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# Light particles emitted in coincidence with Evaporation Residues in $^{79}Br(930MeV)+^{27}Al$ collisions.

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Exclusive measurements of light particles, protons, deuterons, tritons and alphas, in coincidence with Evaporation Residues (ER), were performed at the Holifield Heavy Ion Research Facility of the Oak Ridge National Laboratory using the large detector array HILI (Heavy Ion Light Ion)[1]. Heavy fragments produced in the reaction (Z ¿ 35), were stopped in the Ionisation Chamber, where their energy, atomic number (Z) and position were measured. Coincident light particles, were detected in the 192 element hodoscope placed behind the chamber, where its charge (Z) and energy were measured. Also the time of flight relative to the radio frequency of the cyclotron, allowed identification of protons deuterons and tritons.

It has been found that there are contributions to the yield of heavy residues (Z ¿ 35) from processes other than fusion - evaporation, specially for the lower Z values. Since the fusion - evaporation residues (ER) should be associated with the larger multiplicities. It is found, experimentally, that requiring as little as two light particles in coincidence with any given heavy residue reduces dramatically the contribution from other processes (quasi - elastic, and deep inelastic) to that yield. In contrast, the shape of the energy spectra of the light particles in coincidence with those ER does not show such a strong dependence on multiplicity.

Statistical model calculations for the decay of the compound nucleus were performed using the Monte Carlo code LILITA[2]. Substantial modifications were made to the original code in order to introduce explicit optical - model transmission coefficients using parameters from reference [3]. Each calculated event was "filtered" through the experimental geometrical constrains imposed to the data by the HILI so direct comparisons between the calculations and the data are possible. Figures 1 and 2 show the result of such calculations in comparison with the data. In figure 1, energy spectra for heavy residues (multiplicity = 2) and in figure 2, energy spectra of p, d, t and α in coincidence with heavy fragments (Z ¿ 35), also multiplicity = 2. In each frame the calculation is normalized to the data by an ad hoc factor also given in the figures.

One of the features of figure 1, is that as Z of the fragment decreases, the width of the experimental spectrum increases, in disagreement with the calculation. This fact alone indicates that contributions from processes other that just complete fusion are present. Deviations between data and calculations for the predicted yields as function of Z of the ER, may also be due to these contributions and resulted in normalization factors ranging from 1 to 4. Contributions from the incomplete fusion mechanism can not account for these deviations. Current systematics of incomplete fusion[4, 5], predict contribution of only about 10 this energy, the light partner loosing the particles.

In figure 2 the yields are reproduced more consistently resulting in normalization factors of 2 2 1 and 3 for p, d, t and α respectively. As for the shape of the spectra, it can be seen that for p, d and t, there is a slight disagreement in the low - energy part that may support the idea that the emission barriers are lower than predicted by normal optical model due to deformation effects on the compound nucleus (as claimed in reference [6] and references therein). For $\alpha$'s, this discrepancy is much more important and would require very large deformations to explain it (about 1.5 times that of the normal shape). It is worthwhile noting that this is the opposite trend reported in [6], where the larger discrepancies were found in protons and the smaller in $\alpha$'s. The barriers deduced from the $\alpha$ channel are as low as that of Al. One appealing explanation that would require further analysis is that of pre - equilibrium - shape emission from a dinuclear configuration, that would keep memory of the entrance channel for a long time and yet ultimately evolving to form a fused system.

The high - energy slopes of the data are smaller than those gotten from the calculation. The level density parameter used is a = A/12 in agreement with other works[7, 8] larger values like A/8 produce substantially bigger slopes that strongly deviate from the data. One unique feature of the present data is that the light particles are detected in coincidence with a heavy partner, and for every event, the velocities of the ER and the coincident LP are well determined. We can then reconstruct the relative kinetic energy spectra ($E_{rel}$). The only assumption needed is the mass of the ER, which was done using the LILITA calculations. The most important feature of such spectra is that for every case, the centroid (¡e¿) and slope (T) can be extracted experimentally. Their values are shown on figures 3 and 4 respectively as a function of Z of the ER. In both figures, the open circles correspond to the experimental values and the solid rombs to the Monte Carlo LILITA calculations. The solid line drawn for the protons (bottom panel of figure 8) corresponds to the expected coulomb barrier using a reduced radius of 1.4 fm, which is slightly lower than systematics because the centrifugal barrier is neglected. It is clear that the emission barriers for p, d and t are well reproduced by the calculations, including the trendt as Z increases and provides little support to the idea of deformed barriers. It is evident that the discrepancy with the $\alpha$ channels is very important and the difference of nearly 4 MeV is too large to argue simple deformations.

