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## **Dominance of the seed from a tightly-focused electron bunch over the self-modulation of a long proton bunch in an over-dense plasma**

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The phase and growth rate of the self-modulation of a long proton bunch in over-dense plasma can be controlled by a preceding charged particle bunch. In order to selectively seed the growth of the proton bunch self-field, the dominance of seed over any undesired imperfections of the proton bunch is important. In this work, we investigate analytically and numerically the phase and growth rate of the long proton bunch self-modulation, including the effects of its gently rising current profile and of the wakefields of the tightly focused low energy electron seed at the early stage of the self-modulation. We also show that the low energy electron bunch simultaneously drives a single mode modulation along the entire long proton bunch, mitigating mode polarization with the anomalous phase shift of the long proton bunch self-modulation.

### **Acknowledgments**

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