Experimental liquid-gas phase transition signals and reaction dynamics

R. Wada, W. Lin, H. Zheng, X. Liu, M. Huang, K. Hagel, and J.B. Natowitz

The experimental liquid-gas phase transition signals are examined for quasi-projectiles (QP) reconstructed from the reactions of $^{40}Ar+^{27}Al$, ^{48}Ti, ^{58}Ni at 47 MeV/nucleon, using different measures for the nuclear liquid-gas phase transition. The experimental data were taken, using NIMROD and details can be found in Ref.[1,2]. The data are revisited, using a new thermometer described below.

A quasi-projectile (QP) is reconstructed for a given reaction using a moving source (MS) fit with three sources, a QP, intermediate-velocity (IV) and target-like sources in a similar way as described in Refs.[1,2]. In this analysis, the three fixed source velocities of the IV source are used to study different contributions of the mid-rapidity particles to the QP source. For these different three sources, the light charged particle energy spectra are reasonably well fitted. Using these extracted MS parameters, the excitation energy of the QP source is evaluated in a similar fashion described in Ref.[1,2]. All events of different centrality classes are analyzed.

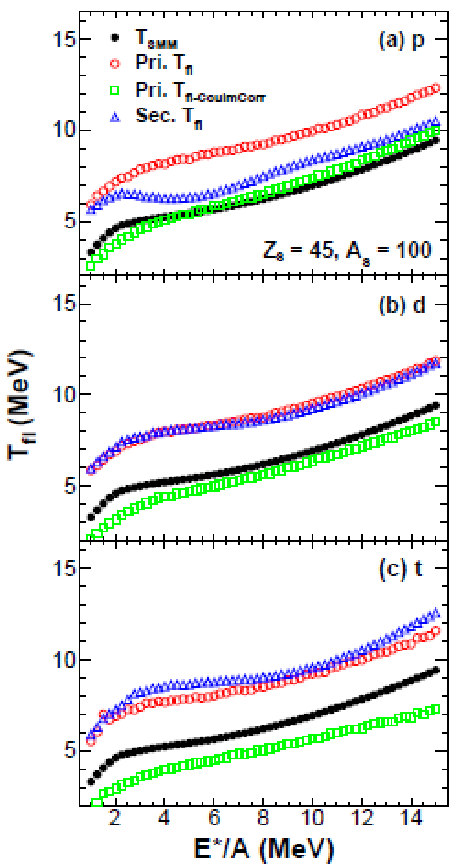

FIG. 1. Quadrupole momentum fluctuation temperatures (T_{fl}) of SMM with A = 100 and Z = 45 for (a) protons, (b) deuterons and (c) tritons. T_{SMM} is the average temperature calculated from the SMM input value. Open circles represent the extracted T_{fl} values from the primary particles and triangles are for those after the secondary decays. Squares represent the Coulomb corrected T_{fl} values of the primary particles.

A new thermometer is proposed from a SMM event study. In Fig.1, the input value of the SMM temperature, T_{SMM}, is compared with the calculated quadrupole fluctuation temperature, T_{fl}, for protons, deuterons and tritons, with and without an fterburner. Only Z=1 particles are examined because of their minimum Coulomb effect. From this study, we concluded that the deuteron fluctuation temperature gives the most reliable temperature both in primary and secondary stages. Therefore in the following, the deuteron thermometer is used.

The quadrupole thermometer uses the average fluctuation values of the quadrupole moment in a given event set and therefore cannot be used on an event by event basis in principle. In Fig.2(a) and (b), the extracted T_{fl} values and their standard deviation (SD) are plotted as a function of the excitation

