Preliminary Study of Transverse Instabilities in PD-PWFA Based on Hollow Plasma

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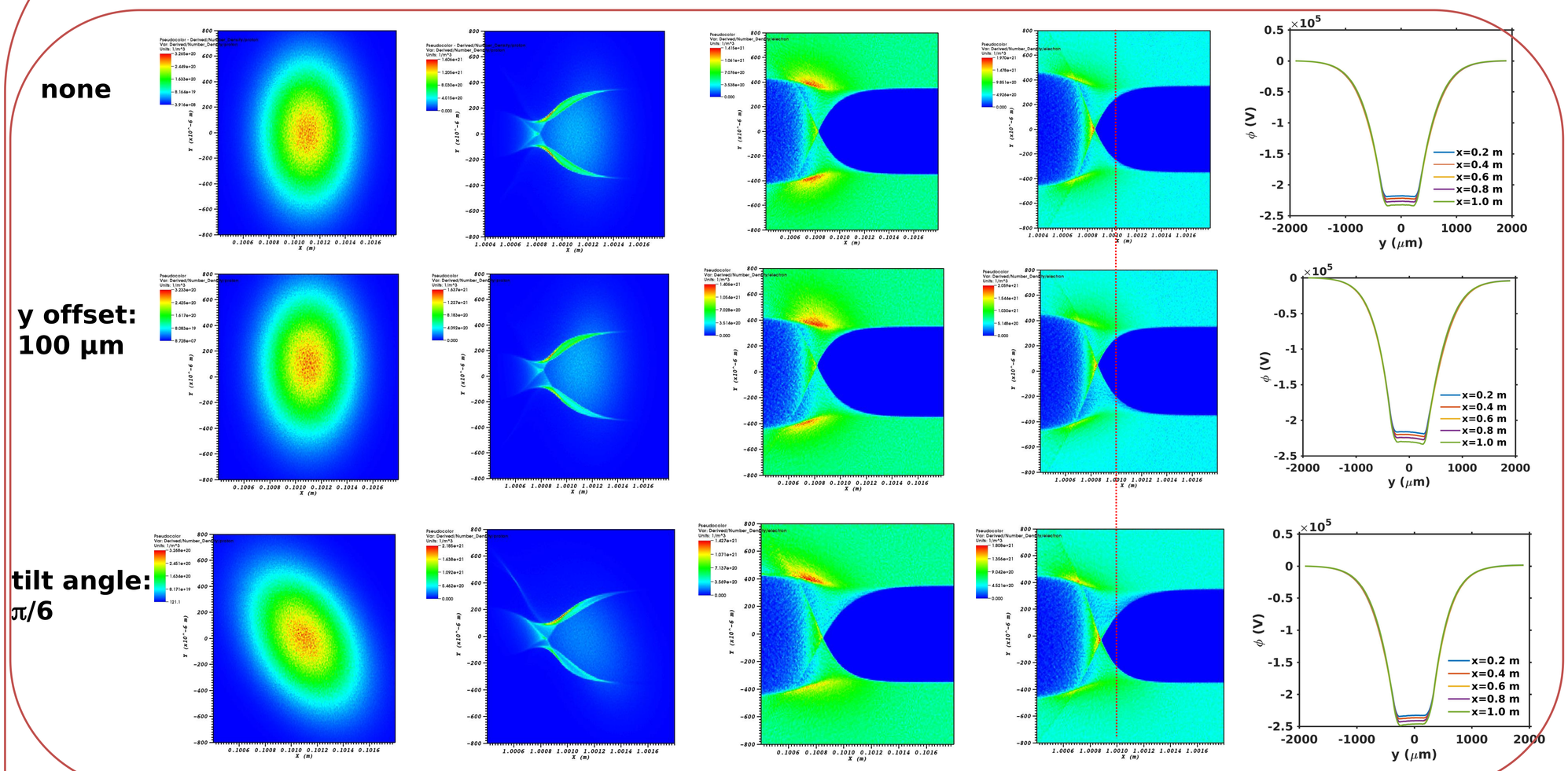
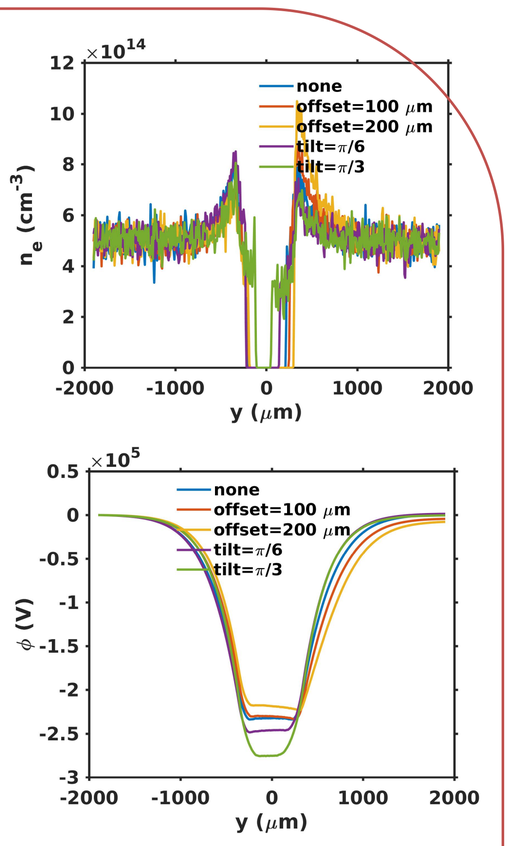
Hollow plasma has been introduced into the proton-driven plasma wakefield accelerator (PD-PWFA) to overcome the issue of beam quality degradation caused by the nonlinear transverse wakefields varying in radius and time in uniform plasma. It has been demonstrated that the electrons can be accelerated to energy frontier with well-preserved beam quality in a long hollow plasma channel. However, for long-term relativistic beam-plasma interaction, this scheme imposes tight requirements on the driving beam to be on axis of the hollow channel. Otherwise the driving bunch could be distorted dramatically due to transverse instabilities. This would successively trigger a series of nontrivial issues such as reduction of the energy transfer efficiency, nonuniformities of the wakefields and degradation of the beam quality etc. In this contribution, we examine these detrimental effects with 2D cartesian PIC simulations.

