A empirical equation of state for nucleonic matter

Providing a polynomial form for the EoS

Rudiney Casali, Anthea Fantina, Jérôme Margueron

A functional approach for nuclei, NS and SN

Requirements:

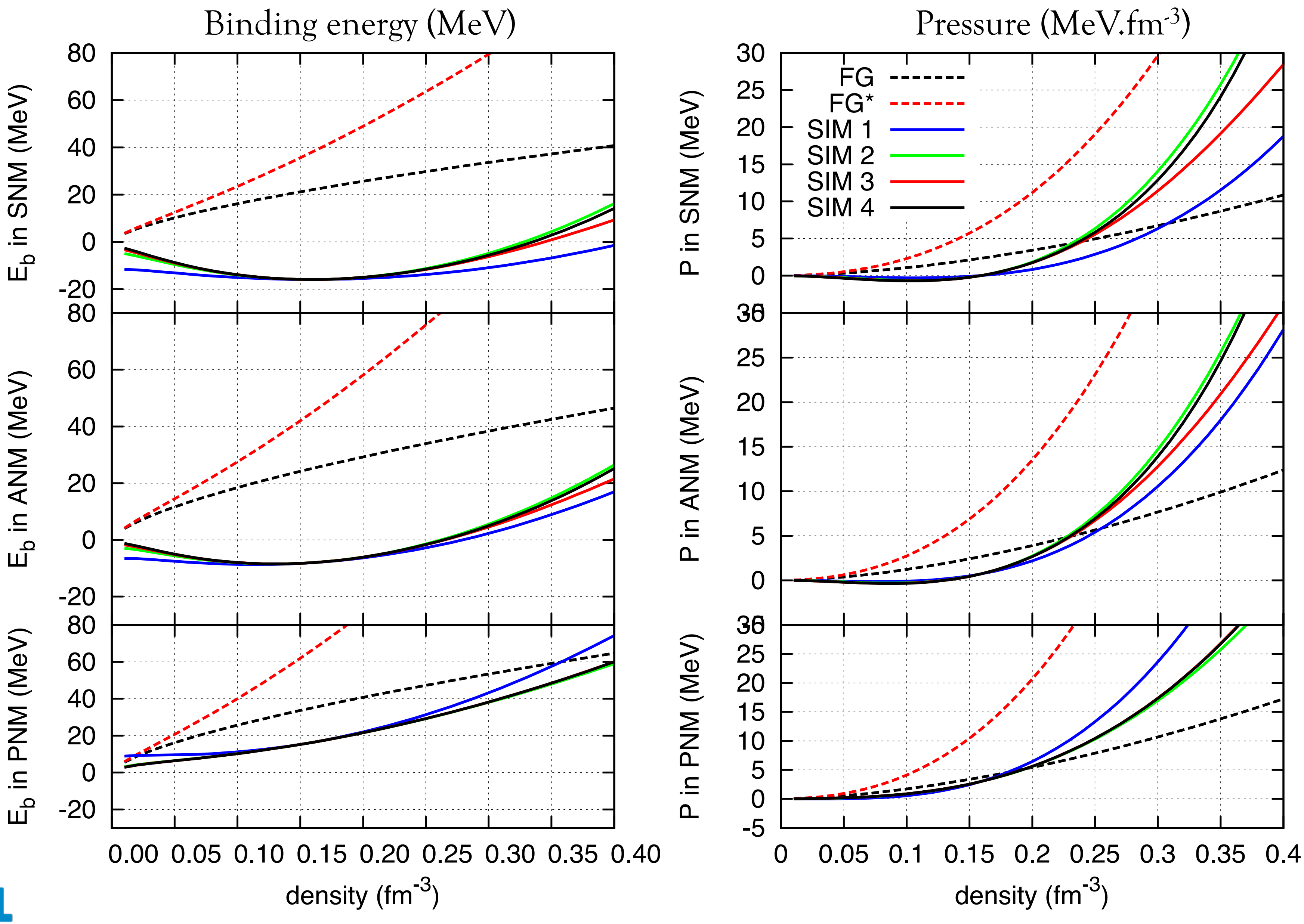
- The model shall be as flexible as possible, eventually at the price of increasing the number of parameters.
- We want to control at best the density dependence of the EoS, and of all its **derivatives**. We want to be able to fix all the derivatives, but one, in a simple way.
- The model shall include an estimation on the theoretical error bars in the extrapolation to unknown regions.
- The relation between experimental constraints and the parameters of the model shall be simple/direct and clear.

How:

