Reply to "Comment on 'Fragmentation of gold projectiles with energies of 200–980 MeV/nucleon. I. Experimental method, charge yields, and transverse momenta' "

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In reply to the Comment of Morrissey we present the standard deviations σ of distributions of transverse momentum components under the assumption that the ratios A/Z of fragments are determined by the parametrization of Sümmerer *et al.* These results do not change in comparison to those derived with a ratio A/Z equal to that of the projectile as presented by Dreute *et al.*

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We have investigated the fragmentation of gold projectiles using a stack of plastic nuclear track detectors [1]. With this experimental technique it is possible to measure with high precision the charge of projectile fragments and their emission angles with respect to the direction of the incoming particle. To determine transverse momenta of individual fragments their mass and their forward velocity $\beta_{\parallel}$ into beam direction must be known. These are not measured quantities in our experiment.

We have calculated the forward velocity from the kinetic energy per nucleon of the beam particle at the point of interaction assuming that the difference $\Delta\beta_{\parallel}$ before and after the collision is small in comparison to $\beta_{\parallel}$ for fragments with charge $Z \geq 6$. This fact has recently been confirmed by results of the ALADIN experiment [2].

The only other data available so far for transverse momenta of spallation products of heavy projectiles are those of Brady *et al.* [3]. To compare our results to these data it was necessary to use the assumption that the mass-to-charge ratio of the fragments is identical to that one of the beam particle, like Brady *et al.* have assumed. The standard deviations σ of distributions of measured transverse momentum components derived from our experiment using this assumption for spallation products are in agreement with the results of Brady *et al.* This confirms the results of both experiments using different experimental techniques.

For the lighter intermediate mass fragments for which transverse momenta have never been measured before we observe considerably larger momenta than expected from the mass dependence of the spallation products. This is our main result for transverse momenta which we discuss also under the aspect of target mass and energy dependence. Furthermore, we discuss the influence of different assumptions of the mass-to-charge ratio and state that the systematics of the observed differences for intermediate mass fragments and spallation products do not depend on these assumptions. However, the question of what is the absolute value of the transverse momenta is left open in our paper. We say that a measurement of fragment masses which is beyond our experimental technique is necessary to determine these values accurately.

Morrissey [4] in his Comment concentrates on transverse momenta of heavy spallation products of the gold projectile. In his discussion he stimulates the idea that based on the assumption of neutron-deficient fragments our data would follow the general systematics observed before for the breakup of lighter projectiles which can be described by the statistical model [5]. Morrissey recommends to use the empirical relation of Sümmerer *et al.* [6] to determine charge-to-mass ratios for the derivation of the standard deviations of transverse momentum distributions.

In Fig. 1 we show a plot that was produced following Morrissey's proposal. For all fragments a mass derived from the prediction of Sümmerer *et al.* [6] was used. This plot shows the same data as Fig. 9 in our publication [1]. Also under this assumption the transverse momenta determined from our experiment are significantly enlarged in comparison to the statistical model.

As we mentioned in our paper [1], Cummings *et al.* [7] have estimated charge-to-mass ratios for spallation fragments of gold from an experiment in which charge and velocity of the fragments were determined. These results suggest that the fragments are even more neutron deficient than predicted by the formula of Sümmerer *et al.* But even if we use their charge-to-mass ratio, the

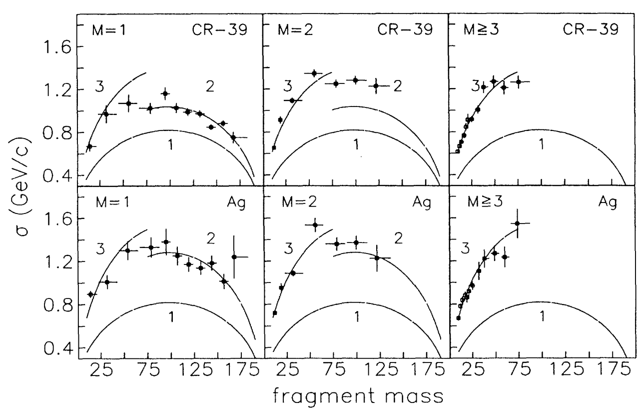

FIG. 1. The standard deviations σ of distributions of measured transverse momentum components. They are shown separately for the two targets and for different multiplicities M. The fragment masses are taken as the ratios A/Z given by Sümmerer *et al.* [4]. The curves shown are as follows: curve 1, statistical model; curve 2, fit for $M=1$, $F>75$; and curve 3, fit for $M \geq 3$, $F \leq 75$.

values of σ determined from our experiment are above the predictions of the statistical model.

Our results can be compared to earlier experiments which were performed under different experimental conditions like smaller projectiles, lower energy, or observation of target fragments in proton-induced reactions. Most of these data do not differ significantly from our result but support the trend described above.

Stéphan *et al.* [8] have measured the total momentum dispersion as a function of the mass loss ΔA for fragments produced in peripheral collisions of ^{84}Kr with ^{197}Au target. In Fig. 3 of their paper systematical deviations between the data and statistical model predictions (Goldhaber model) can be seen with increasing ΔA. At a value of $\Delta A \approx 30$ their measured dispersions lie about 15% above the Goldhaber curve. For the much heavier projectile ^{197}Au we observe a 30% enhancement at $\Delta A \approx 30$.

In comparison to the large body of target fragmentation data which were summarized by Morrissey [9], we also notice a general agreement to our observations. In Fig. 2(d) of [9] the momentum dispersions for proton-induced fragments of Au are shown. For smaller fragment masses $A \leq 100$ the experimental data again show a significant enhancement in comparison to the statistical model and thus follow the same trend we reported in our paper. The agreement between the Goldhaber curve and data in Fig. 2(d) of [9] for spallation fragments (masses $A \geq 150$) is not necessarily in conflict with our results, keeping in mind that these fragments were produced in collisions with protons and not with heavier target nuclei. We clearly observe that the deviations increase with target mass and therefore the fact that they vanish for target mass $A = 1$ is not in contradiction to our findings.

We must conclude that the standard deviations for transverse momentum components of spallation fragments coming from gold projectiles are larger than predicted by the statistical model [5]. It is even more surprising that these differences increase with target mass as can be seen in Table I. This table replaces Table I of our paper [1] with the modified conditions discussed above.

TABLE I. The values of σ_0 in MeV/c for curves 2 and 3 in Fig. 1.

	Multiplicity M fragment mass	1 $F > 75$	≥ 3 $F \leq 75$
Target	Energy (MeV/nucleon)	σ_0 (MeV/c)	
CR-39	$200 \leq E \leq 986$	147±2	199±2
Ag	$200 \leq E \leq 986$	182±4	219±3
CR-39, Ag	$E \geq 750$	149±2	165±3
CR-39, Ag	$E < 750$	197±3	214±2

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