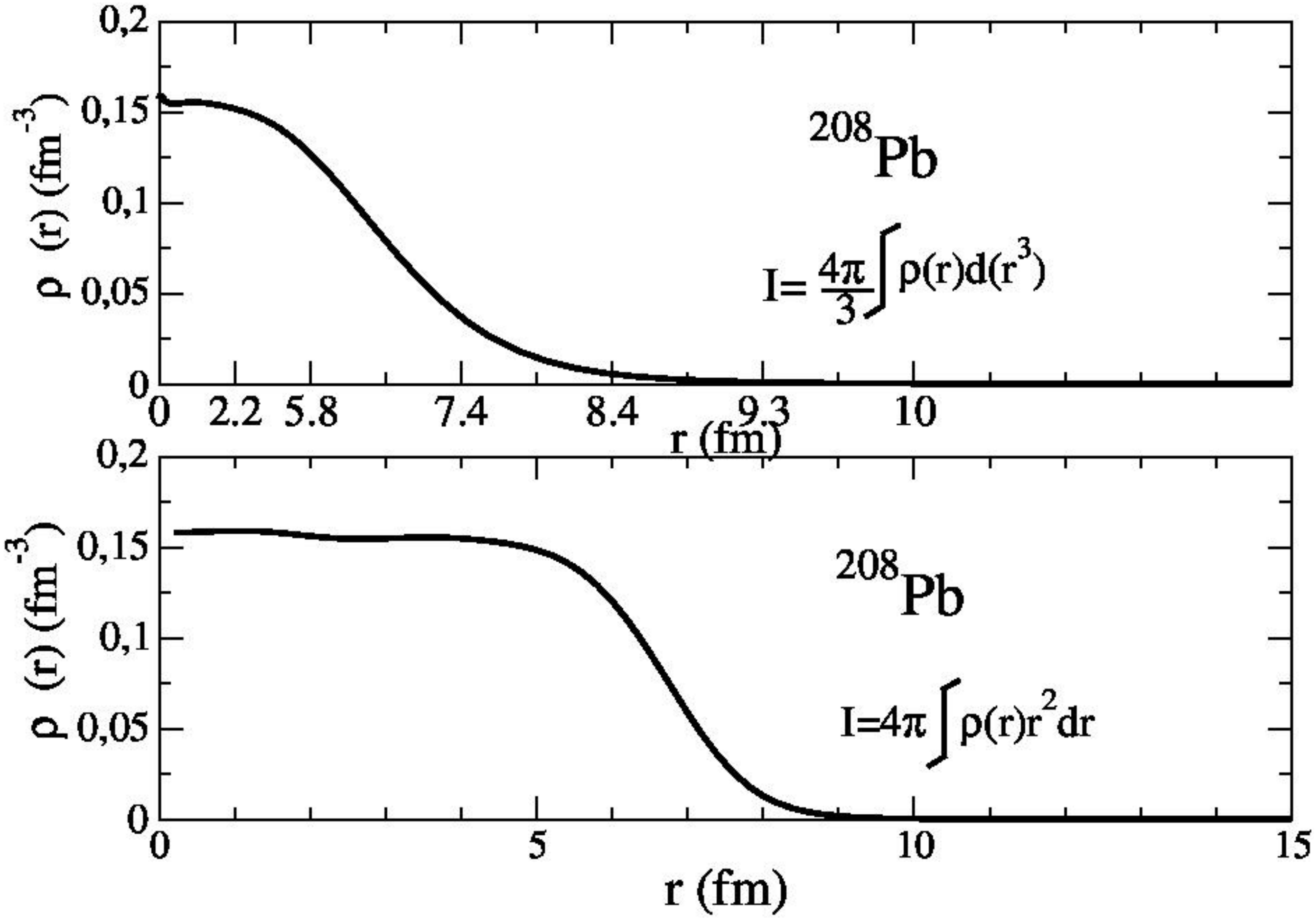
- **Microscopic method**: prediction of the GMR centroid using mean-field approach
- Then K_0 obtained from the functionnal describing the GMR data



D. Vretenar et al, PRC**68**(2003)024310



Saturation ?