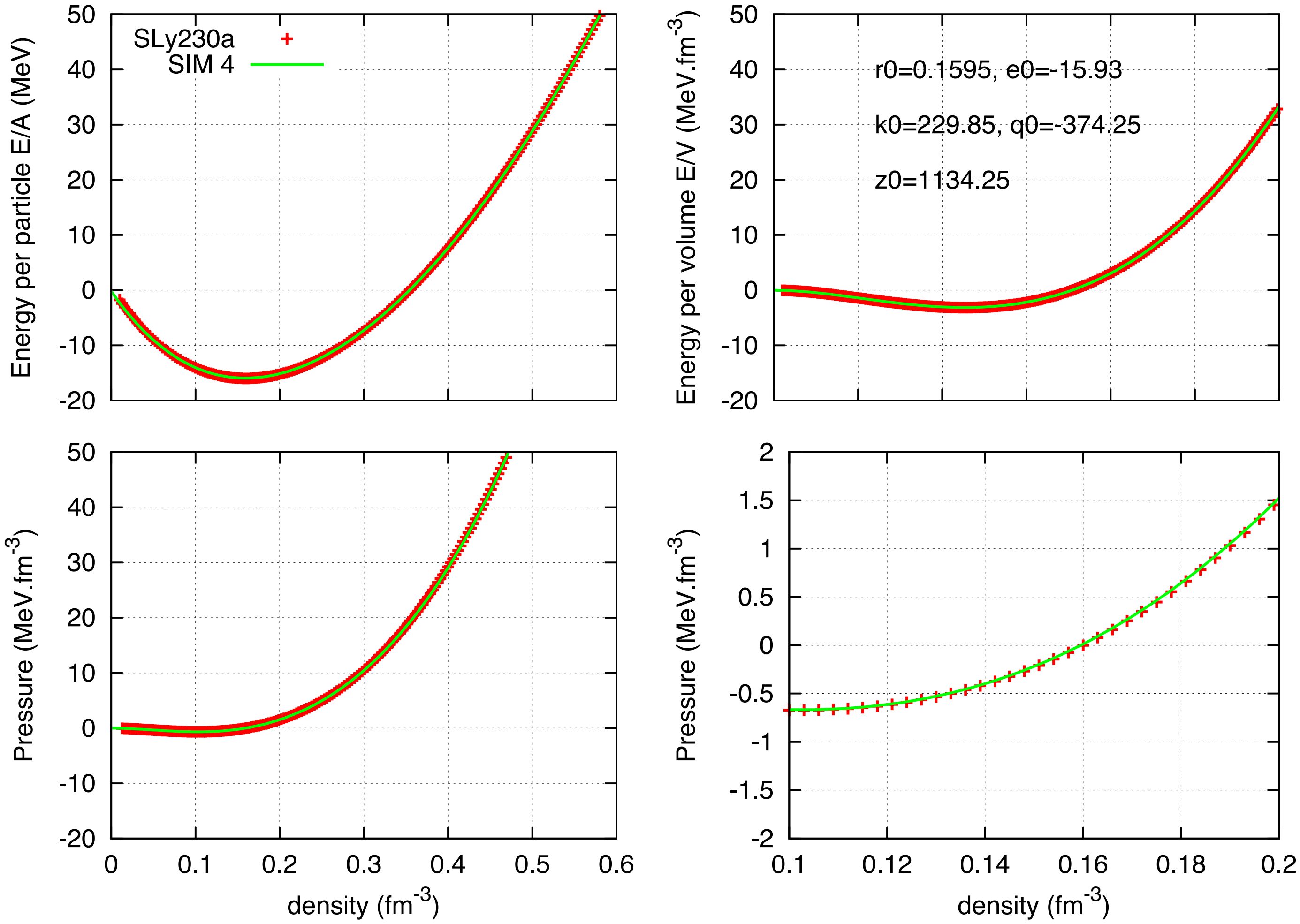
- We take advantage of the density functional theory → $E(\rho,\delta)$.
- We take a reference density, for instance the saturation density in symmetric matter → ρ_0.
- We decompose the energy into: a kinetic energy + potential (non-relativistic model).
- The parameters of the model are the *n*-derivative of the EoS at ρ_0.

How good does it works?

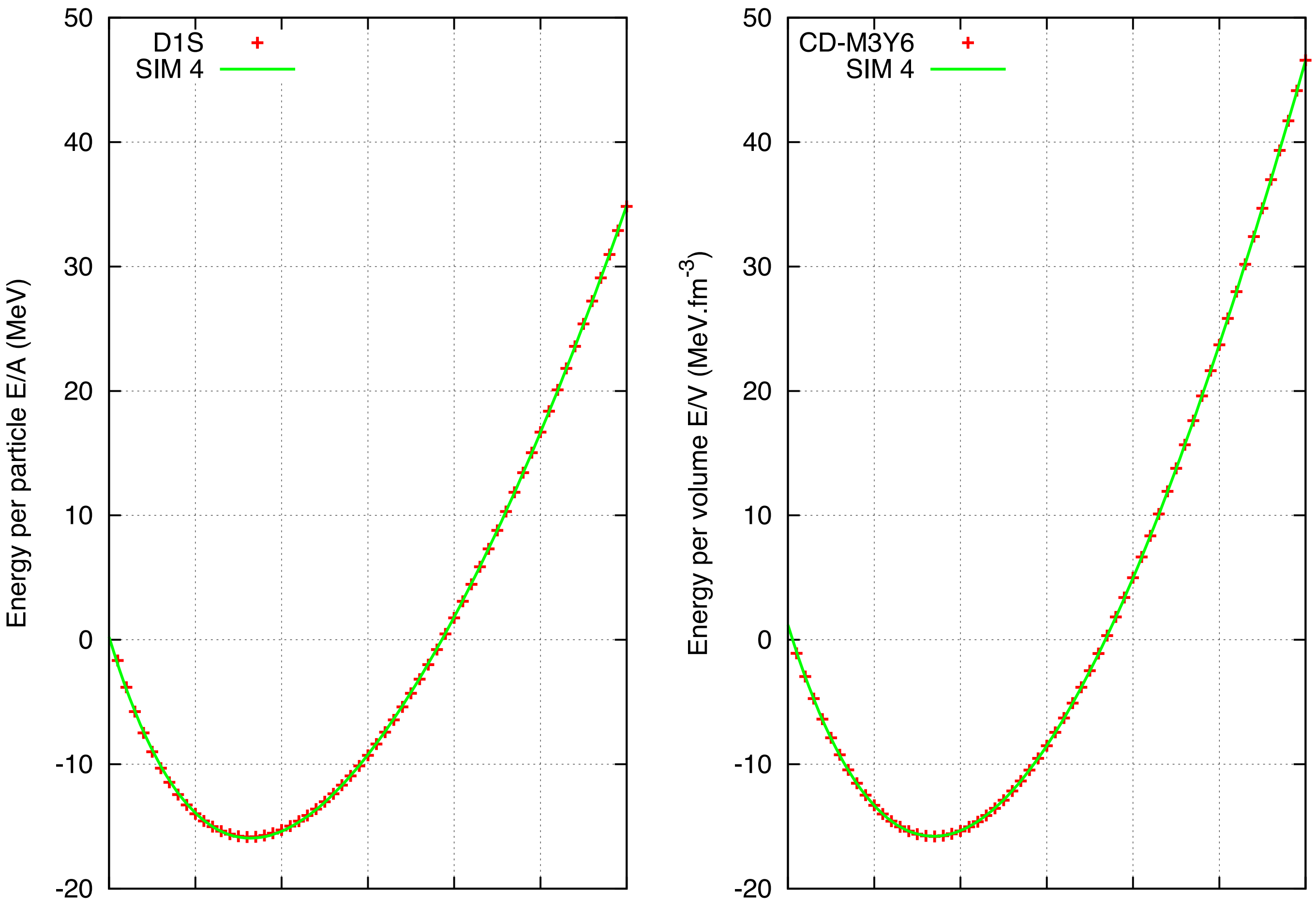
Effect of the different orders in the SI model



Can SI model reproduces the Skyrme SLy230a EoS ?



