Electron response in Laguerre-Gaussian beam interaction with plasma targets

Mohammad Yasir[1], Satyabrata Kar[2], Vikrant Saxena[1]

[1] Department of Physics, Indian Institute of Technology Delhi, Hauz Khas, New Delhi, India
[2] Centre for Light-Matter Interactions, School of Maths and Physics, Queen's University Belfast, Belfast BT7 1NN, United Kingdom

Introduction

- Modestly intense vortex (Laguerre-Gaussian) can now be generated in experiments [1, 2].
- These vortex beams carry orbital angular momentum (OAM) of $l\hbar$ per photon [3].
- Vortex modes have lower peak fields at same pulse energy (see figure 1).
- With normalization factors of $\sqrt{\frac{p!}{(p+|l|)!}}$ or $l^{-1/2}\exp(l/2)$, one can get same total energy or same peak intensity across vortex and Gaussian modes.
- In figure 2, we plot how the laser intensity or pulse energy changes when one of them is kept constant across various vortex modes.

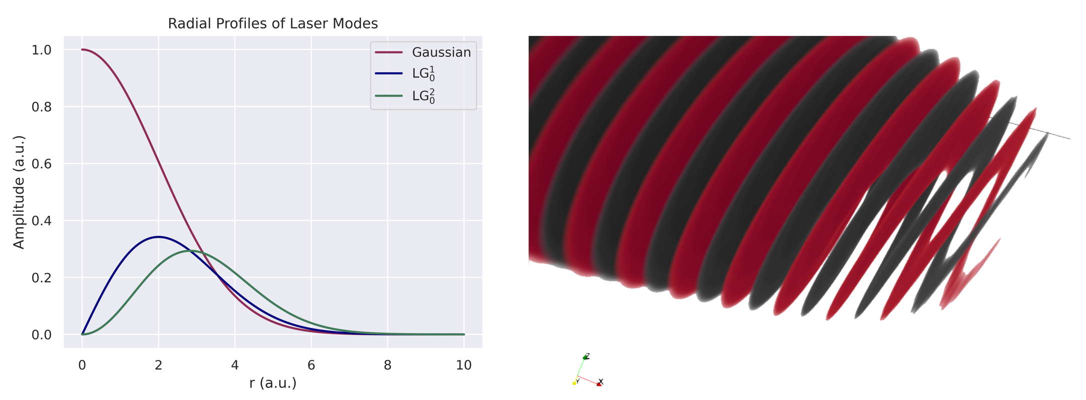

Figure 1: (Left) Radial profile of the Gaussian and the vortex modes. (Right) Electric field distributions of the LG_0^1 mode.

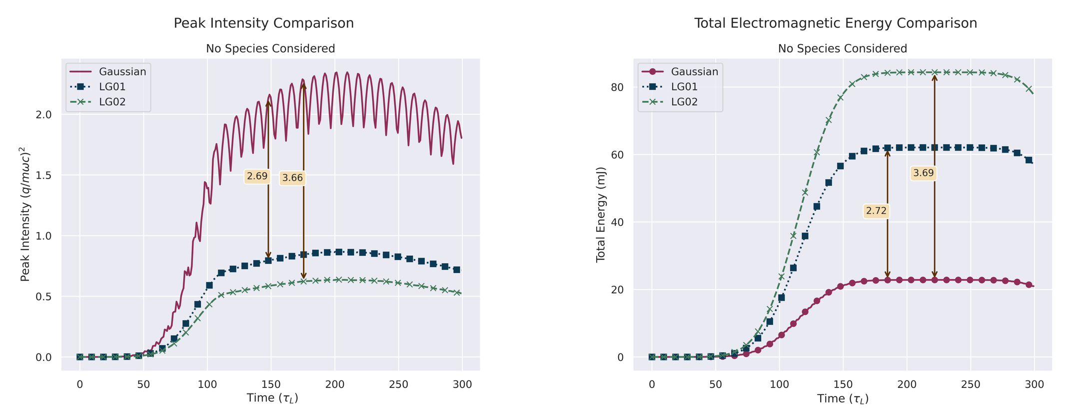

Figure 2: (Left) Intensity of various laser modes at same pulse energy. (Right) Energy of various laser modes with same peak intensity.