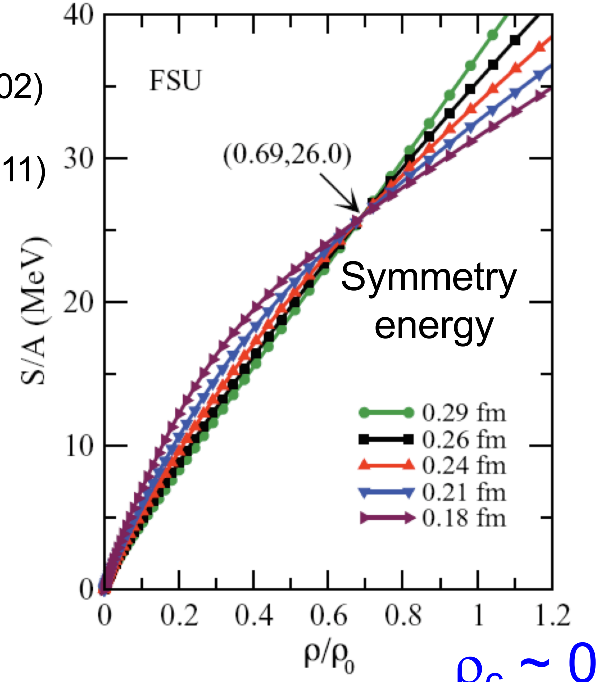


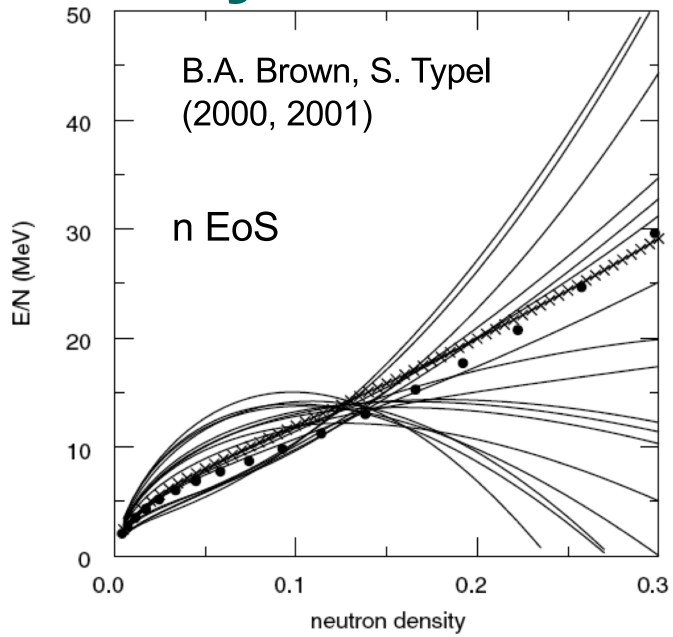
•2/3 of nucleons are in the surface of ^{208}Pb

•Saturation density area may not be the most probed by GMR measurement

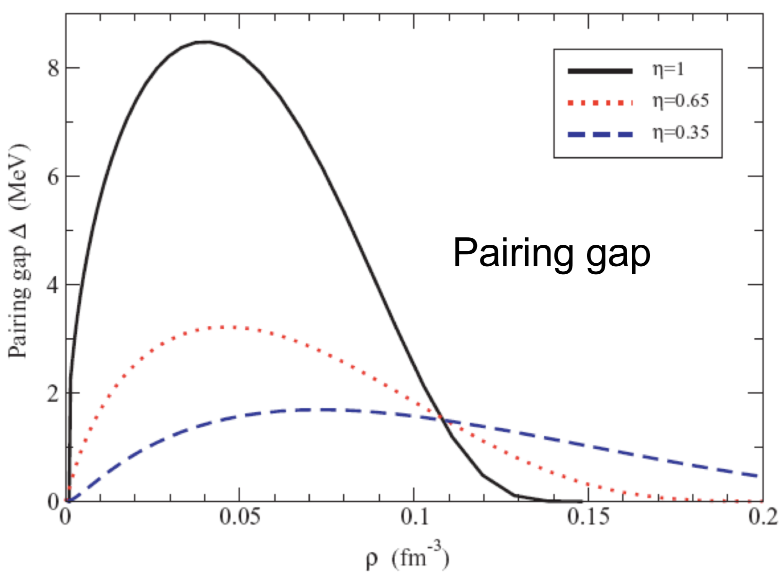
The crossing density

R.J. Furnstahl (2002)
G. Colò (2004)
J. Piekarewicz (2011)