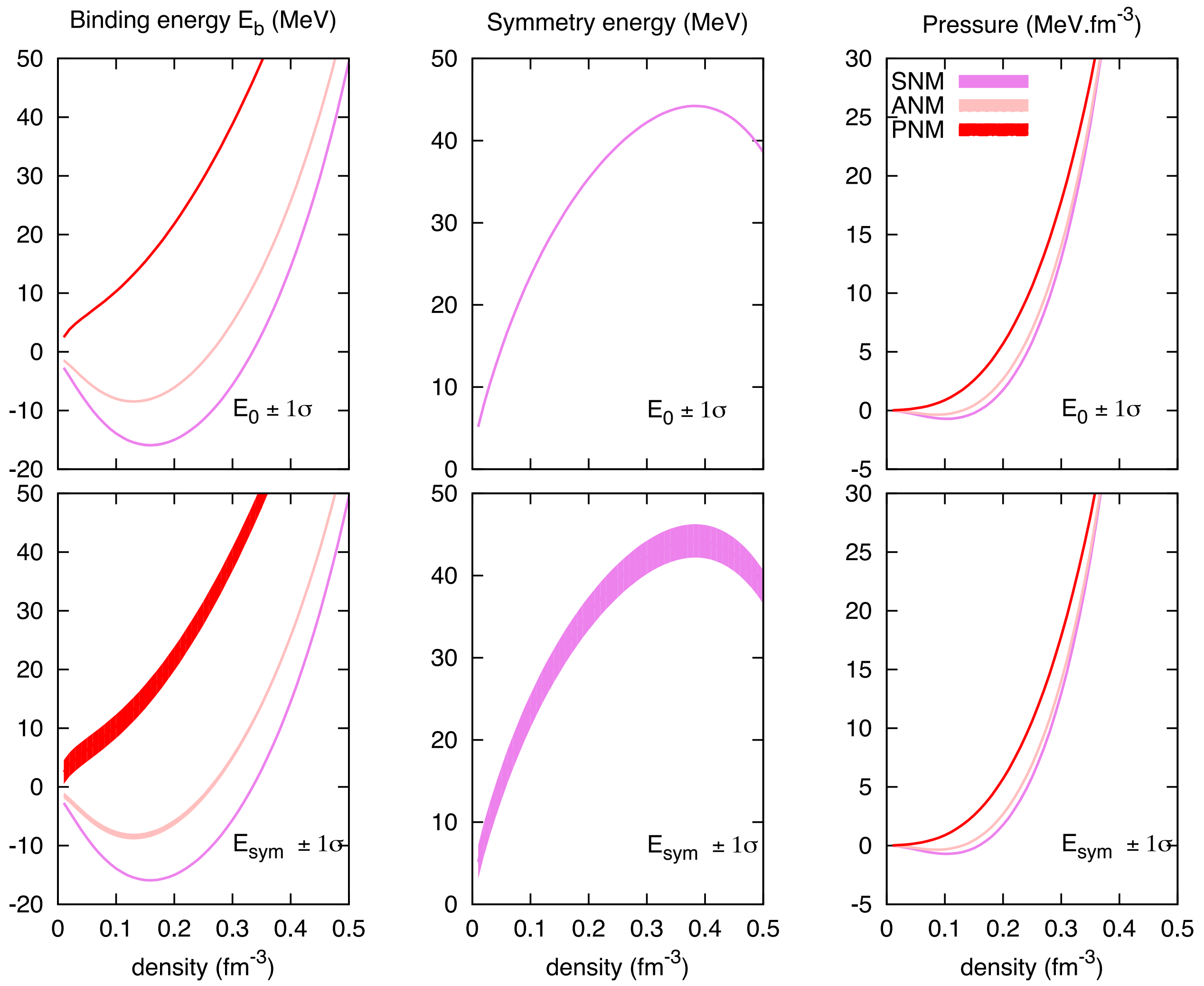
Can SI model reproduces D1S (Gogny) & CD-M3Y6 ?



Impact of E_0 and E_{sym}

$$E_0 = E/A(\rho = \rho_0, \delta = 0)$$

$$E_{sym} = \frac{1}{2}\frac{\partial^2 E/A}{\partial \delta^2}|_{\rho=\rho_0,\delta=0}$$



