NUMERICAL SIMULATION ON PLASMA-BASED BEAM DUMPS USING SMILEI

Presented by Guoxing Xia
On behalf of
S. Kumar*[1,2], G. Xia[1,2], A. Bonatto[3], R. P. Nunes, B.S. Nunes, L. Liang[1,2], C. Davut[1,2]
[1]The University of Manchester, Department of Physics and Astronomy, Manchester, United Kingdom.
[2]The Cockcroft Institute, Daresbury, United Kingdom.
[3]Universidade Federal de Ciências da Saúde de Porto Alegre, Porto Alegre, Brazil.
[4]Universidade Federal do Rio Grande do Sul, Escola de Engenharia – Departamento de Engenharia Elétrica, Porto Alegre, Brazil.
***Email: sanjeev.kumar@manchester.ac.uk**

INTRODUCTION

The plasma beam dump is a scheme to depose the relativistic beam kinetic energy in plasma medium, after the accelerated particle beam used purposefully. The plasma-based beam dump can be categorized into two types based on sources used to induce the wakefield: passive plasma beam dump (PPBD); and active plasma beam dump (APBD). In passive plasma beam dump [1] a relativistic particles bunch propagates in an undisturbed plasma and loses its energy through excitation of wakefield, whereas in an APBD a precursor laser pulse is introduced to excite the wakefield in plasma before an electron beam is injected in decelerating phase of the plasma wakefield for energy loss. Compared to the conventional beam dump where the high-density materials such as graphite or other metals are used to depose beam energy, the plasma beam dump offers compact footprint, low radiation hazards and therefore low costs. To investigate the beam energy loss, 2D particle-in-cell (PIC) simulation was performed with Smilei [2].

Numerical Simulation

An analytical model was solved using 2D particle-in-cell (PIC) code to extract the evolution of relativistic factor γ and the beam energy loss along the propagation direction with the optimum Laser and beam parameters (adopted from EuPRAXIA Conceptual Design Report [3]) are shown in Table 1.

$$\gamma(s) = \gamma_0 - \frac{k_p}{E_0}\left(s\, E_{zb} + \int ds\, E_{zl}\right)$$

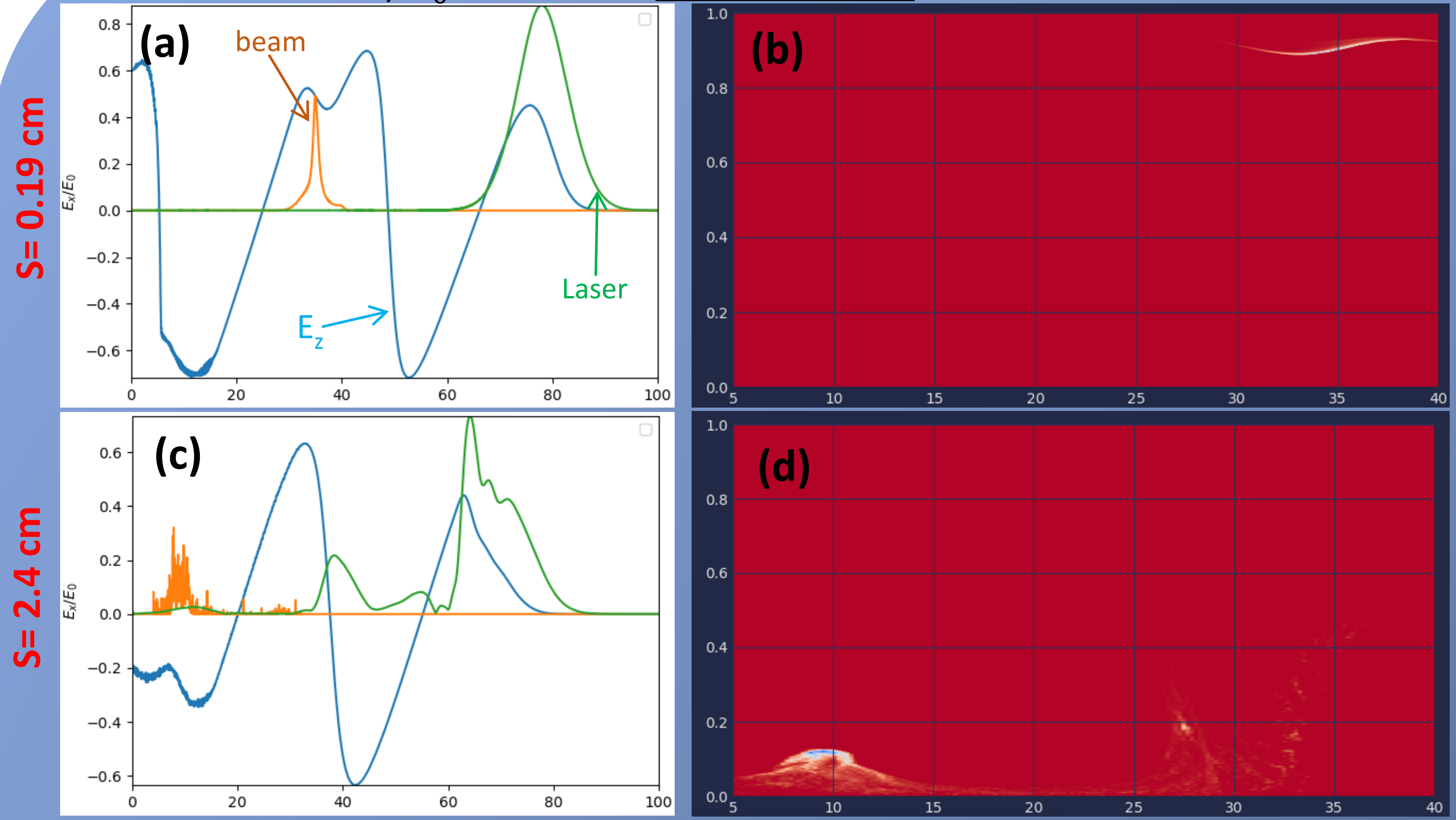
$$U(s) = \int_V dV\, \gamma(s)\; n_b(\xi, r)/n_0$$