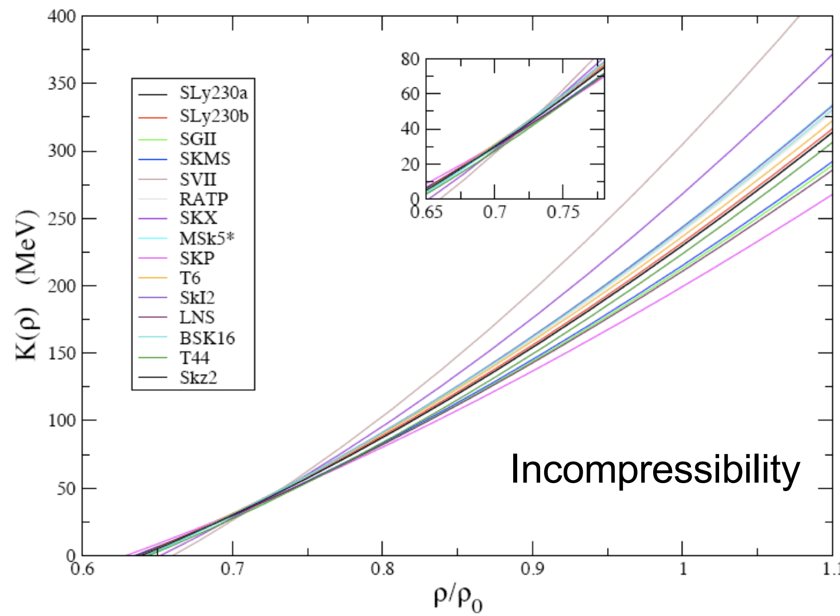




$\rho_c \sim 0.11\ \mathrm{fm}^{-3} = 0.7\ \rho_0$



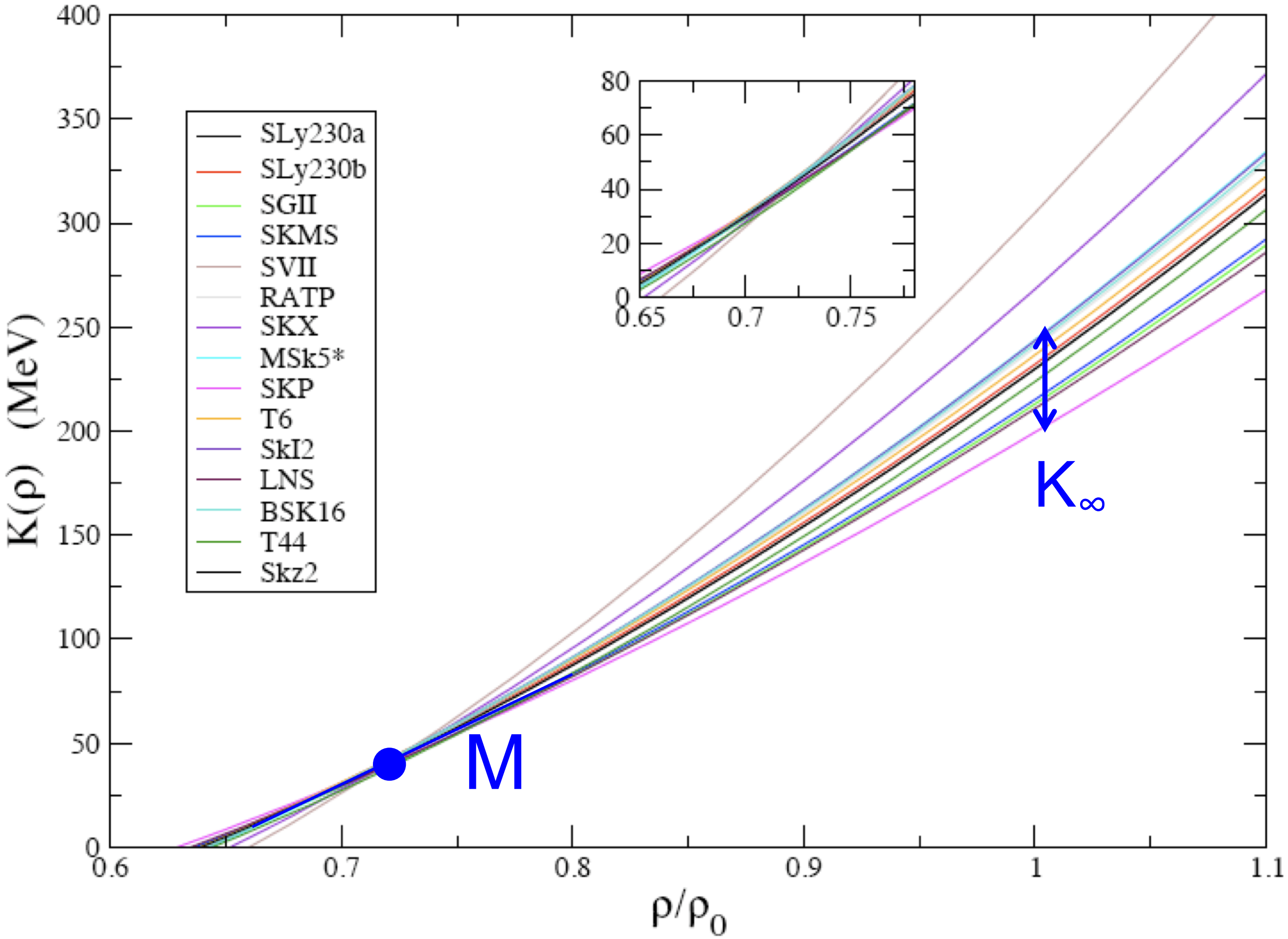
E. Khan, M. Grasso, J. Margueron (2010)