-15.91

$\pm$ 0.21

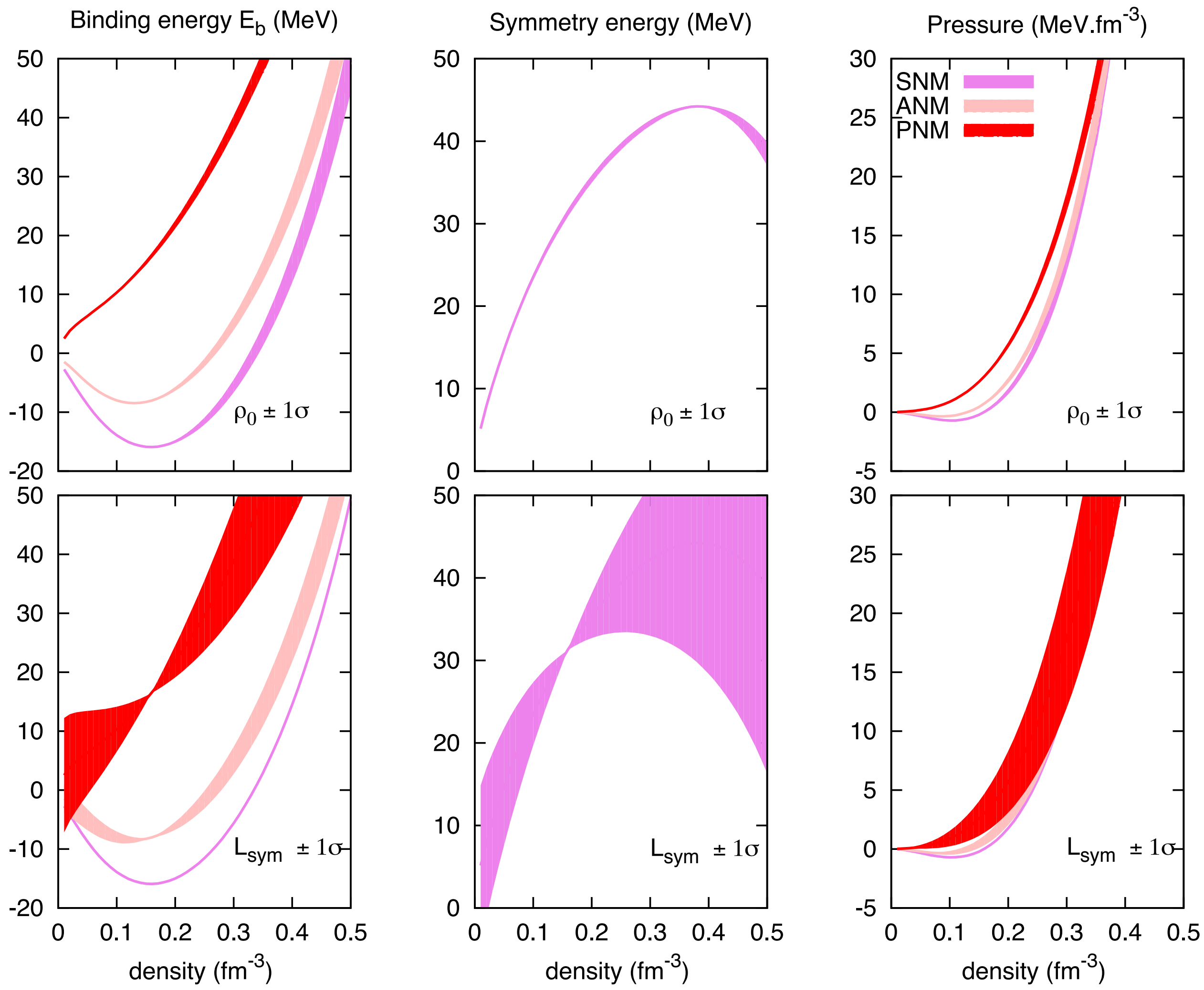
31.22

$\pm$ 2.03

$$P(\rho_0, \delta = 0) = 0$$

Impact of ρ_0 & L_{sym} (1^{st} derivatives)

$$L_{sym} \# \frac{\partial E_{sym}}{\partial \partial \rho}|_{\rho=\rho_0}$$



0.1586

± 0.0040

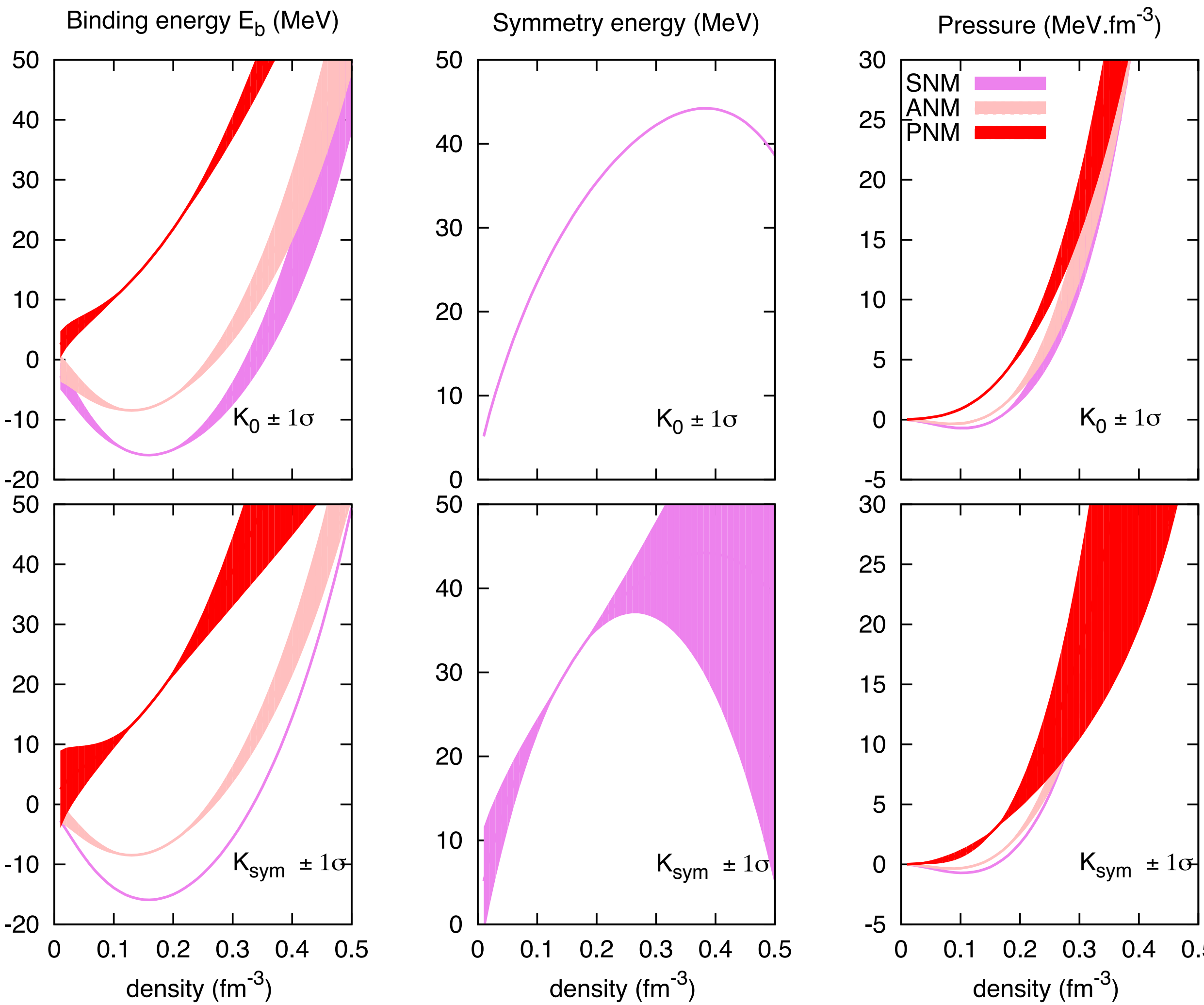
53.52

± 31.06

Impact of K_0 & K_{sym} (2^{nd} derivatives)

