Reply to "Comment on 'Fusion-fission dynamics of ^{188,190}Pt through fission fragment mass distribution measurements' "

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The Comment by Caamaño concerns the issue of single versus multiple Gaussian fits to the observed mass distributions in the fusion-fission reactions as studied in Kavita *et al.* [Phys. Rev. C **100**, 024626 (2019)]. The Comment suggests an alternative approach to the analysis of fission mass distribution data, which appears to deviate from the observed trends of mass distributions at the measured energies and thus was not used in our study. However, we would like to emphasize that multi-Gaussian fit as suggested will not have any impact on the conclusion of our work.

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The initial concern of the author of the Comment arises from the presence of a tail/offset in the fitted function in our original work [1]. This discrepancy arose due to the presence of an offset parameter in the Gaussian function plotted in our work, leading to the observed tail. The measured mass ratio distributions fitted with the single Gaussian function (without offset) for both the reaction systems (^{12}C + ^{178}Hf and ^{28}Si + ^{160}Gd) are shown in Figs. 1 and 2 (corresponding to Figs. 3 and 4 of Ref. [1]), respectively. We would like to mention that the sigma values mentioned in our original work and shown in Fig. 3 of this reply were obtained from a fit that did not involve any offset parameter. Furthermore, it is worth mentioning that the focus of our study in Ref. [1] was the analysis of mass width σ_{MR} for reactions with varying entrance channel mass asymmetry. Therefore, rather than probing for microscopic effects, we opted for a single Gaussian fit to determine the width of the measured mass ratio distributions.

The remaining remarks of the Comment's author are centered around the differences in residue distributions between single Gaussian fits and multi-Gaussian fits. In particular, residues exhibit greater magnitudes in single Gaussian fits, along with an oscillatory behavior, and based on these observations the Comment's author claims that multi-Gaussian fits are required to reproduce the distributions.

In the relatively neutron-deficient pre-actinide mass region, asymmetric fission can be observed at very low excitation energies, typically far below the barrier. At these energies, the mass distribution data display distinct features that cannot be adequately described by a single Gaussian curve. Therefore, it becomes necessary to employ multi-Gaussian fits to effectively account for these observable peaks or shoulders in the data [2]. Further, the presence of asymmetric fission component depends on entrance channel, relative neutron deficiency, as well as the excitation energy of the nuclei undergoing fission [3]. However, due to the lack of any apparent asymmetric behavior, such as a dip corresponding to the symmetric fission in the experimental mass distributions, even at the lowest studied energies for both the reactions, we used single Gaussians to perform data fitting for the purpose of extracting width values from the distributions.

The Comment's author has referred to article [4] with a mention that the fitted function should contain a realistic description of the fission components. We would like to point out that Prasad *et al.* [2] measured the mass distributions resulting from the fission of ^{182}Hg and ^{195}Hg at different laboratory energies. A particular section of their study focused on the fission of ^{182}Hg at the lowest energy, which demonstrated structural features and exhibited a flat-topped behavior at higher studied energies, and still the authors utilized single Gaussian fits to calculate the mass widths.

Tripathy *et al.* [4] too reported similar observations in the fission of ^{35}Cl + ^{144,154}Sm reactions, where relatively poor single Gaussian fits were observed, particularly at the lowest studied energies for both reactions. However, the authors quoted sigma values obtained from single Gaussian fits, though they did attempt to identify asymmetric components based on residue distribution, but only for ^{35}Cl + ^{144}Sm reaction and that too at the lowest excitation energy (36.7 MeV), which is just 7.7 MeV above the barrier. Recently, Dhuri *et al.* [5] studied the reaction ^{12}C + ^{175}Lu, which is very similar to one of the reactions studied in our work (^{12}C + ^{178}Hf) in terms of entrance channel, populated compound nucleus, and excitation energies. At nearly matching excitation energies (E_{sad} ≈21 MeV onwards), fission was observed to be symmetric in nature. However, they did find a very small contribution

