Progress in the fragment yields analysis in ^{124}Sn+^{112,124}Sn at 26*A* MeV reaction

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As described in reference [1], we are currently using a nucleation time moderated statistical equilibrium model, previously used to reproduce ternary fission isotopic yields, to characterize the neck emission in Sn+Sn collisions at 26*A* MeV obtained with the NIMDOR detector array [2]. The model description and experimental procedure and selection are detailed in reference [1]. In summary, the model uses the chemical potential and a time limitation to generate cluster formation yields inside a low density nuclear gas. The free parameters are the temperature, the density, the proton fraction, the time limit and the critical cluster size. To select fragments from the mid-rapidity region, we use the relative angle in the center of mass between the largest fragment and the fragment of interest velocity vectors. This angle must be inside the 50°-130° window in order to reject most of the QP contribution while keeping enough statistics. Fig. 1 shows the corrected yield as a function of N/Z for each detected isotope for this relative angle selection.

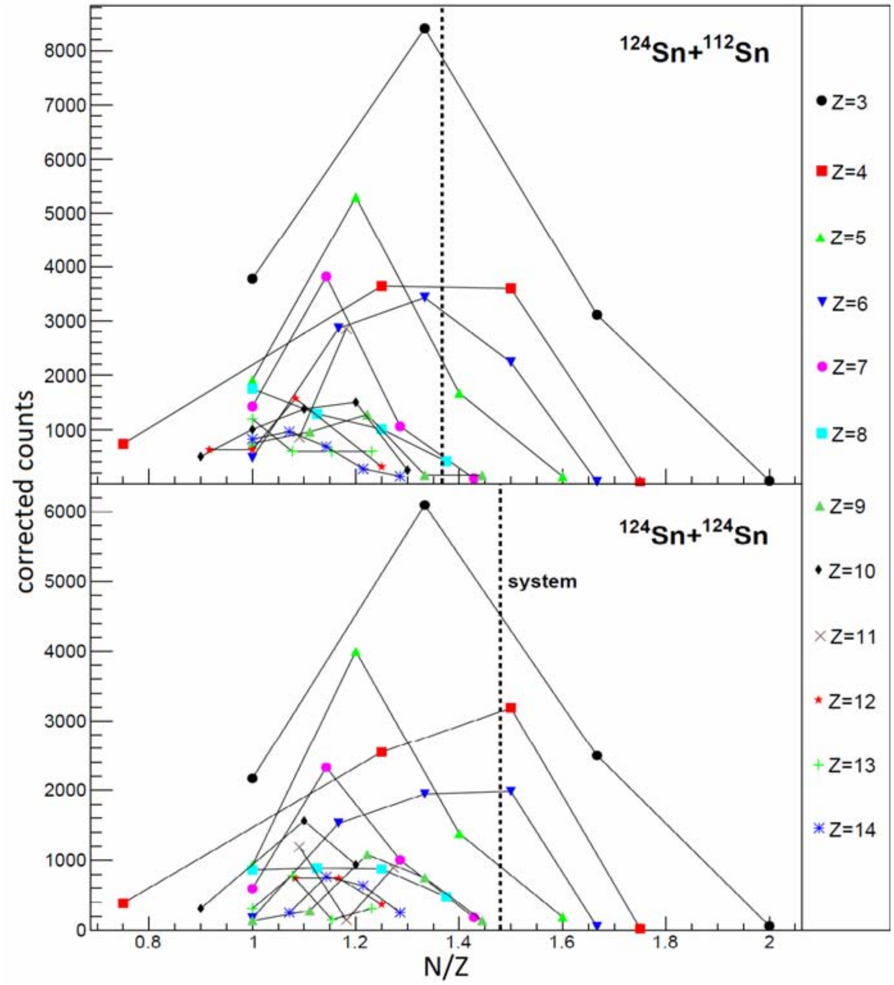

FIG. 1. Corrected yield as a function of N/Z for each isotope and both reactions inside the relative angle selection window.