$$K_0 \# \frac{\partial^2 E_0}{\partial \rho^2}|_{\rho_0}$$

$$K_{sym} \# \frac{\partial^2 E_{sym}}{\partial \rho^2}|_{\rho_0}$$



251.68

± 45.42

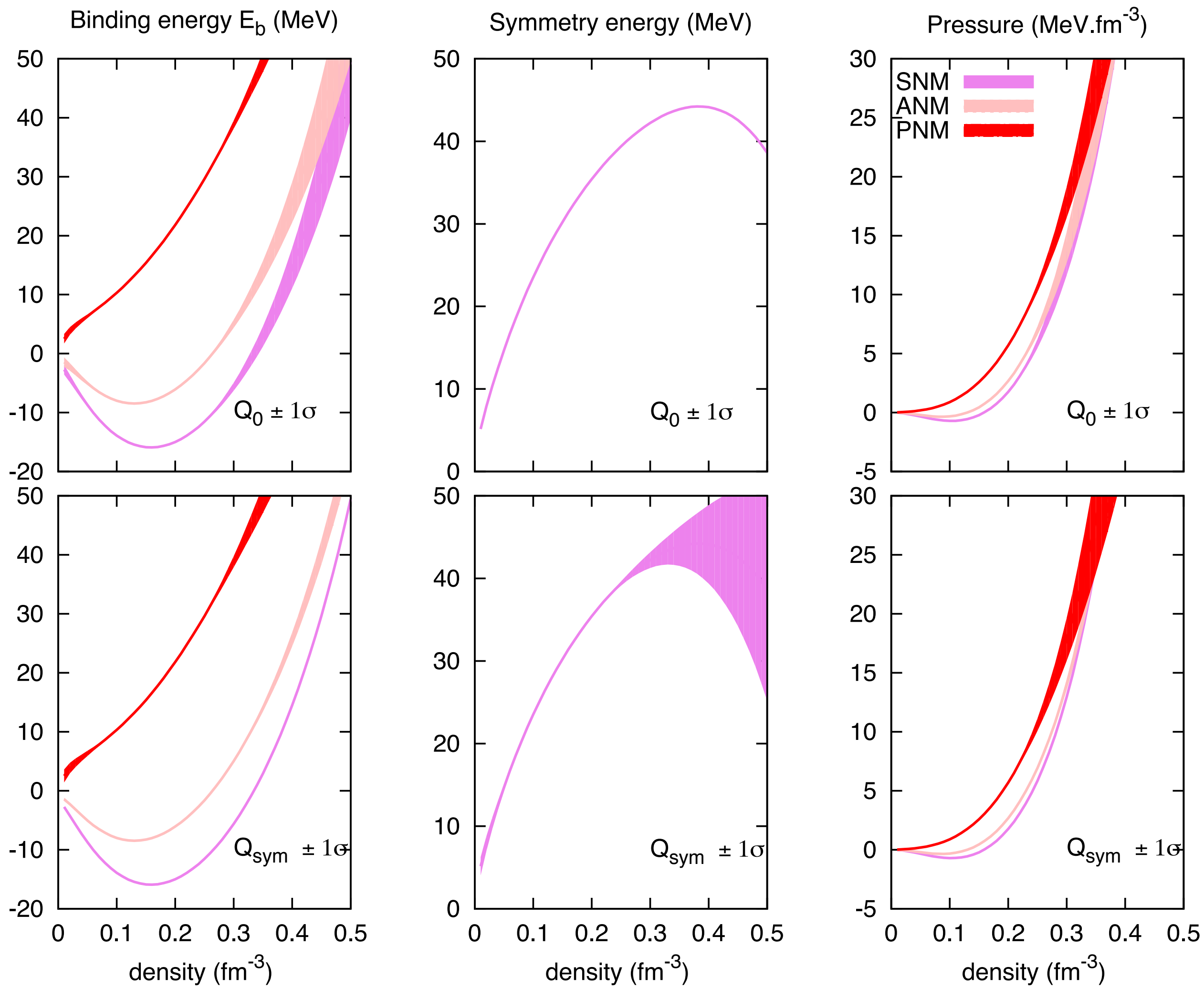
-130.15

± 132.03

Impact of Q_0 and Q_{sym} (3^{rd} derivatives)