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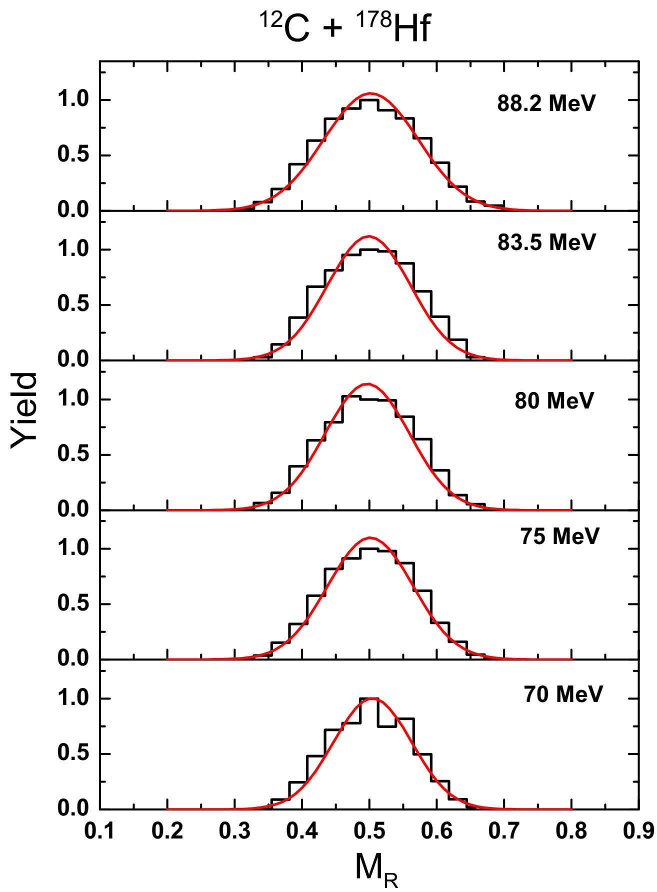

FIG. 1. The measured mass ratio (M_R) distributions (black histogram) for $^{12}C + ^{178}Hf$ at all studied energies. The red line represents the single Gaussian fit to the data.

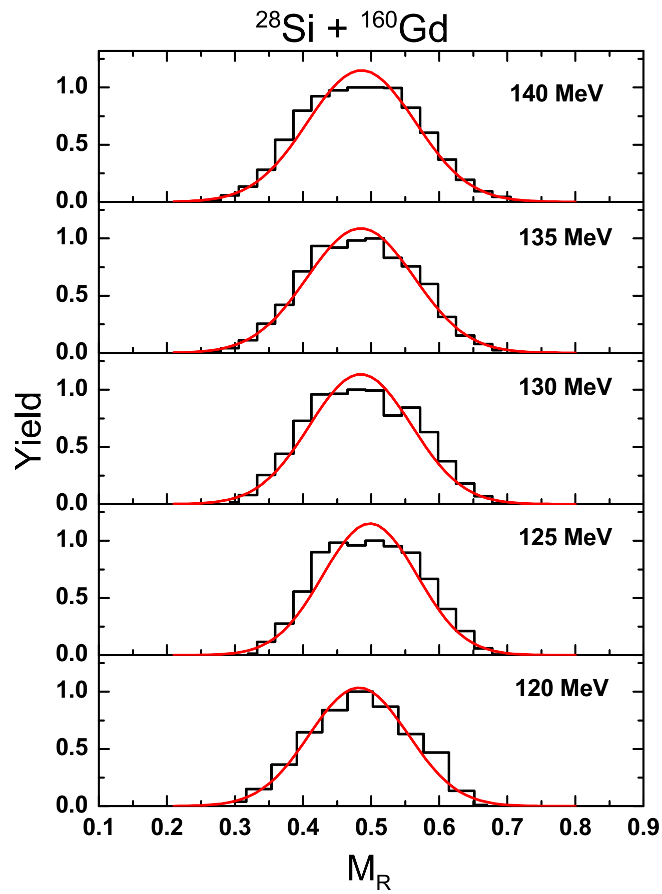

FIG. 2. The measured mass ratio (M_R) distributions (black histogram) for $^{28}Si + ^{160}Gd$ at all studied energies. The red line represents the single Gaussian fit to the data.