Beam dynamics of the proton driving bunch





- With hollow plasma, the protons bunch is free from defocusing by ions in the channel and confiend by plasma electrons outside which form a reflecting-wall like focusing structure (deep potential well).
- The proton driving bunch can sustain a relatively large offset (200 μm) and tilt (π/3) without drastic distrotion of the beam shape or hosing instability, only the wakefield decreases.
- In comparison with the offset case, the wakefield decreases considerably with beam tilt as it equivalently extends the beam length.
- The offset of the decelarating bubble is almost half of the beam offset. The unsymmetric bubble incurs a oblique bottom of the potential well, which could cause more protons to accumulate in one side in a long distance.

Parameters

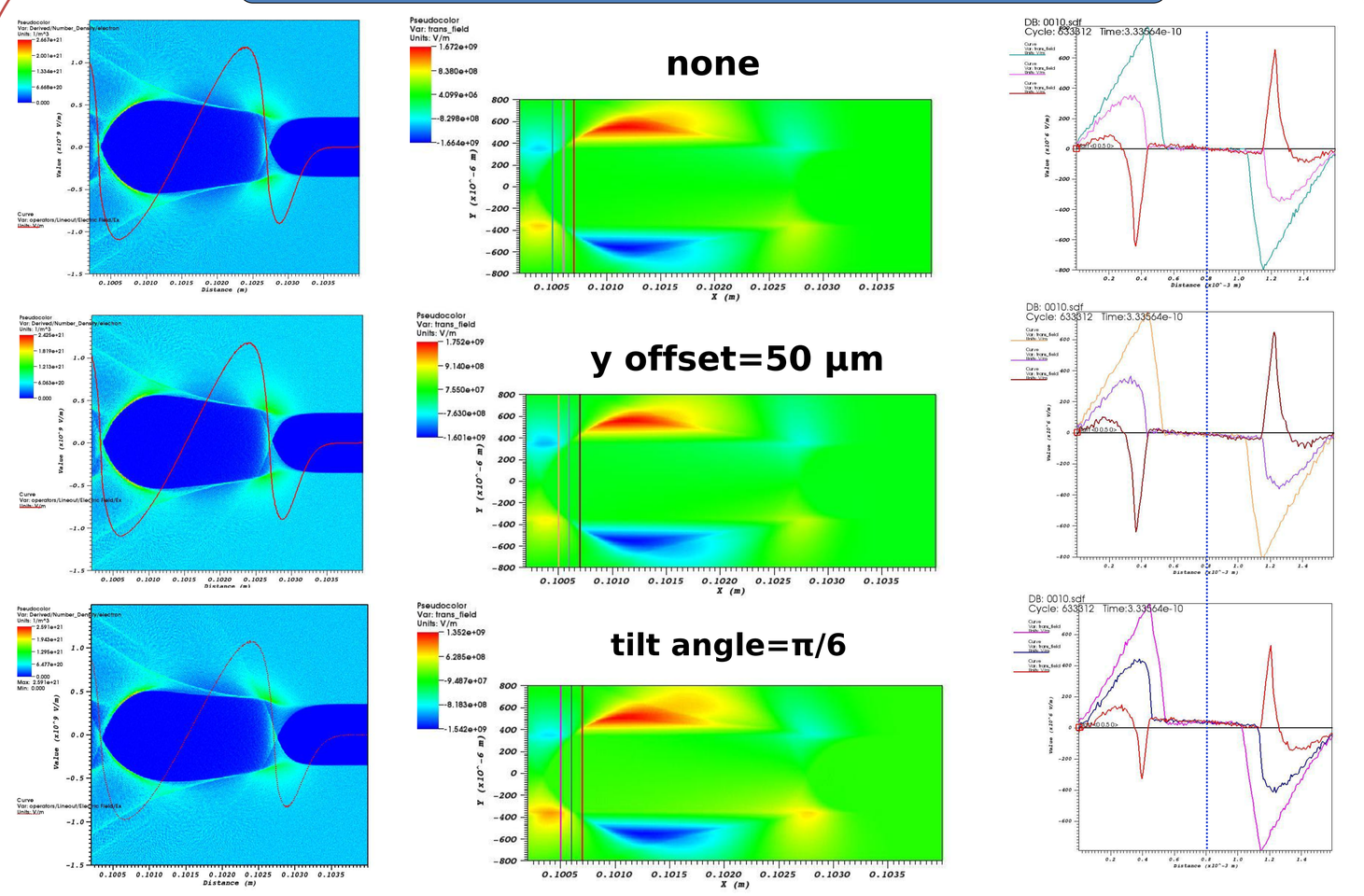
Parameters	Values	Units
Initial proton bunch:		
Bunch population, N_b	1.15×10^{11}	
Energy, W_{d0}	1	TeV
Energy spread	10%	
Bunch length, σ_x	220	μm
Bunch radius, σ_y	350	μm
Angular divergence, σ	3×10^{-5}	
Unperturbed hollow plasma:		
Plasma density, n_p	5×10^{14}	cm^{-3}
Hollow channel radius, r_c	350	μm

☆ No external quadrupoles

Summary & Outlook

With EPOCH, we have done some preliminary 2D simulations to investigate the effect of the driving proton beam with offset or tilt traveling in the hollow plasma. The proton bunch itself is less sensitive to the initial distortion, but the resultant unsymmetry of the accelerating bubble might drastically lead to the divergence of the witness bunch and degradation of beam quality. Apart from validating the effect of addition of quadrupoles, change of beam loading location and alternative near-hollow plasma scheme on the improvement of the witness quality, further investigation in terms of the beam and plasma parameters are also ongoing.

Wakefield in the witness area



- The offset or tilt of the driving bunch although causes the unsymmetry of the second bubble in a lower level, the transverse fields acting on the witness electron bunch change from zero to be defocusing. Some possible solutions are: 1) adding proper quadrupole focusing. 2) loading the witness bunch in the region where there are much larger focusing at the channel boundaries. 3) considering near-hollow plasma scheme which introduces some foucsing from plasma ions in the channel.