$$Q_0 \# \frac{\partial^3 E_0}{\partial \rho^3}|_{\rho_0}$$

$$Q_{sym} \# \frac{\partial^3 E_{sym}}{\partial \rho^3}|_{\rho_0}$$



-300.20

± 157.81

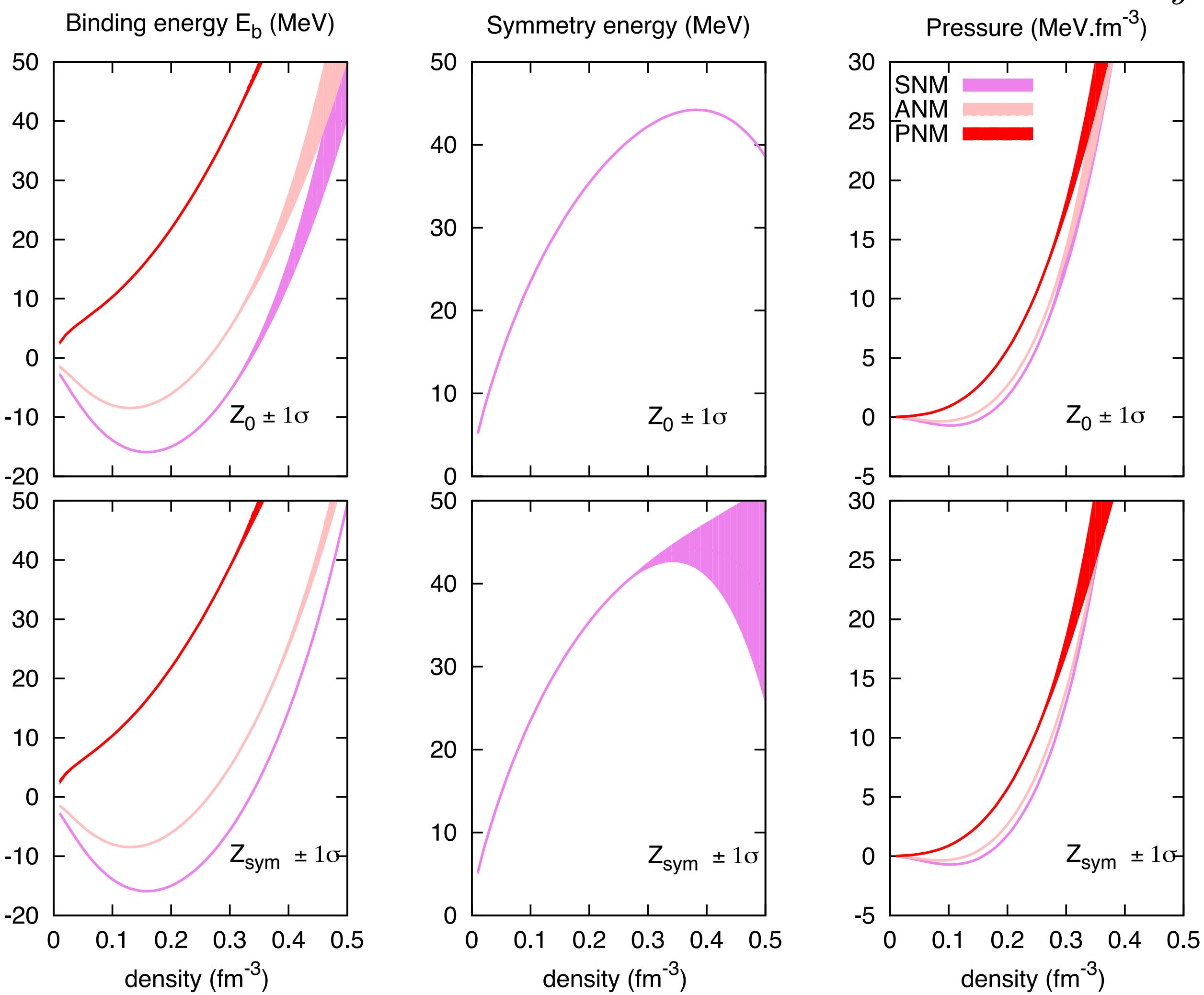
316.68

± 218.23

Impact of Z_0 and Z_{sym} (4^{th} derivatives)