Simulation Setup

Simulation Setup	
Methodology	3D PIC with SMILEI
Box dimensions	56.98 μm × 18 μm × 18 μm
Resolution	42 × 42 × 42 nm^3

Plasma Parameters	
Target type	Overdense cylinder
Target size	$r = 8.0\ \mu m, t = 1.6\ \mu m$
Target density	$n = 1.026 \times 10^{28}\ m^{-3}$
Target start	$x = 26\ \mu m$

Laser Parameters	
Laser Modes	Gaussian, LG_0^1 and LG_0^2
Intensity	$I = 8.55 \times 10^{18}$ W/cm^2
Wavelength	$\lambda = 0.8\ \mu m$
Time Profile	Gaussian
Spot size	3 μm, 40 fs

Electron Temperatures

Without Preplasma			
Laser	Laser Energy	Front (keV)	Bulk (keV)
Gaussian	≈ 23 mJ	231	177
LG_0^1	≈ 62 mJ	664	186
LG_0^2	≈ 84 mJ	625	210

With Preplasma ($5\ \lambda$ Scale Length)			
Laser	Laser Energy	Front (keV)	Bulk (keV)
Gaussian	≈ 23 mJ	1284	344
LG_0^1	≈ 62 mJ	1180	321
LG_0^2	≈ 84 mJ	1192	276

Magnetic Field Comparison

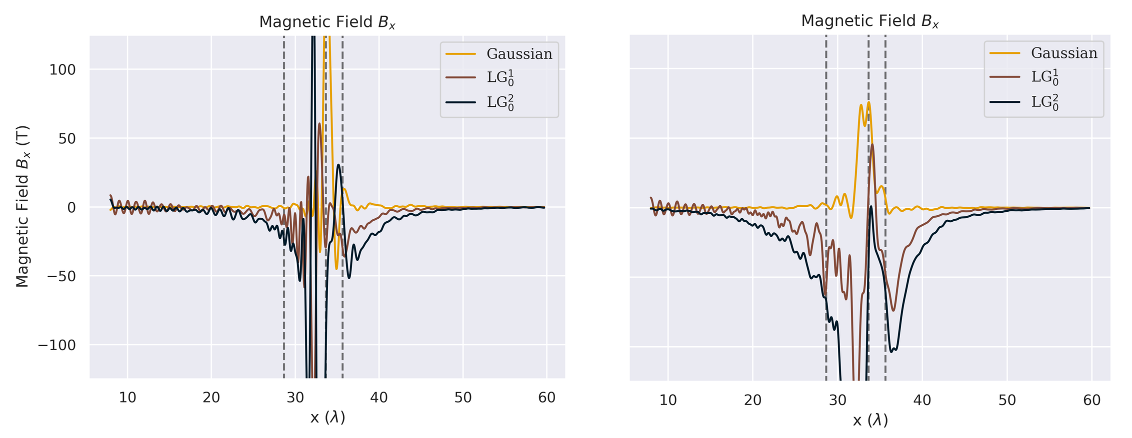

Figure 3: Comparison of on-axis longitudinal magnetic fields without (left) and with (right) preplasma on the front.

Orbital Angular Momentum

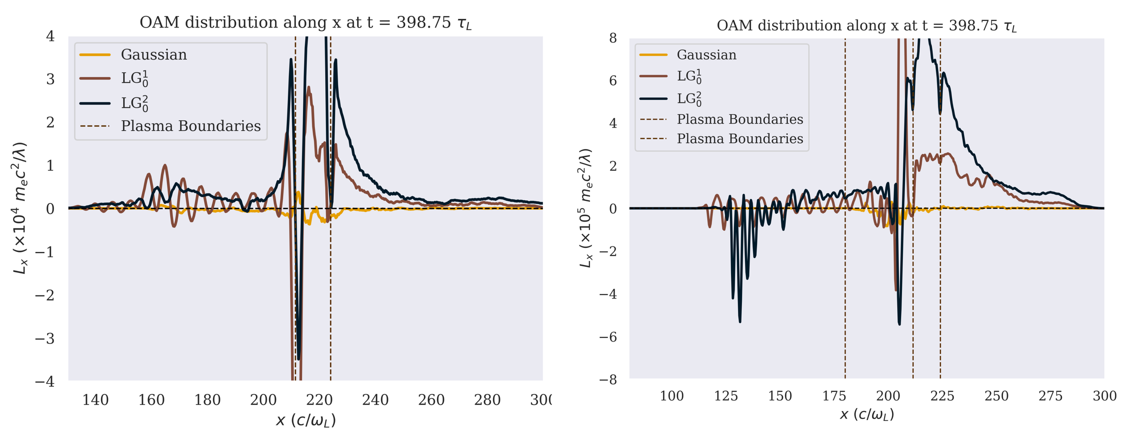

Figure 4: Comparison of orbital angular momentum L_x at t = $398.75\ \tau_L$ without (left) and with (right) preplasma on the front.