The slope parameter (T) extracted from both data and simulations shown on figure 4 (same symbol convention as for figure 3). The solid line corresponds to the expected temperature for the compound nucleus (5.1 MeV) using the level density parameter $a = A/12$. The agreement here between data and calculations is better than in that found in compairing the centroids.

To summarize, our study of light particles in coincidence with evaporation residues allows no simplifying assumptions concerning the source velocities of these particles and hence characterization of the light particles spectra in terms of barriers and temperatures is made meaningful. We found some discrepancies between the expected barriers and those measured, specially in the $\alpha$ channel. Further measurements will be necessary to better understand this feature.

# REFERENCES

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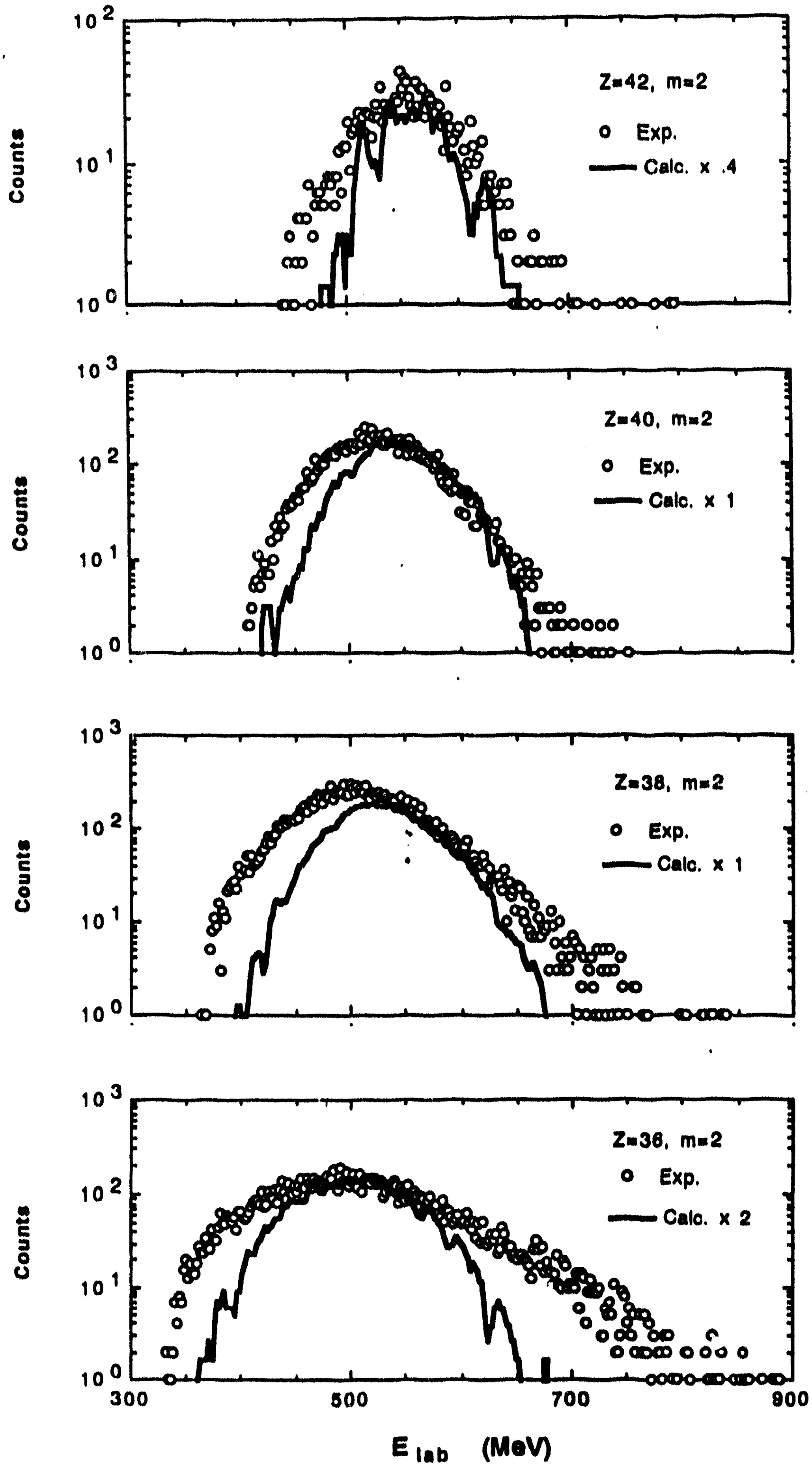
# FIGURES

FIG. 1. Energy spectra for Evaporation Residues, in coincidence with two light particles (m=2), for Z = 42, 40, 38 and 36 from top to bottom. Experimental, open circles, and result of Monte Carlo simulation using LILITA[2], solid line. Normalization factors for each Z are also shown.