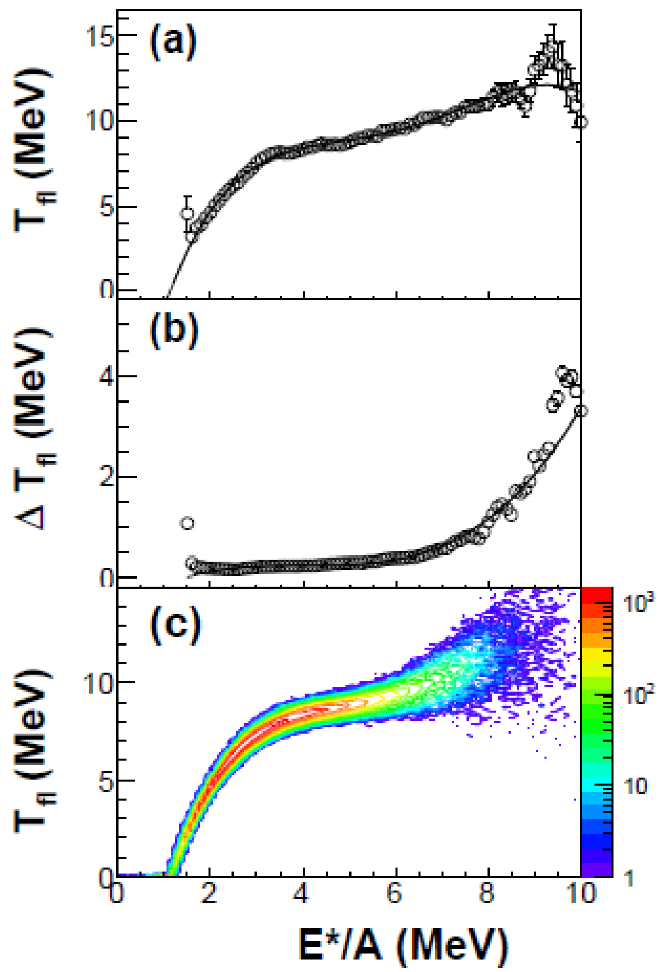

FIG. 2. Experimental deuteron quadrupole momentum fluctuation temperature, T_{fl} in (a) and the standard deviation values ΔT_{fl} in (b), as a function of E*/A for inclusive data of ^{4}0Ar + ^{48}Ti at 47 MeV/nucleon with the QP selection of $V^{NN}{}_{s}$ = 4:0 cm/ns. Curves in (a) and (b) are from a polynomial fit. (c) Calculated T_{fl} vs E*/A distribution using the fit parameters in (a) and (b) on the event-by-event basis. Z axis is the yield given by a logarithmic scale.

energy, E*/A, for a given event set. As one can see, the SD values are rather small for E*/A<8 MeV. These values are fit by polynomial functions as shown by the solid curves in the figure. Using these polynomial parameters, a T_{fl} value is generated randomly using a Gaussian distribution for each extracted E*/A in event-by-event basis and used as the temperature for QP. A result is shown in (c). As one can see in Fig.2(c), the extracted caloric curve shows a plateau at E*/A ~ 4 MeV with T_{fl}~9 MeV, which is a strong indication of the first phase transition at this temperature. After a Coulomb correction (~ 0.7 MeV), we extracted the phase transition temperature of 8.3 +/- 0.4 MeV. This same feature is observed for ^{27}Al and ^{58}Ni target runs and different source velocity event sets in each reaction system.

In this work, other measured values are examined and all show a peak or pleateu at similar temperature values. Therefore we conclude that in a system size of A~ 40, a liquid-gas phase transition indeed occurs at the temperature of ~8.3 MeV. The results has been published in Ref.[3].

[1] Y.G. Ma, J.B. Natowitz, R. Wada, K. Hagel, J. Wang, T. Keutgen, Z. Majka, M. Murray, L. Qin, P. Smith *et al.*, Phys. Rev. C **71**, 054606 (2005).

[2] Y.G. Ma, R. Wada, K. Hagel, J. Wang, T. Keutgen, Z. Majka, M. Murray, L. Qin, P. Smith, J.B. Natowitz *et al.*, Phys. Rev. C **69**, 031604(R), (2004).

[3] R. Wada, W. Lin, P. Ren, H. Zheng, X.Liu, M. Huang, K. Yang, and K. Hagel, Phys. Rev. C **99**, 024616 (2019).