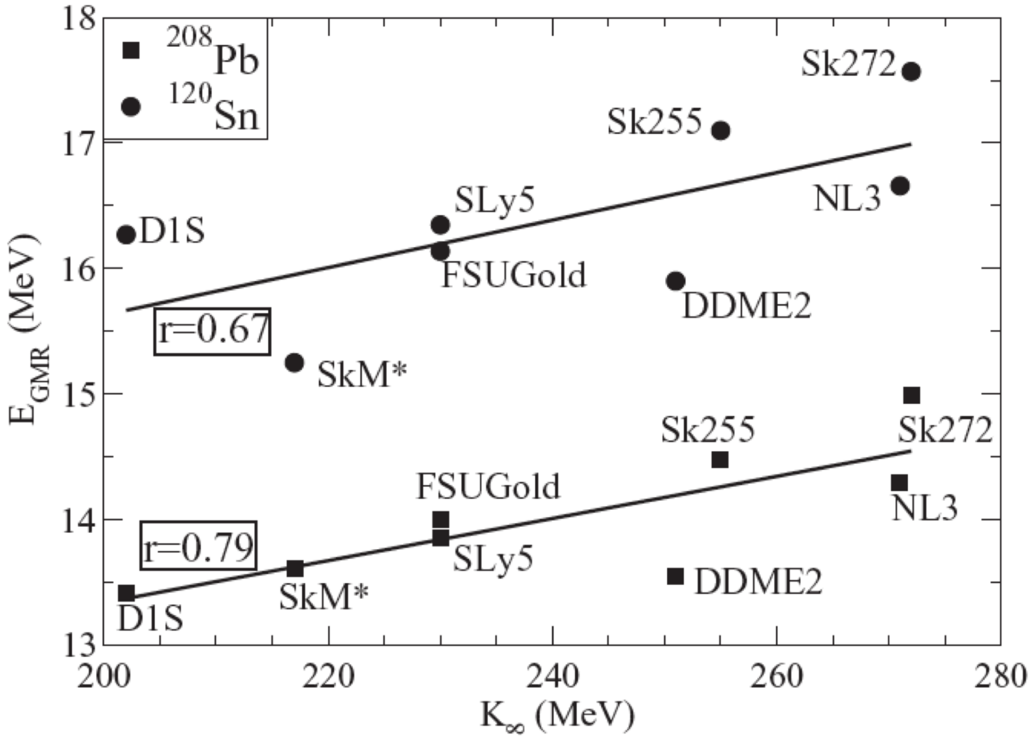
E. Khan, J. Margueron, I Vidaña, Phys. Rev. Lett. 109, 092501 (2012)