$$Z_0 \# \frac{\partial^4 E_0}{\partial \rho^4}|_{\rho_0}$$

$$Z_{sym} \# \frac{\partial^4 E_{sym}}{\partial \rho^4}|_{\rho_0}$$



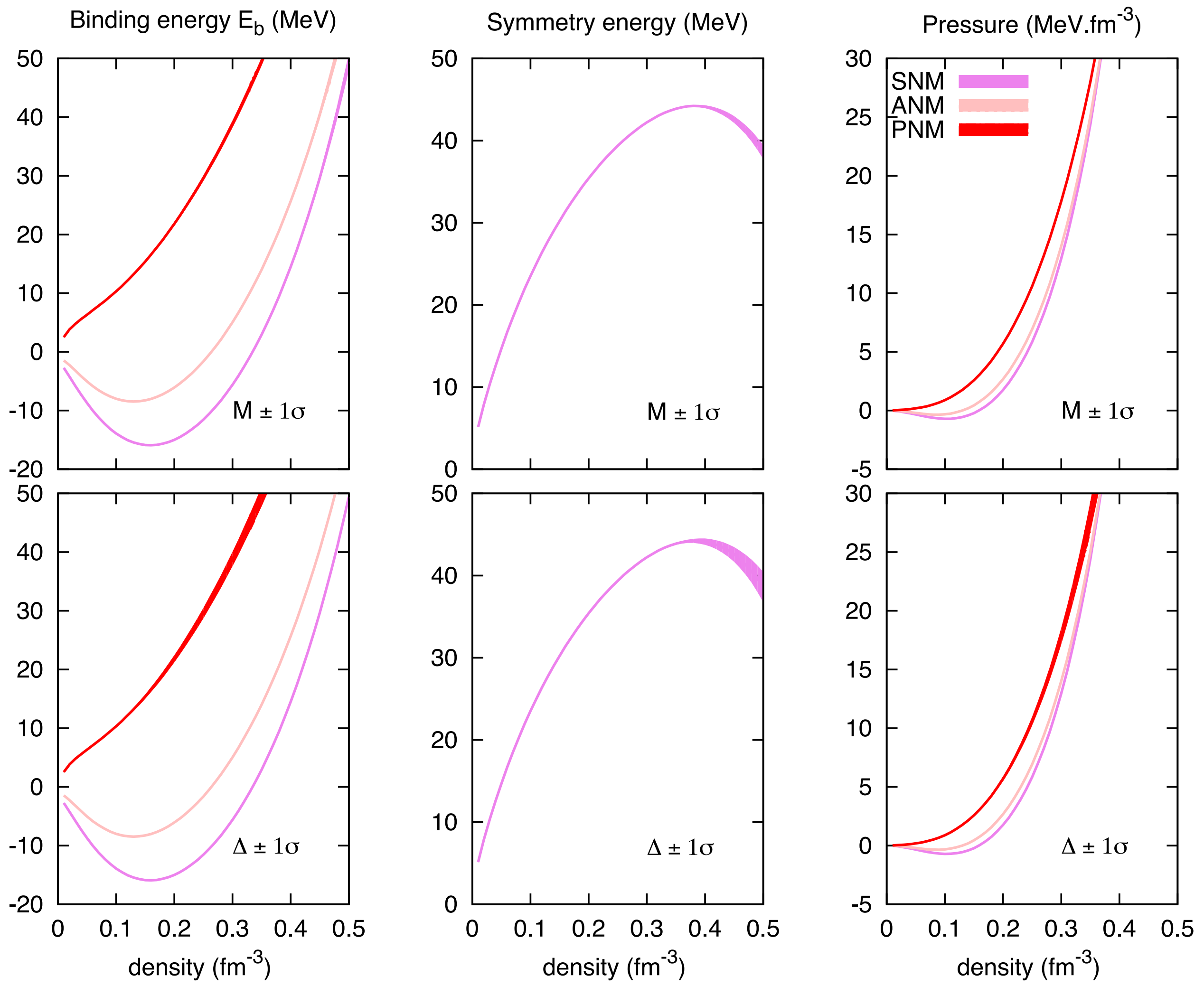
1178.35

± 848.47

-1890.99

± 1191.23

Impact of the in-medium effective mass



0.75

± 0.15

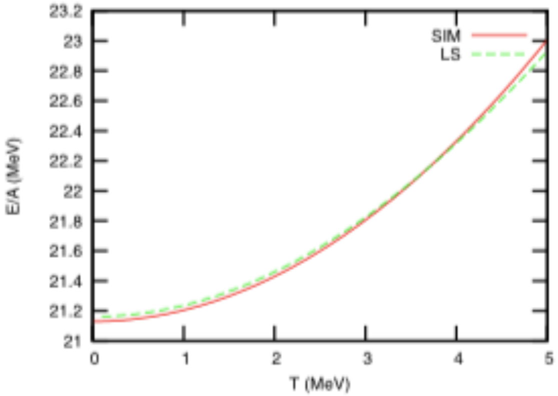
0.12

± 0.30

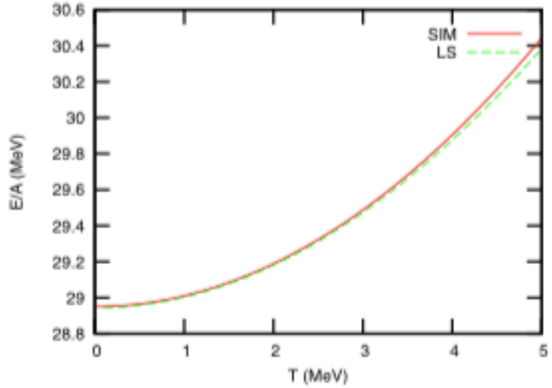
Fit of Lattimer-Swesty LS220 EoS

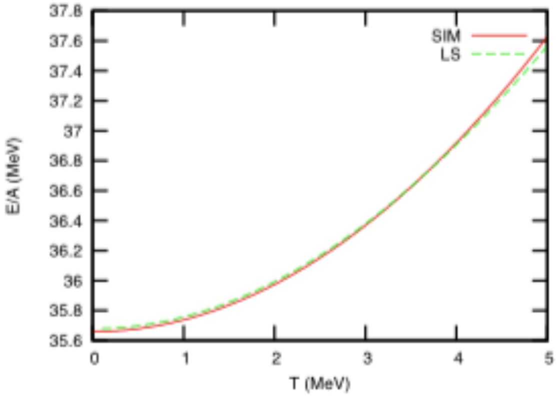
ρ=0.14 fm^{-3}

ρ=0.2 fm^{-3}

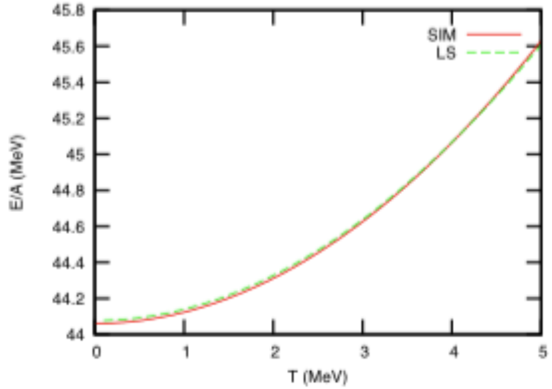


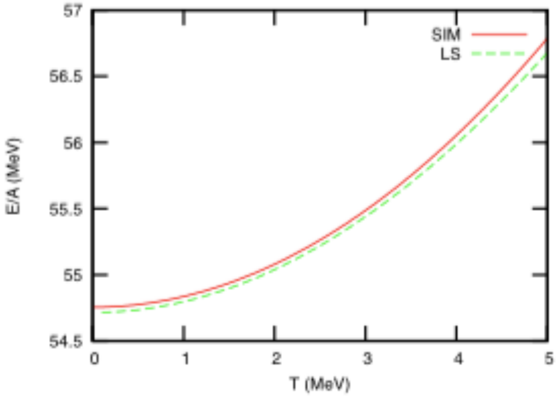
y_e=0.0



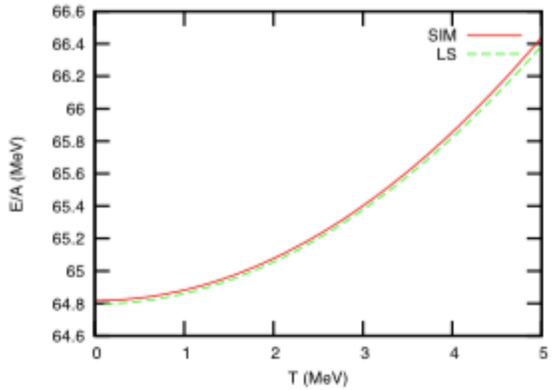


y_e=0.25





y_e=0.5

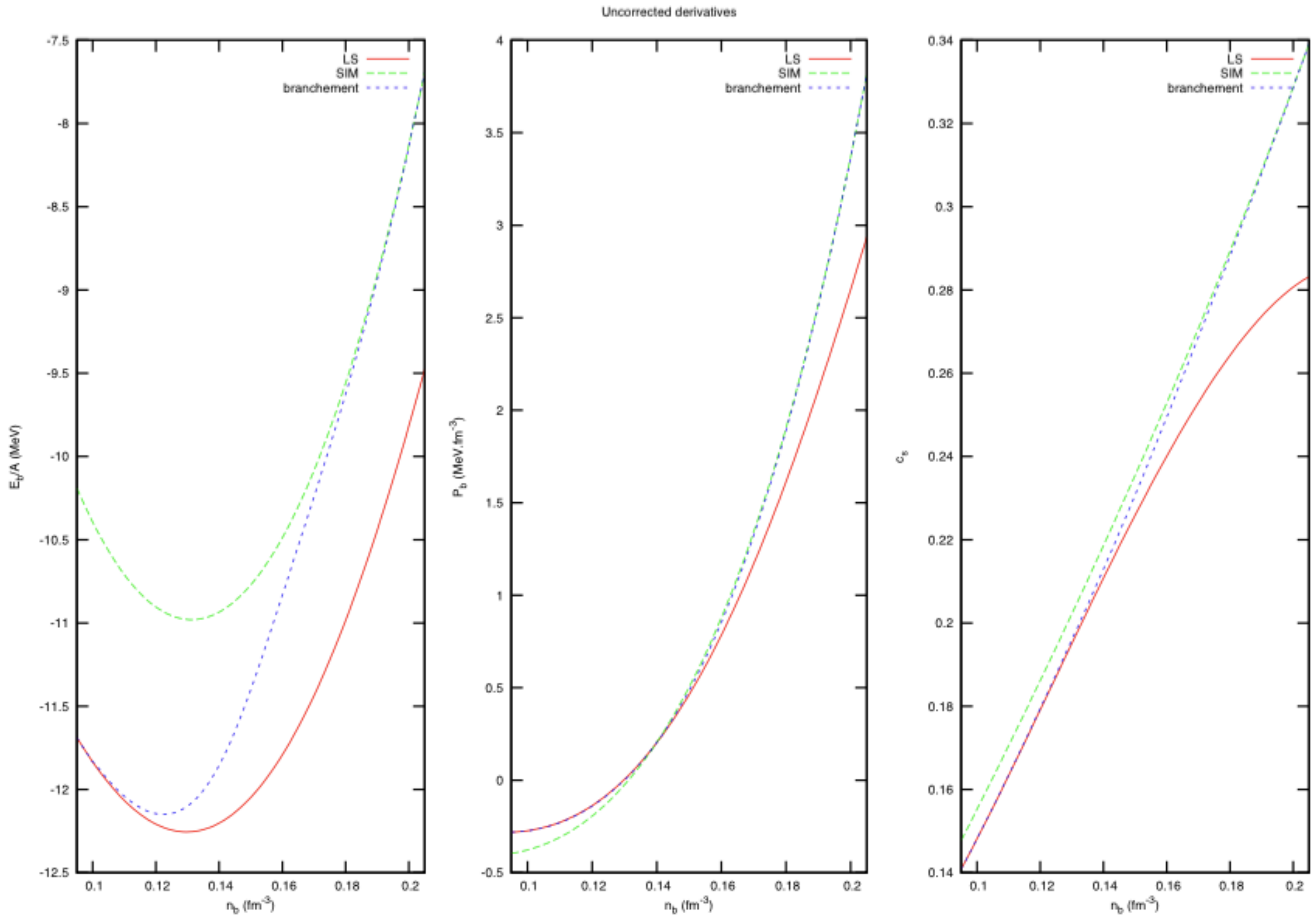


Interpolating from LS 220 towards the SIM EoS

$$\frac{E}{A}|_{interp} = f(\rho)\frac{E}{A}|_{LS220} + [1 - f(\rho)]\frac{E}{A}|_{SIM}$$

$$P|_{interp} = f(\rho)P|_{LS220} + [1 - f(\rho)]P|_{SIM}$$

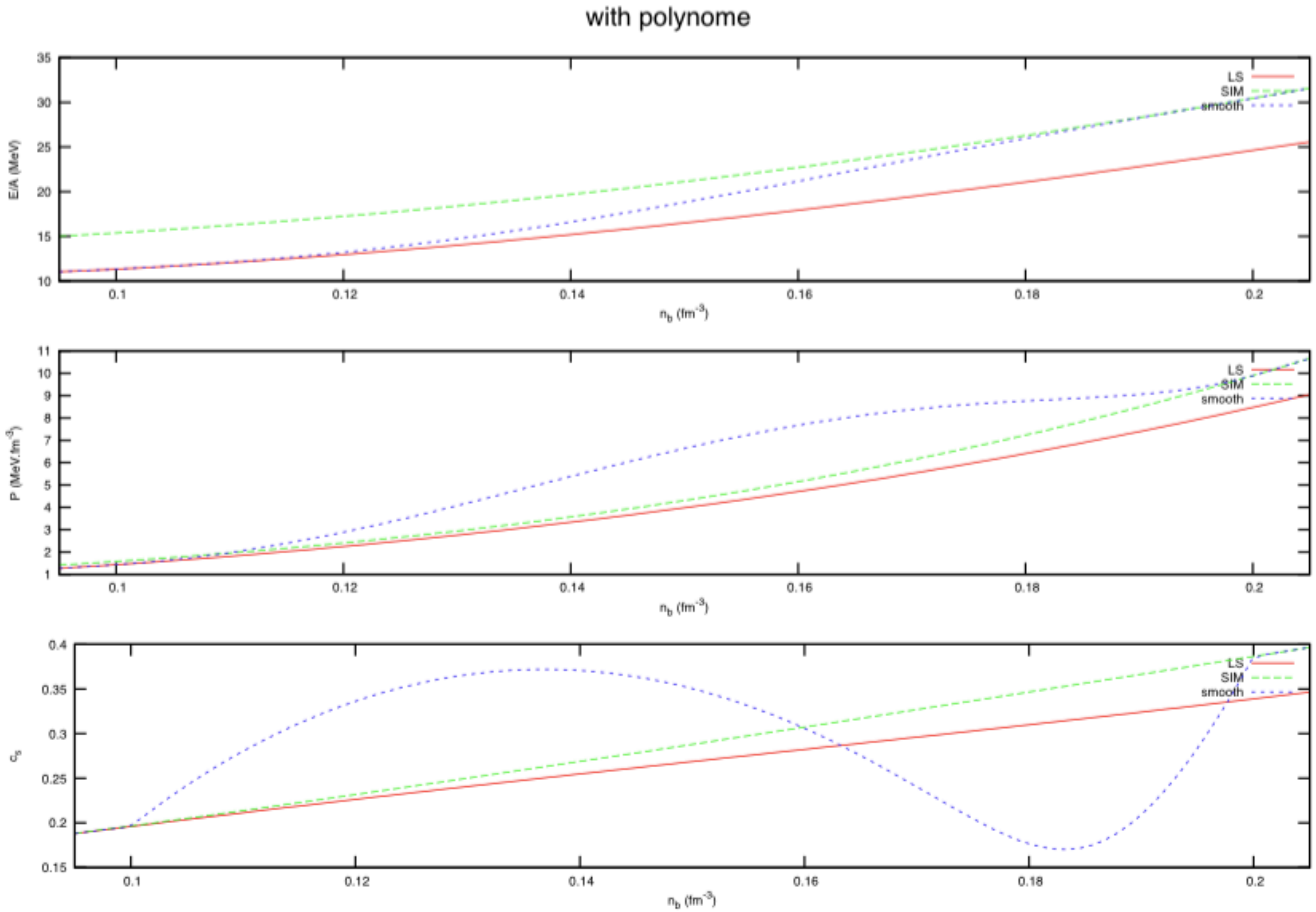
Derivatives of P consistently derived.



Where the devil is hidden

$$\frac{E}{A}|_{interp} = f(\rho)\frac{E}{A}|_{LS220} + [1 - f(\rho)]\frac{E}{A}|_{SIM}$$

P and other derivatives consistently derived.



Conclusions and outlooks

- With a flexible paramerization of the EoS: the impact of the "*experimental*" uncertainty on our knowledge of the dense matter EoS can be accurately estimated. **L_{sym} and K_{sym} are very important parameters to further constrain.**
- Matching between LS and new EoS is not easy. It could be done at the price of breaking the consistency between E/A and P.
- First modelling where the effect of the EoS properties (embedded in the empirical coefficients) could be directly checked on the core-collapse SN evolution.
- Outlooks:
  - reduce the degrees of freedom and the number of free parameters (work of R. Casali), by injecting correlations among empirical parameters
  - Calculate EoS of matter with nuclei within the same empirical modelling (work of F. Aymard & A. Raduta).