During the last few months, we improved our minimization technique and extended the fit to isotopes up to Z=14 with a reasonable fit metric. As a reminder, the fit metric is a measure of the average discrepancy and is defined as

$$M^2 = \sum_j \frac{\{ln[Y_{TF}^{exp}(Z_j,A_j) - Y_{TF}(Z_j,A_j)]\}^2}{n} \quad (1)$$

In Fig. 2 we show the results of the best fit we achieved so far and the list of parameter values derived from it is presented in Table I. As we expected, the temperature and density are higher than the

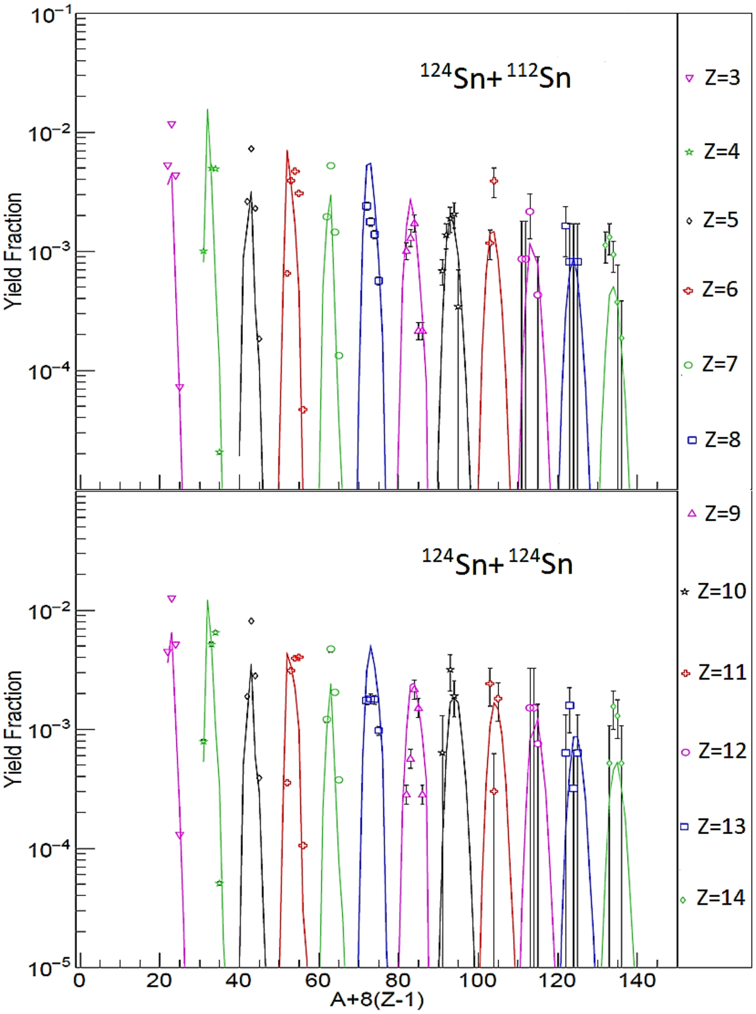

FIG. 2. Normalized fit results for both Sn systems. Lines represent the calculation and symbols are the experimental data.

Table 1. Fit parameter values.

System	^{124}Sn+^{112}Sn	^{124}Sn+^{124}Sn	^{241}Pu
Temperature (MeV)	2.76	2.72	1.4
Density (10^{-4} fm^{-3})	18.67	16.38	4
Time (fm/c)	6000	7300	6400
Critical Cluster Size	15.8	16.1	5.4
Proton Ratio (system)	0.47 (0.42)	0.44 (0.40)	0.34 (0.39

Pu fission ones. To have a comparison point, we calculated the Albergo experimental temperature [3] defined by

$$T_{source} = \frac{14.3}{ln\left[1.6\frac{Y(^2H)Y(^4He)}{Y(^3H)Y(^3He)}\right]}, \qquad (2)$$

where T is the emission source temperature and Y are the isotope yields. By applying the same relative angle selection to those isotopes, we get 2.74 MeV for ^{112}Sn and 2.88 MeV for ^{124}Sn, which is in very good agreement with the calculation. The time parameters are very similar to the Pu fission and with our 2.7 MeV temperature these times are also in very good agreement with recent fusion-fission time calculations [4]. Another interesting way to test the results and compare with the Pu fission is the equilibrium constant. We know that

$$K = \frac{Y_{product}}{Y_{reactive1}Y_{reactive2}}V = Se^{\frac{\Delta G^o}{T}} \qquad (3)$$

where K is the equilibrium constant, Y is the isotope yield, V is the source volume, S is the reaction spin factor, ΔG^o is the Gibbs free energy and T is the source temperature. By considering a small contribution of the volume difference we write that, for each fragment detected,

$$\frac{K_{Sn}}{K_{Pu}} = \frac{e^{\frac{\Delta G^o_{Sn}}{T_{Sn}}}}{e^{\frac{\Delta G^o_{Pu}}{T_{Pu}}}}. \qquad (4)$$

