Reply to "Comment on 'Measurement of the space-time extent of the hard-photon emitting source in heavy-ion collisions at 100 MeV/nucleon'"

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We reply to the preceding comment. [S0556-2813(98)00305-7]

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The preceding Comment criticizes our paper [1] in two respects: (1) the comparison of the extracted and estimated sizes, and (2) the parametrization of the relative-momentum correlation function.

In the following we give our answers to the above criticisms.

Criticism 1. Reading the preceding Comment, one can observe that criticism 1 can be split into three parts concerning (i) the definition of R_{ov}, (ii) the way we calculated $\langle N_{pn}\rangle_{\gamma\gamma}$, and (iii) the way we calculated R_{tot}.

Concerning point (i) the author of the Comment is correct. The values of R_{ov} reported in Table V of Ref. [1] are overestimated by a factor of $\sqrt{2}$. Indeed, if a Gaussian source distribution like that reported in Eq. (4) of Ref. [1] is used, the right expression for the overlap radius is

$$R_{ov}=1.2\langle N_{pn}\rangle_{\gamma\gamma}^{1/3}/\sqrt{5} \tag{1}$$

instead of

$$R_{ov}=\sqrt{\tfrac{2}{5}}\left(1.2\langle N_{pn}\rangle_{\gamma\gamma}^{1/3}\right). \tag{2}$$

Table V of Ref. [1] has been modified to Table I in this paper. It is worth noting, however, that this change does not modify at all the conclusions of Ref. [1].

Independent of that, some more general comments about the way R_{ov} is usually calculated are in order. By its definition, R_{ov} depends on the number $N_{pn}(b)$ of first chance n-p collisions. An estimate of this latter quantity is generally made within the equal-participant geometrical model [2] where it is assumed to be proportional to the volume of the overlap region. Recent dynamical calculations [3], based on the solution of the BNV transport equation, give a quite different impact parameter dependence of $N_{pn}(b)$ (see Fig. 2 of Ref. [3]). Central collisions are partially forbidden due to the action of the Pauli-blocking effect, while peripheral ones are enhanced due to those collisions taking place outside the geometrical overlap zone and which are ignored in the equal-participant model. Thus, the comparison in Ref. [1] between the extracted spatial size of the source and the overlap radius performed if Ref. [1] has to be intended only qualitatively. It has been performed for uniformity with already published data [4] with the awareness that it represents only a zero-order approximation of what really happens in the first phase of the collision. For all of the above, the intrinsic validity of the method of calculating R_{ov} is, in principle, questionable, and a variation of a factor of $\sqrt{2}$ does not change our understanding of the hard-photon emission in heavy-ion collisions at intermediate energies.

TABLE I. The values of the root-mean-squared radius r_{rms} are compared, for the three studied systems, with those of overlap radius R_{ov} and those of the total radius R_{tot}.

System	r_{rms} (fm)	R_{ov} (fm)	R_{tot} (fm)
^{36}Ar+^{27}Al	1.4±0.7	1.38	7.56
^{36}Ar+^{112}Sn	3.0±1.2	2.12	9.75
^{36}Ar+^{197}Au	3.8±1.9	2.37	10.94

(ii) In Ref. [1] one reads that $\langle N_{pn}\rangle_{\gamma\gamma}$ is calculated as the mean value, averaged over the impact parameter, of the quantity $N_{pn}(b)[N_{pn}(b)-1]$. In every statistical context this means that

$$\langle N_{pn}\rangle_{\gamma\gamma}\equiv\langle N_{pn}(N_{pn}-1)\rangle_b = \frac{\int_0^{R_p+R_t}2\pi N_{pn}(b)[N_{pn}(b)-1]b\,db}{\int_0^{R_p+R_t}2\pi b\,db}, \tag{3}$$

which is exactly what the author of the preceding Comment claims we would have to do. Indeed, comparing the values of R_{ov} given in Table I of the preceding Comment with those given in our Table I (corrected by the factor of $\sqrt{2}$), one can easily see how they agree within 20–30 %. Small differences may be due to different methods and/or steps of numerical integration.

(iii) In the preceding Comment the author asserts that we should have used

$$R_{tot}=1.2(A_p+A_t)^{1/3} \tag{4}$$

instead of

$$R_{tot}=1.2(A_p^{1/3}+A_t^{1/3}), \tag{5}$$

as we did in Ref. [1]. This is not correct because dynamics must be considered along with geometry. In recent works [5,6] the author himself has demonstrated, using the results of microscopic transport calculations, that most of the hard-photon production in heavy-ion collisions at 100 MeV/nucleon is gathered in the first 20–30 fm/c of time when the two colliding nuclei are far from an uniform compound system which would lead to the first definition of R_{tot}. Then, from a temporal point of view, the second form which refers to the separation between the centers of the two nuclei is more realistic. For the same reason the substitution of R_{tot} with $\sqrt{3/5}R_{\mathrm{tot}}$ claimed by the author [see Eq. (3) of [1]] need not be made (even if it would be uninfluential on the conclusions of Ref. [1]) because the density of the colliding systems is definitely not uniform and not constant during the first phase of the collision (when most hard photons are emitted).

Criticism 2. This has to do with the parametrization of the correlation function. Before entering into the details of the answer some general comments are in order.

(i) As has been well stated by Zajc *et al.* [7] and pointed out in Refs. [1] and [8], any one-dimensional correlation function $C(q)$ (regardless of the correlation observable q one wishes to use) is *not* a *true* correlation function but only a projection of the multidimensional correlation function, and, therefore, the information one can extract from it is highly spectrometer dependent and should be carefully analyzed.

(ii) Recent publications [9,10] have strongly questioned, from a quantum statistical point of view, the validity of the usual way the one-dimensional correlation function is defined.

Then, any full run application of the intensity interferometry formulas could be, in principle, strongly discussed. What is peculiar in the analysis performed in Ref. [1] is the study of the response of the used multidetector to the pairs of correlated photons for different values of the source parameters. We have used the same one-dimensional Gaussian parametrization both for real and simulated data, carefully taking into account the detector efficiency. It is worth stressing that the values of R and τ are not directly determined from the fit of the correlation function but have been unfolded from R' and τ'.

As it is stated in Eq. (16) of Ref. [1] the fit procedure has been performed using a Gaussian without the ''1'' in front. The same function has been used to analyze simulated data (see Eq. (10) of Ref. [1]).

Concerning the normalization factor, it has been checked that the ratio of the run times was approximately equal to calculating the mean of the correlation function between about 45 and about 60 MeV/c (this is explained because some points are less than 1 in that range) where no correlation should be present. The correlation function has been plotted in the form $1+C(q_{\mathrm{rel}})$ for uniformity reasons. The function reported in Eq. (16) has been then simply multiplied by a factor only to show the quality of the fit.

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