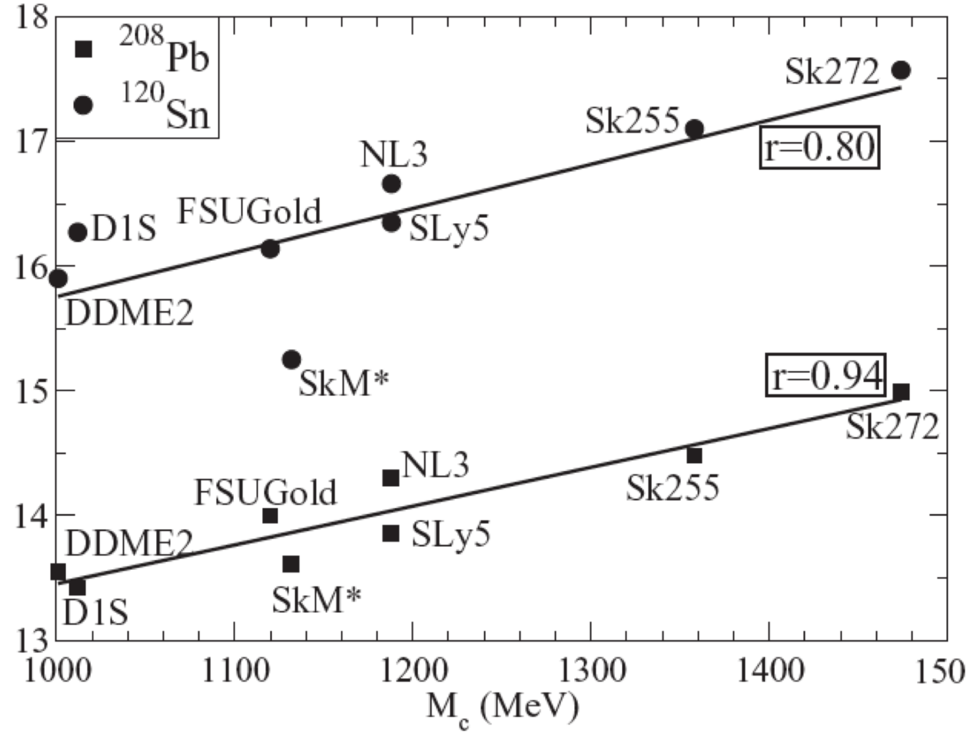
M

$M = 3\rho K'(\rho)|_{\rho=\rho_c}$: third derivative of EoS at the crossing density