We assume that the fission of Pu leads to fragments in their ground states so we know ΔG^o_{Pu}. We also know the temperatures from the calculation and the experimental yields, so we can extract ΔG^o_{Sn} from equation (4). Since the temperature of the mid-rapidity region in the Sn collisions is higher, excited states must be available to be populated. In Fig. 3, we show $\Delta G^{o}_{Sn} > \Delta G^{o}_{Pu}$ for 22 reactions. ΔG^{o}_{Sn} is in average 33% higher than ΔG^{o}_{Pu}. A paper draft about those results is being written.

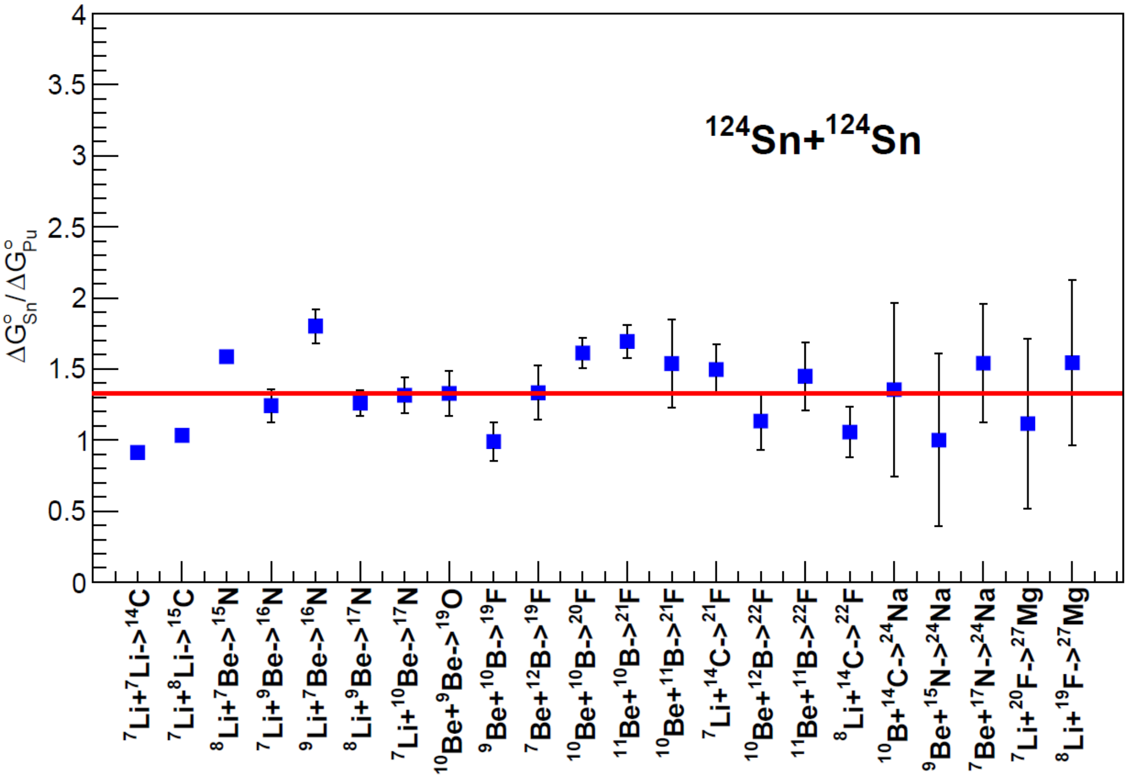

FIG. 3. ^{124}Sn+^{124}Sn over ^{241}Pu Gibbs free energy ratio for 22 nuclear reactions. The mean value is 1.33.

[1] J. Gauthier *et al.*, *Progress in Research*, Cyclotron Institute, Texas A&M University (2016-2017), p. II-3.

[2] S. Wuenschel *et al.*, Nucl. Instrum. Methods Phys. Res. **A604**, 578 (2009).

[3] S. Albergo *et al.*, Il Nuovo Cimento, **89 A**, N. 1 (1985).