Comment on ''Quantum-mechanical equivalent-photon spectrum for heavy ion physics''

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We critically discuss the recently developed quantum-mechanical equivalent photon spectrum by Benesh *et al.* [Phys. Rev. C **54**, 1404 (1996)]. We point out that the key point, the strong absorption in heavy ion collisions, is not treated adequately. Conclusions drawn from such a spectrum are invalid. Equivalent-photon spectra appropriate for heavy ions have been given before in quantal, as well as semiclassical versions, and were found to be very satisfactory. [S0556-2813(97)05707-5]

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In a recent paper [1] a quantum-mechanical equivalent-photon spectrum for heavy ion physics was calculated. Significant deviations from the prediction of previous calculations for mildly relativistic collisions ($\gamma < 2-3$) were found [1]. This is surprising, since the usual assumption of classical trajectories in semiclassical calculations, or eikonal wave functions in quantal calculations, are well known as valid for heavy ion reactions [2,3].

We can trace the origin of the discrepancy to the inadequate treatment of strong interaction effects in Ref. [1]. Their Eq. (1) is based on the plane-wave Born approximation. In the notation of Ref. [3]

$$T_{\rm Born}=\frac{1}{c}\int d^3r A_\mu(\mathbf{r})\langle I_f M_f|J_\mu(\mathbf{r})|I_i M_I\rangle, \quad (1)$$

where A_μ represents the four potential created by the transition current of the projectile. Our point is most clearly explained in the case of extreme strong absorption (*black disk* model). We give a quantum-mechanical equivalent-photon spectrum using Glauber wave functions for the projectile in the initial and final state [3,4]. Thus the Glauber phase is given by

$$e^{i\chi(b)}=0, \quad \text{for } b<R,$$
$$=e^{i\psi_c(b)}, \quad \text{for } b>R, \quad (2)$$

where R denotes the strong absorption radius. The Glauber Coulomb phase is denoted by $\psi_c(b)$. The appropriate T matrix is now given by [3,4]

$$T_{fi}(\mathbf{q})=\frac{1}{(2\pi)^2}\int_{b>R} d^2b \; e^{i\mathbf{q}_\perp\cdot\mathbf{b}}e^{i\psi_c(b)} \times\int d^2q'_\perp e^{-i\mathbf{q}'_\perp\cdot\mathbf{b}}T_{\rm Born}(\mathbf{q}'_\perp,q_\parallel). \quad (3)$$

This leads to an equivalent-photon spectrum [see Eq. (12) of Ref. [4]]. In this derivation, it was assumed that the projectile and target do not overlap [2]. The form factor of the projectile charge distribution does not enter, since the electric field of a spherically symmetric charge distribution depends only on the charge contained within its radius R. Diffraction effects due to the finite wavelength of the projectile are taken into account in this approach (see, e.g., Fig. 3 of Ref. [4], or Figs. 2–4 of Ref. [5]). It is interesting to note that the total (i.e., angle-integrated) cross section is the same for the semiclassical and quantum treatment in the sharp-cutoff model [3,4].

It is evident from Eq. (2) that an adequate treatment of strong interaction effects cannot be obtained by using a Born-approximation T matrix and calculating total cross sections by introducing a phenomenological cutoff $q_{\rm max}\sim 1/R$ on the transverse momentum transfer $\mathbf{q}_\perp$, as it was done in Ref. [1]. At most, this would lead to a very approximate result. A good quantitative description of the cross sections, as stated by the authors, cannot be obtained. The key point here is that this calculation is better treated in coordinate space, since the strong absorption is treated in a simple way. In momentum space one has to introduce momentum cutoffs which do not have a one-to-one correspondence with r-space (or impact parameter space) cutoffs.

Moreover, in Ref. [1] it was stated that ''the new spectra ... leave little room for more exotic multiphoton mechanisms required in a semiclassical analysis.'' Such criticism of Refs. [6,7] (Refs. [20] and [21] of Ref. [1]) is based on a wrong assumption and is therefore invalid. Indeed, multiphonon effects are a natural consequence of QED and have been clearly observed in relativistic electromagnetic excitation [8,9].

A small effect worth mentioning in this context is the change of the state of the projectile during the excitation process. It is genuinely of a quantum-mechanical nature. This leads to mutual excitation, and a simple form of the corresponding equivalent-photon spectrum is given in Ref. [10]. The case of a deformed projectile is treated in Ref. [11].

Finally, we note that quantum corrections, similar to those presented in Ref. [1] have been studied earlier in Refs. [12]. They also conclude that these effects lead to rather large discrepancies with semiclassical calculations. However, as shown by the same authors later [13], a correct treatment of absorption effects restores the validity of semiclassical calculations.

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[1] C.J. Benesh, A.C. Hayes, and J.L. Friar, Phys. Rev. C **54**, 1404 (1996).
[2] A. Winther and K. Alder, Nucl. Phys. **A319**, 518 (1979).
[3] C.A. Bertulani and G. Baur, Phys. Rep. **163**, 299 (1988).
[4] C.A. Bertulani and A.M. Nathan, Nucl. Phys. **A554**, 158 (1993).
[5] *Coulomb Break-up of Nuclei - Application to Astrophysics*, G. Baur and H. Rebel, Forschungszentrum Karlsruhe, Wissenschaftliche Berichte FZKA 5771 and Annu. Rev. Nucl. Part. Sci. **46,** 321 (1996).
[6] J.W. Norbury and G. Baur, Phys. Rev. C **48**, 1915 (1993).
[7] W.J. Llope and P. Braun-Munzinger, Phys. Rev. C **48**, 799 (1993); T. Aumann *et al.*, *ibid.* **47**, 1728 (1993).
[8] H. Emling, Prog. Part. Nucl. Phys. **33**, 629 (1994); P. Chomaz and N. Frascaria, Phys. Rep. **252**, 275 (1995); and references given therein.
[9] K. Boretzky *et al.*, Phys. Lett. B **384**, 30 (1996).
[10] K. Hencken, D. Trautmann, and G. Baur, Phys. Rev. C **53**, 2532 (1996).
[11] C.A. Bertulani, Phys. Lett. B **319**, 421 (1993).
[12] M.C. Nemes, D. Galetti, and T. Kodama, Phys. Rev. Lett. **59**, 59 (1987); Ann. Phys. (N.Y.) **77**, 229 (1987).
[13] L. Gonzaga Filho, M.C. Nemes, and T. Kodama, Nucl. Phys. **A499**, 837 (1989).