**Willingale *et al.* Reply:** In the preceding Comment [1], the significance of the quasistatic magnetic field is discussed, which enhances the ion accelerating space-charge field and also gives rise to a collimation mechanism to explain the results presented in the Letter [2].

Reconsidering the simulation performed for the Letter [2], the relative contributions of the charge separation and the time varying magnetic field to the longitudinal ($x$ direction) electric field are calculated. Figure 1(a) shows how each contribution compares with the simulation longitudinal electric field, $E_{\rm sim}$. The charge separation contribution, $E_\rho$, is found by numerically solving Poisson's equation using the ion and electron data. $E_\rho$ [Fig. 1(a) (ii)] is found to constitute the largest part of $E_{\rm sim}$; there is, however, a discrepancy.

A large induced magnetic field is observed at the rear vacuum plasma interface and is shown in Fig. 1(b). The time varying magnetic field contribution, $E_{\dot{B}}$, can be calculated by studying the temporal evolution of the vector potential due to the quasistatic magnetic field alone using $\nabla \times \mathbf{B} = -\nabla^2 \mathbf{A}$. The induced electric field can then be calculated from $\mathbf{E} = -\frac{\partial \mathbf{A}}{\partial t}$ and is shown in Fig. 1(a) (iii). Together $E_\rho$ and $E_{\dot{B}}$ give $E_{\rm sim}$. The peak value of $E_{\dot{B}}$ is 0.2 TV/m which compares to a peak value of 0.5 TV/m for $E_\rho$. Furthermore, $E_\rho$ is larger than $E_{\dot{B}}$ at all times throughout the simulation. Hence, for these parameters, charge separation provides the major contribution to the longitudinal electric field.

The simulations show that a large radial ($y$ direction) electric field at the channel vacuum interface is generated at around 1.5 ps into the simulation [see Fig. 1(c)]. The quasistatic magnetic field pinches the electrons producing the collimating electric field on the ions, as suggested in the Comment [1] and is shown in Fig. 1(d). Although the quasistatic magnetic field enhances the sheath field, the simulations indicate this is not the dominant effect on the ion acceleration. Indeed, in simulations with no magnetic fields (i.e., 1D simulations), ions can still be accelerated from high intensity laser interactions with underdense plasmas, which shows that magnetic field effects are not a requirement for ion acceleration.

In conclusion, the induced electric field due to the time varying magnetic field associated with the fast electron current provides a significant contribution to the accelerating sheath field. The quasistatic magnetic field is likely to enhance the charge separation to extend the lifetime of the sheath field and centrally focuses electrons, generating a collimating radial electric field for ions. It is noted that for shorter duration laser pulses (as in [3–5] rather than $\tau \sim$ 500 fs presented here) the $E_{\dot{B}}$ will become substantial and therefore has implications for ultrashort pulse petawatt class laser ion acceleration.

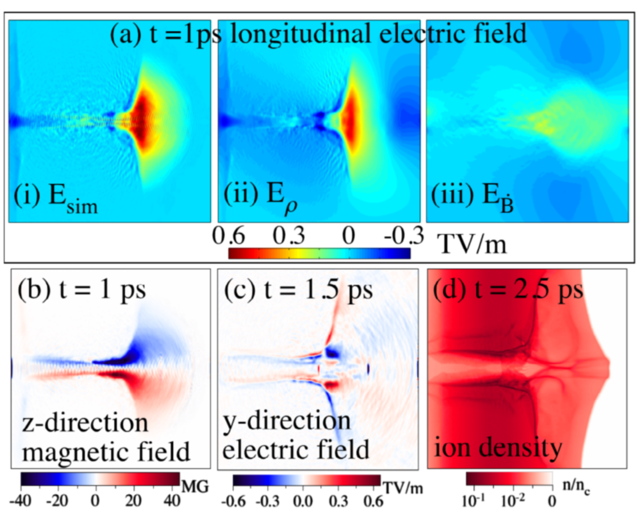


FIG. 1 (color online). (a) Longitudinal electric fields at 1 ps from (i) the simulation, (ii) charge separation, (iii) the time varying magnetic field. (b) $z$-direction magnetic field at 1 ps, (c) radial electric field at 1.5 ps, and (d) the ion collimation at 2.5 ps.

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