Where, k_p is the plasma wave number. E_{zb} and E_{zl} are the bunch self-driven longitudinal plasma wakefield and laser-driven longitudinal plasma wakefield respectively, and $E_0 = c m_e \omega_p / e$ is the cold non-relativistic wave breaking electric field, c is speed of light, m_e is the electron rest mass, ω_p is plasma frequency, and e is electron charge.

Table 1. Simulation Parameter

Constant parameters	
Beam Energy	1 GeV
Bunch charge (Q)	30 pC
Transverse bunch size (σ_r)	1.4 μm
Longitudinal bunch size (σ_z)	2.0 μm
Energy spread	1.0%
Angular divergence (rad)	1.0×10^{-5}
Laser amplitude (a_0)	2.0
Laser length (σ_l)	7.5 μm
Laser waist(r_w)	17.0 μm

Results



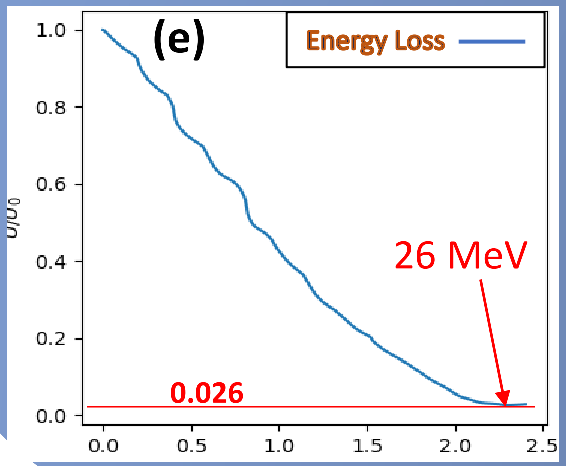


Fig: 2D simulation of active plasma beam dump was performed for the electron beam with peak density $n_b/n_0 \sim 3$ and $\gamma_0 = 1960$, propagating in a uniform plasma with density $n_0 = 1 \times 10^{18}\ cm^{-3}$. (a) Beam spatial distribution (orange curve), net longitudinal wakefield (blue curve) and the laser envelope (green curve) and (b) initial phase space at s = 0.19 cm. (c) Beam distribution, net wakefield, deformed laser envelope and (d) a phase space at s = 2.4 cm, bunch moved to the acceleration phase of wakefield. (e) The maximum energy loss was observed at s = 2.2 cm.

Conclusion

The particle-in-cell code Smilei was used to investigate the plasma-based beam dump first time in our group.

- In this study, we observed that the electron beam losing its maximum energy at s = 2.2 cm, reaching to a minimum average energy of 26 MeV. Whereas the previous study shows in passive plasma beam dump scheme for the same configuration of optimum parameters electron beam reaches to its minimum energy at a distance of 6 cm. Therefore, in active plasma beam dump, the electrons in the bunch lose their energy fast as compared to the passive beam dump scheme that could lead to the more compactness of the plasma particle accelerators.

- We also observed the high intensity laser envelope deformed due to the transverse nonlinear effect in plasma. To avoid the laser deformation because of transverse nonlinear effect further simulation has to be done with lower laser intensity.

References

1. G. Xia, A. Bonatto et al., *Instruments* 4 (2) 10 (2020).
2. A. Derouillat, et al., *Comput. Phys. Commun*. 222, 351-373 (2018).
3. R. W. Assmann, M. K. Weikum, T. Akhter et al. EuPRAXIA Conceptual Design Report., *Eur. Phys. J. Spec. Top.* 229, 3675–4284 (2020).
4. A. Bonatto et al. "Passive and active plasma deceleration for the compact disposal of electron beams", *Phys. Plasmas*, vol. 22, no. 8, pp. 083106 (2015).
5. O. Jakobsson, A. Bonatto et al., *Plasma Physics and Controlled Fusion* 61 (12), 124002, (2019).
6. K. Hanahoe, G. Xia, et al., Simulation study of a passiveplasma beam dump using varying plasma density. *Phys. Plasmas*, 24, 023120, 2017.