From the GMR to nuclear matter

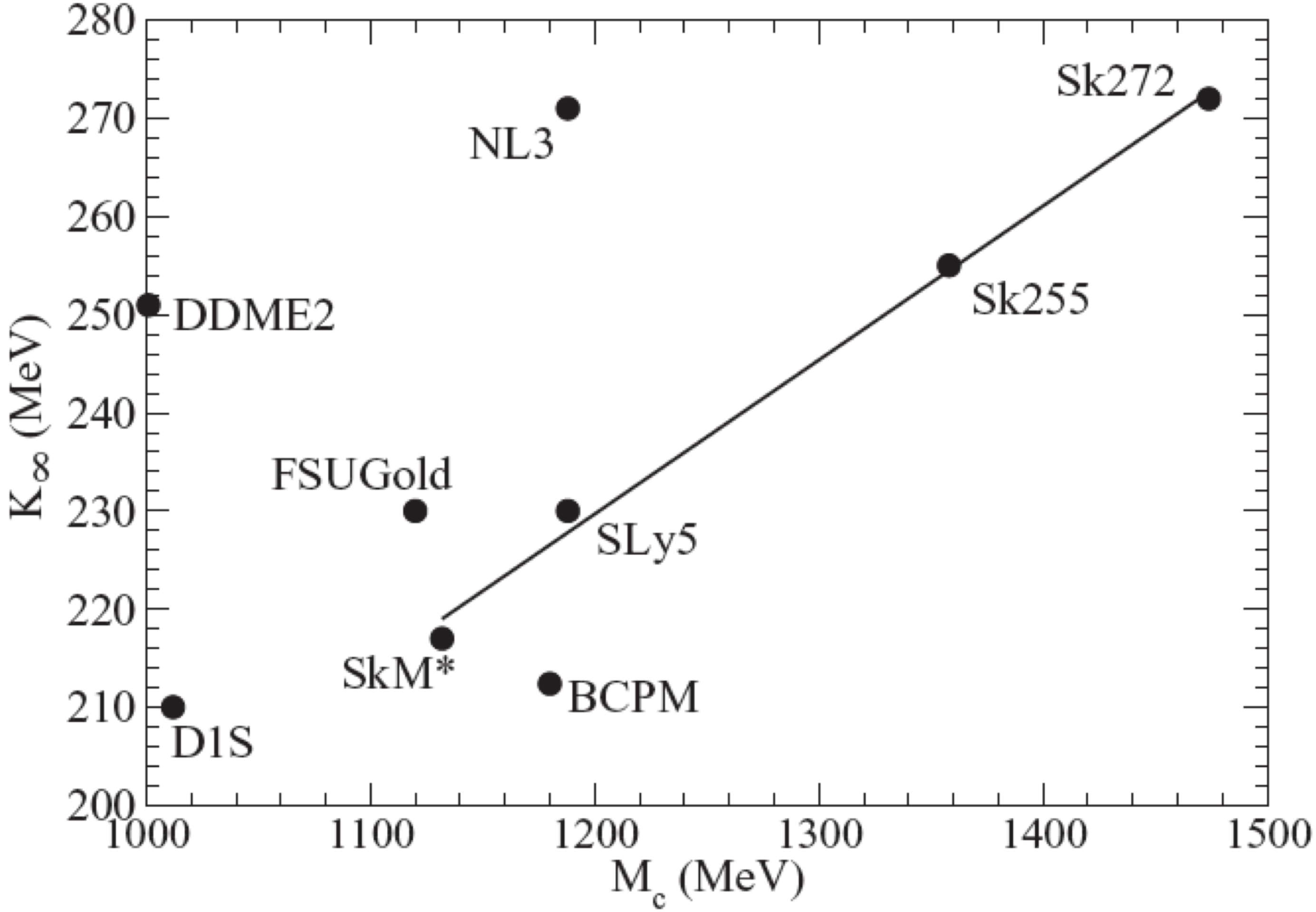




M_c better constrained by the data than K_∞

E. Khan, J. Margueron, Phys. Rev. C 88, 034319 (2013)

The reason for dispersed K_∞ values



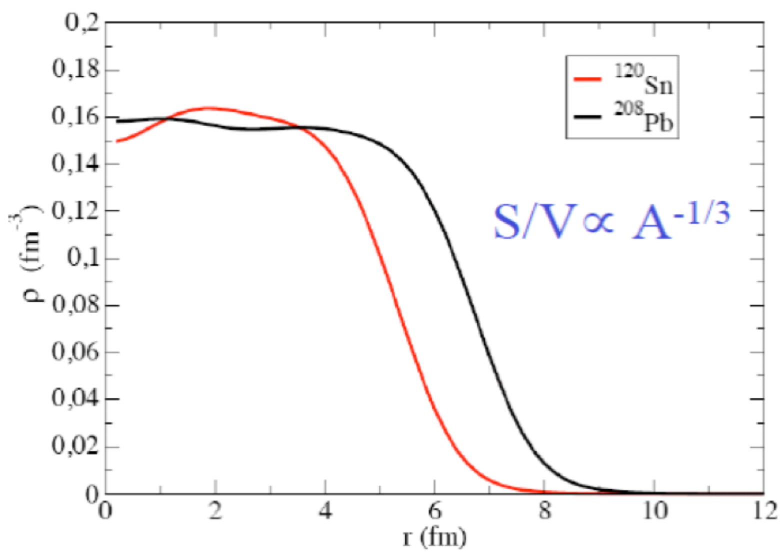
Lack of constraints on the density dependence of the EDF generates dispersion of K_∞

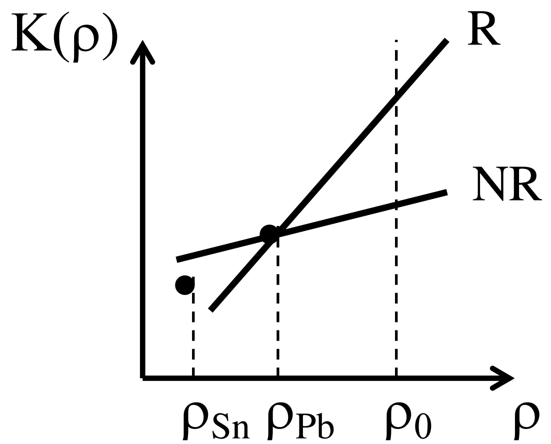
Solving puzzles ?

- **GMR in nuclei (K_A) are probing $K(\rho)$ (variation of several ten's of MeV)**
- **This may explains:**

•Puzzle1: different K_∞ values obtained within the same nuclei between R (260 MeV) and NR (230 MeV) models

K_∞ is not the only part of the functional probed by the GMR measurement.
K at different ρ are also involved. A compensation between K_∞ and different density dependencies allows to reproduce the same data





•Puzzle2: different K_∞ values obtained within the same model between Pb and Sn nuclei

Nuclei have different density fluctuations around ρ_0 (skin, …).
Only a functional with the correct $K(\rho)$ may allow to describe both data.