(∼12%) of asymmetric fission at the lowest saddle point energy of 10.2 MeV. Although the contribution is small, it is still evident as weak shoulders in the overall mass distribution data [5]. The mass widths obtained from single Gaussian fits in their work are consistent with those obtained in our study for the $^{12}C + ^{178}Hf$ reaction. Furthermore, for both of the aforementioned reactions, i.e., $^{12}C + ^{175}Lu$ and $^{12}C + ^{178}Hf$, the obtained widths are compatible with the liquid drop systematic of compound nucleus fission.

Based on the arguments put forth by the author of the Comment, if we are to interpret the magnitude of residues as an indication of the presence of asymmetric fission associated with microscopic effects, it is anticipated that the magnitude would decrease as energy increases, mirroring the diminishing contribution of asymmetric fission [5,6]. The double Gaussian fits at the highest energy (as shown in Fig. 2 of the Comment) suggest that fission is primarily asymmetric in nature despite the absence of any visible asymmetric component in the data.

As suggested by the Comment's author, we attempted to check for the presence of different fission modes using triple Gaussian fits to the mass distribution data at the lowest and highest energies, for both the reactions, and the results are shown in Figure 4, where, at a given energy, asymmetric components exhibit the same amplitudes, and widths, and are symmetric about the mass ratio ($M_R \sim 0.5$). We performed a 200% normalization of the data, presented in Ref. [1], to perform the multi-Guassian fitting in order to improve the

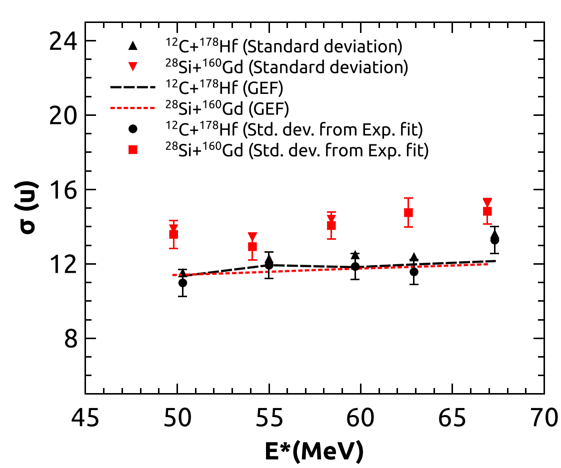

FIG. 3. Experimental mass widths for $^{12}C + ^{178}Hf$ (solid circles) and $^{28}Si + ^{160}Gd$ (solid squares) reactions. GEF predictions are plotted as black dashed and red dotted lines. Standard deviations calculated from the data are shown by triangles.

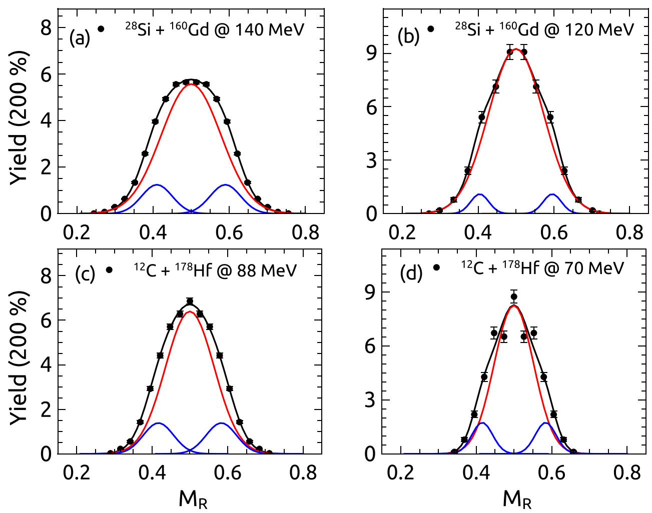

FIG. 4. Experimental mass distributions for ^{28}Si + ^{160}Gd and ^{12}C + ^{178}Hf reactions along with the triple Gaussian fits at the highest and lowest studied energies for the respective reaction. Symbols are used for the experimental data and lines are for Gaussian fits. The black, red, and blue lines represent the overall fit and symmetric and asymmetric components, respectively.