FIG. 2. Energy spectra for Light Particles (LP) in coincidence with an Evaporation Residue (35 ¡ Z ¡ 44) and one more LP (m=2); $\alpha$s, tritons, duterons and protons from top to bottom. Experimental, open circles, and result of Monte Carlo simulation using LILITA[2], solid line. Normalization factors for each Z are also shown.

FIG. 3. Centroid of the $E_{rel}$ spectra for alphas, tritons, deuterons and protons (from top to bottom), in coincidence with one Evaporation Residue (ER) and one more LP (m=2) as a function of Z of the ER. Open cirles: Experimental data, full rombs: LILITA calculation.

FIG. 4. Temperature (slope parameter) for alphas, tritons, deuterons and protons (from top to bottom), in coincidence with one Evaporation Residue (ER) and one more LP (m=2) as a function of Z of the ER. Open cirles: Experimental data, full rombs: LILITA calculation.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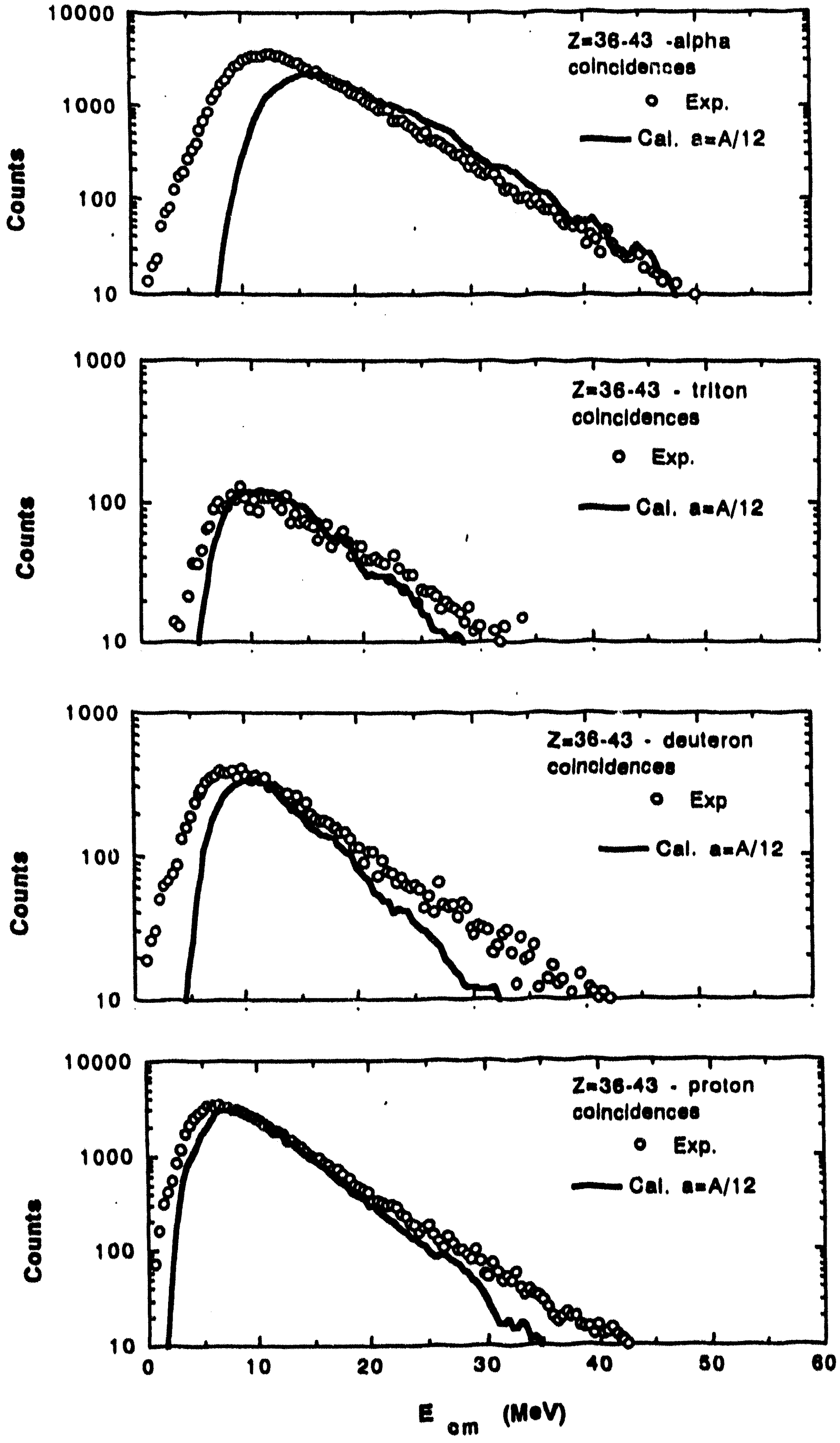
