The nuclear matter free symmetry energy at $0.03 \leq \rho/\rho_0 \leq 0$

L. Qin, K. Hagel, R. Wada, J. B. Natowitz, S. Shlomo, A. Bonasera, G. Roepke,[1] Z. Chen,[2] M. Huang,[2] J. Wang,[2] H. Zheng, S. Kowalski,[3] M. Barbui, M. Rodrigues, K. Schmidt, D. Fabris,[4] M. Lunardon,[4] S. Moretto,[4] G. Nebbia,[4] S. Pesente,[4] V. Rizzi,[4] G. Viesti,[4] M. Cinausero,[4] G. Prete,[5] T. Keutgen,[6] Y. El Masri,[6] and Z. Majka[7]

[1]*University of Rostock, FB Physik, Rostock, Germany*

[2]*Institute of Modern Physics HIRFL, Chinese Academy of Sciences, Lanzhou, 730000, China*

[3]*Institute of Physics, Silesia University, Katowice, Poland*

[4]*Dipartamento di Fisica dell'Universita di Padova and INFN Sezione di Padova, Italy*

[5]*INFN Laboratori Nazionali di Legnaro, Italy*

[6]*Universit´e Catholique de Louvain, Louvain-la-Neuve, Belgium,*

[7]*Smoluchowski Institute of Physics, Jagiellonian University, Krakow, Poland*

We previously pointed out [1, 2] that measurements of nucleon and light cluster emission from the participant matter which is produced in near Fermi Energy heavy ion collisions could be employed to probe the EOS at low density and moderate temperatures where clustering is important. Our data demonstrated a large degree of alpha clustering in matter with average proton fraction, Yp ~0.44, densities at and below ~0.05 times normal nuclear density and temperatures of 4 to 10 MeV. Using these data we derived experimental free symmetry energies in low density nuclear matter [1,2] The analysis employed the isoscaling technique which compares yields for two systems with similar temperatures but different N/Z ratios to determine the differences in chemical potentials and symmetry energy.

The NIMROD multi-detector at Texas A&M University has now been used to extend our measurements of free symmetry energy to higher densities. Clusters production in collisions of 47A MeV ^{40}Ar with ^{112,124}Sn and ^{64}Zn with ^{112,124}Sn was studied.. Thermal Coalescence model analyses have been

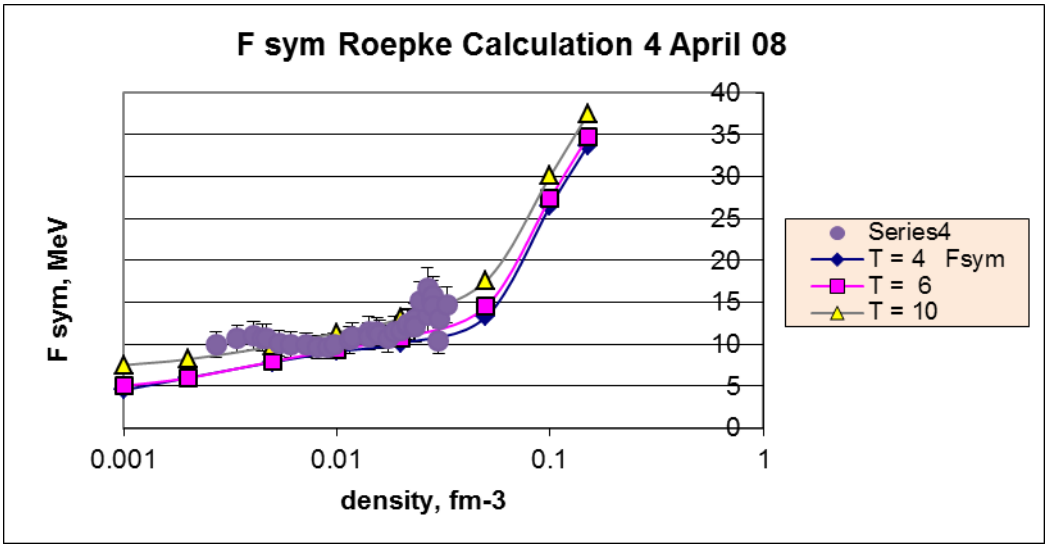

FIG. 1. Free symmetry energy vs nuclear density. Lines show values calculated for T=4, 6 and 10 MeV. Grey circles indicate experimental data.

employed to derive densities and temperatures. The preliminary results of the measurements are presented in Fig. 1, where they are compared with predictions made using a model developed by G. Roepke and collaborators [3].This model explicitly treats medium modifications of the cluster binding energies. A paper on this work is in preparation.

[1] S. Kowalski *et al.*, Phys.Rev. C **75**, 014601 (2007).
[2] J.B. Natowitz *et al.*, Phys. Rev. Lett. **104**, 202501 (2010).
[3] G. Roepke *et al.*, Private Communication.