fitting procedure, as was used in Refs. [3,5,7,8]. 200% normalization involves acquiring the fission fragment mass data by combining the counts from two detectors. This approach becomes imperative when the fissioning nucleus exhibits both symmetric and asymmetric modes of fission. There may be some fission events which were observed only in one of the detectors, due to geometrical limitations or the angular coverage of the detectors, which may lead to discrepancy/deviation in the distribution on either side of half of the compound nucleus mass or mass ratio; i.e., the distribution may not be symmetric around mass ratio 0.5. So, in order to avoid this discrepancy in data because of the experimental setup, we did 200% normalization of the mass distribution, and the same was employed in recent similar studies as mentioned above in order to perform multi-Gaussian fitting to look for asymmetric fission contribution. However, it is imperative to mention here that this normalization procedure may not be necessary in the case of very high statistics data [9]. It is relevant to mention that at the plotted energies for both reactions, three-Gaussian fits were obtained by constraining the width of asymmetric peaks. However, for the lowest energy in the case of the ^{12}C + ^{178}Hf reaction, in addition to constraining the width of asymmetric peaks, the mean positions of these peaks were also fixed [3,5,7]. For the ^{12}C + ^{178}Hf reaction, the contribution of asymmetric fission is ≈18% at the lowest energy and ≈21% at the highest energy. Similarly, for the ^{28}Si + ^{160}Gd reaction, the corresponding values are ≈8% and ≈19%, respectively. The observation that the contribution of asymmetric fission remains nearly consistent and increases (rather than diminishing, as expected) as energy increases raises valid concerns about the presence of different fission modes in the studied reactions at such high excitation energies. It is expected that any contribution from asymmetric fission at such high excitation energies would be negligible.

It is relevant to mention here that in the multi-Gauss fitting procedure, the width of symmetric component is usually fixed based on the liquid drop (LD) model expectations while estimating the contribution of different fission modes. Such analysis in our case yielded ≈6% and ≈12% contributions of the asymmetric fission mode for the ^{12}C + ^{178}Hf reaction at the lowest and highest energies, respectively. Similarly, for the ^{28}Si + ^{160}Gd reaction, the contributions were ≈7% and ≈19%, respectively.

The calculation using GEF [10] shows ≈11% contribution of asymmetric fission for the ^{12}C + ^{178}Hf reaction at the highest studied energy but it corresponds to $Z = 38$, which in our case falls under the category of symmetric fission as Z_{CN} for the above reaction is 78 and, assuming the unchanged charge density (UCD) hypothesis, charge resolution as derived from mass resolution (≈4 u) comes out to be ≈2.

We recognize that the residues' distributions resulting from single-Gaussian fits exhibit deviations in quality. However, it is important to note that relying solely on this criterion may not justify the use of fits with multiple components. These deviations do not necessarily imply asymmetric fission in both the studied reactions, especially considering the high excitation energies involved. Since there were no asymmetric peak structures, even at the lowest studied energies, in the experimental data, along with the fact that the focus of our original work was the analysis of fission mass width for different entrance channels, we fitted the data with single Gaussians to obtain the width values, compared these values with the saddle point model, and found that they are comparable for the ^{12}C + ^{178}Hf reaction. However, for the ^{28}Si + ^{160}Gd reaction, the experimental mass widths are relatively larger than the saddle point model [1], indicating the presence of quasifission in the studied reaction.

The direct calculation of standard deviation from the content of the histograms matches reasonably well with the one obtained from Gaussian fits. Therefore, the choice of fit does not really impact the results thus obtained. The GEF [10] predictions for the studied reactions are also shown in the same figure. These comparisons suggest that the mass widths for the ^{12}C + ^{178}Hf reaction are consistent with the model predictions, while they are larger for the ^{28}Si + ^{160}Gd reaction.

To summarize, although there is scope to fit the mass distributions data with multi-Gaussians to improve the quality of fits, since the focus of our original work was to compare the widths of mass distributions from asymmetric and symmetric reactions, widths obtained from single Gaussian fits were used in the analysis. Nevertheless, the procedure of fitting does not have any impact on the conclusion of our original work.

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