$E_{lab}$ (MeV)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Z=36-43 - triton coincidences
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o Exp
Cal. a=A/12
Z=36-43 - proton coincidences
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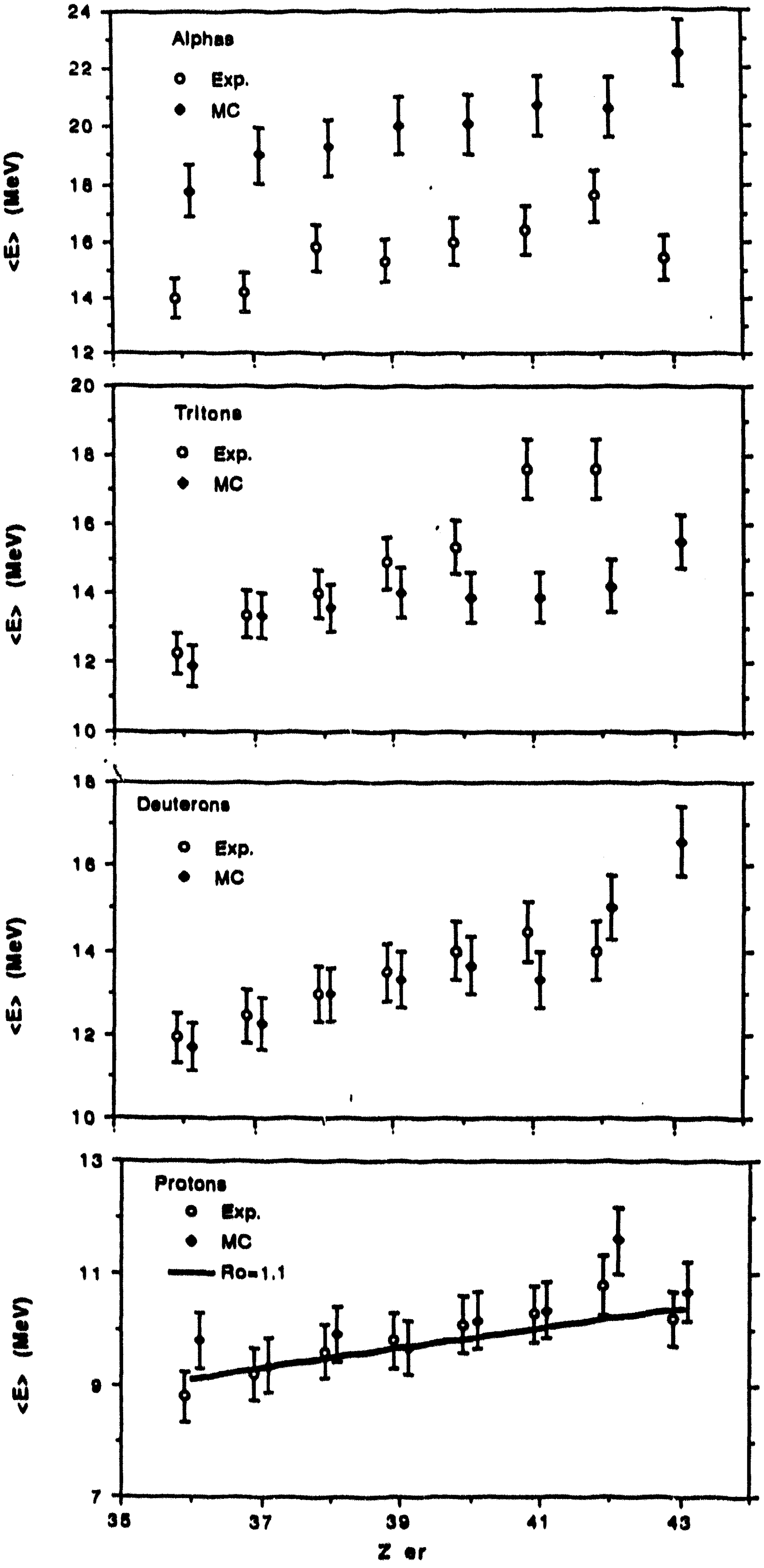
E cm (MeV)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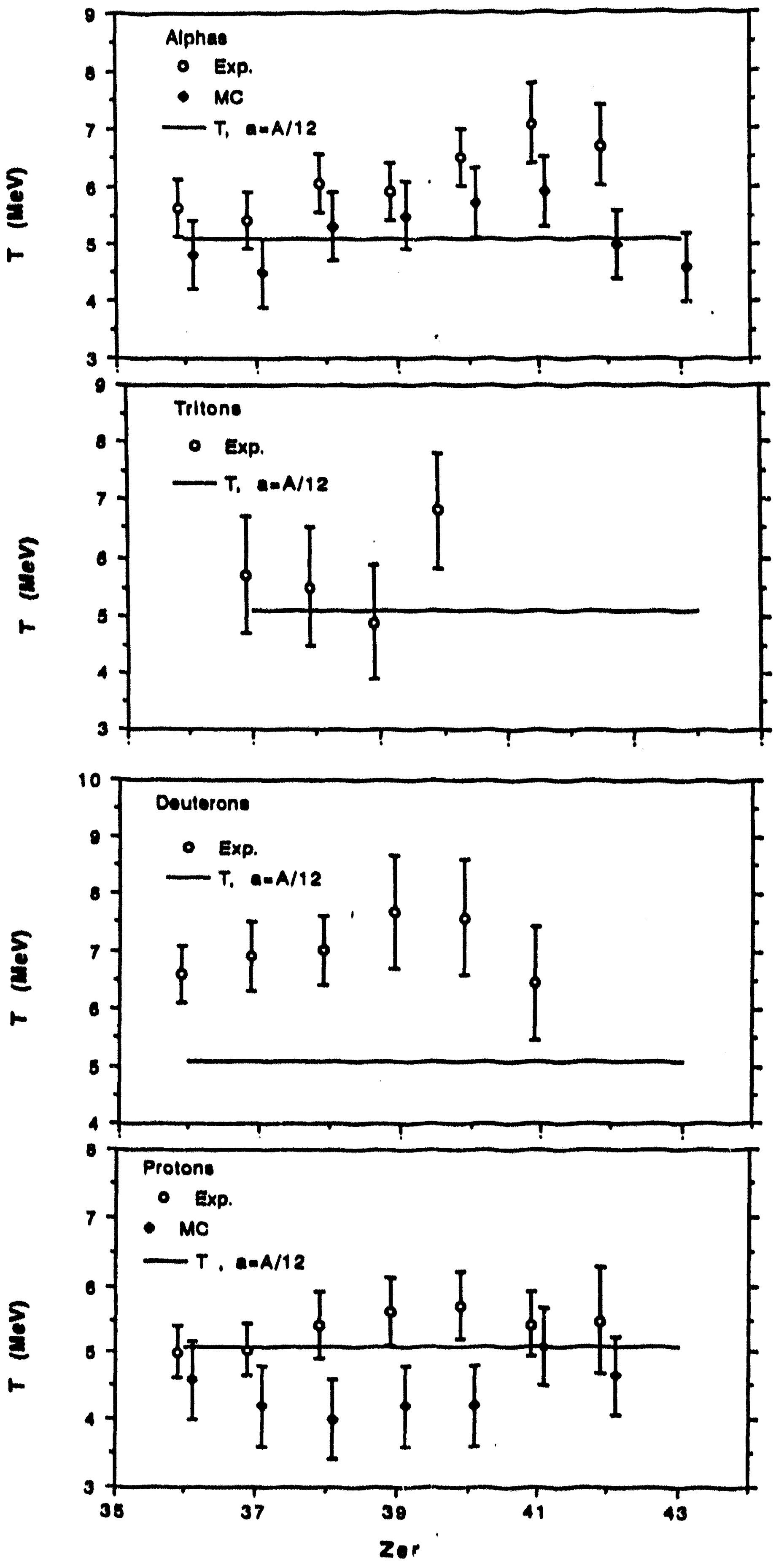
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