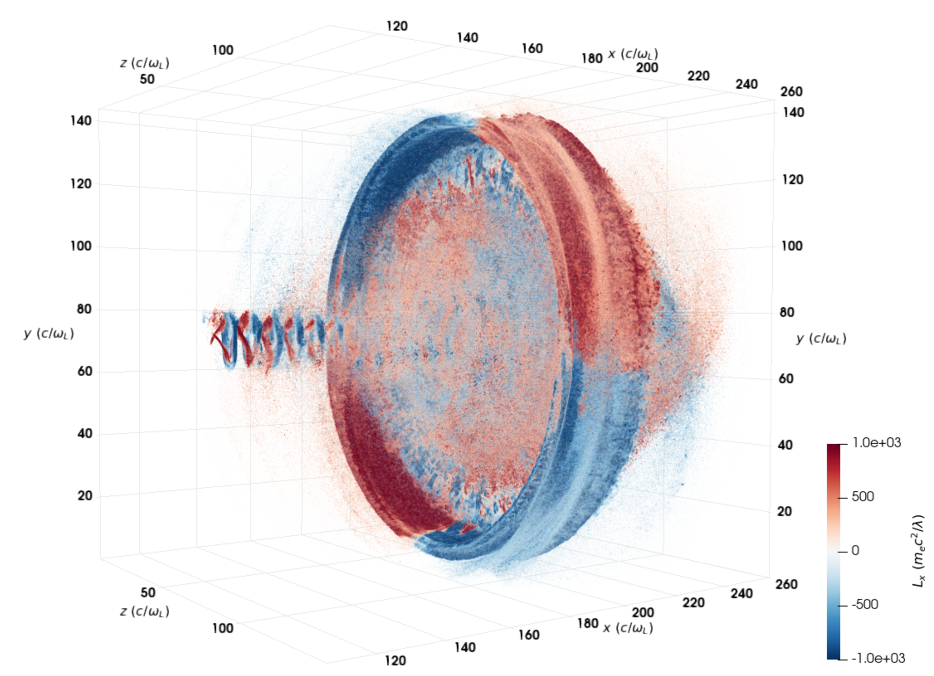

Figure 5: Structure of the OAM deposited inside the box by plasma electrons when irradiated with LG_0^1 laser (with preplasma case).

Temperature Scaling With Preplasma Scale Length

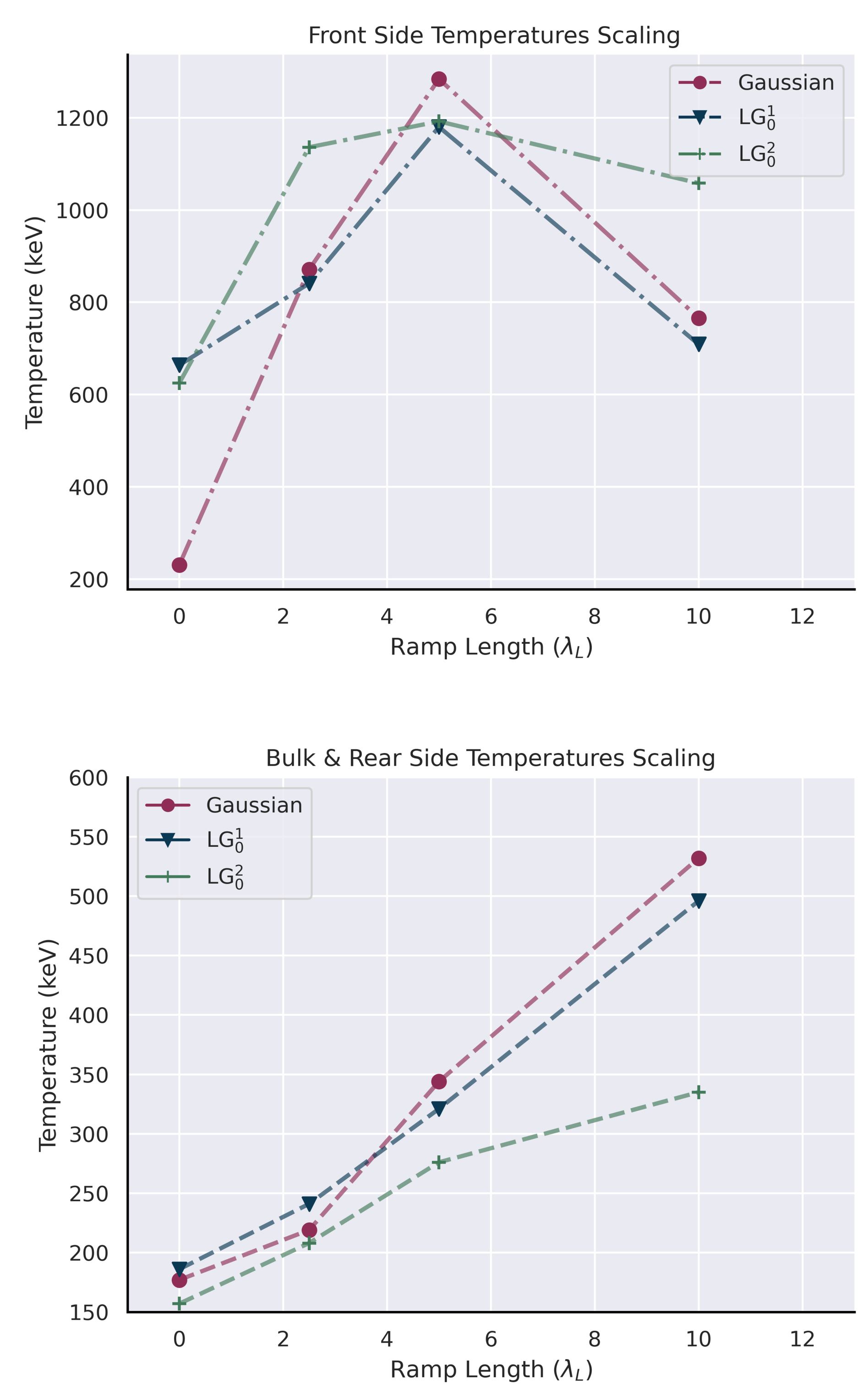

Figure 6: Variation of electron temperatures with preplasma scale length.

Comparison At Same Laser Energy (≈ 23 mJ)

Without Preplasma			
Laser mode	Laser a_0	Front (keV)	Bulk (keV)
Gaussian	2	231	177
LG_0^1	1.21	280	98
LG_0^2	1.04	147	31

With Preplasma ($5\ \lambda$ Scale Length)			
Laser mode	Laser a_0	Front (keV)	Bulk (keV)
Gaussian	2	1284	344
LG_0^1	1.21	736	211
LG_0^2	1.04	365	155

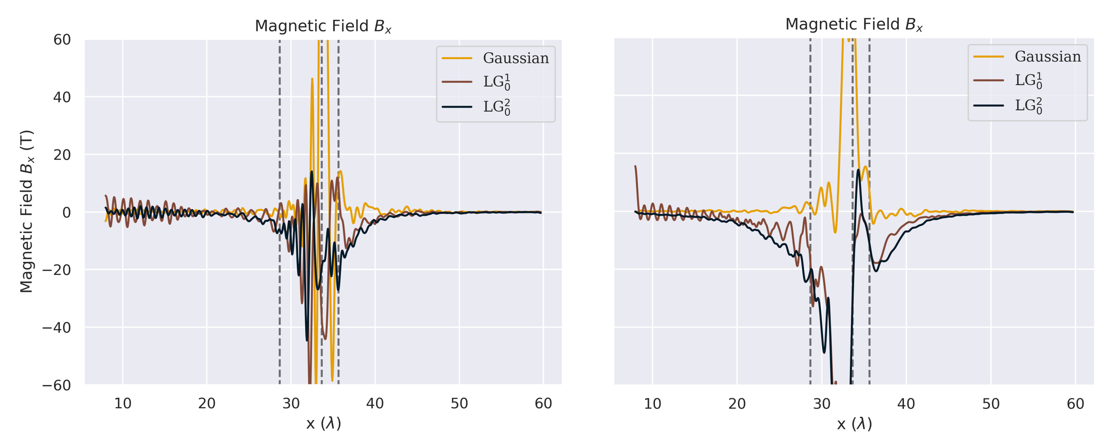

Figure 7: On-axis longitudinal magnetic fields generated without (left) and with (right) preplasma when laser mode energies are same.

Conclusion

- At **same laser intensity**, there is noticeable **enhancement in electron temperatures** with vortex modes in the absence of preplasma, but not so much with a preplasma.
- Vortex mode interaction generates **on-axis longitudinal magnetic fields** that can surpass $70 - 80$ Tesla at $a_0 = 2$.
- Noticeable **OAM is transferred** to plasma electrons due to vortex modes.
- The OAM distribution has **specific structure** on the front side.
- Electron **temperatures on the rear** side are **less affected by preplasma length** with higher-order LG mode.
- At **same laser pulse energy**, there is a **decay in temperatures** when using vortex modes, possibly due to the fall in laser intensity for vortex modes.

References

1. Brabetz, C. *et al.* en. in *Conference on Lasers and Electro-Optics 2012* (OSA, San Jose, California, 2012), JTu1K.5. ISBN: 978-1-55752-943-5. (2025).
2. Porat, E. *et al.* en. *Journal of Optics* **24,** 085501. ISSN: 2040-8986. (2025) (July 2022).
3. Allen, L. *et al.* en. *Physical Review A* **45,** 8185–8189. ISSN: 1050-2947, 1094-1622. (2025) (June 1992).

Acknowledgements

- M. Yasir acknowledges IIT Delhi for providing financial grant & access to the institute HPC cluster.
- We acknowledge the National Supercomputing Mission for the computing resources of PARAM Rudra located at IUAC New Delhi.

Contact: mohammad.yasir@physics.iitd.ac.in