# Effects of Chromatic Aberration in a Dephasingless Laser Wakefield Accelerator

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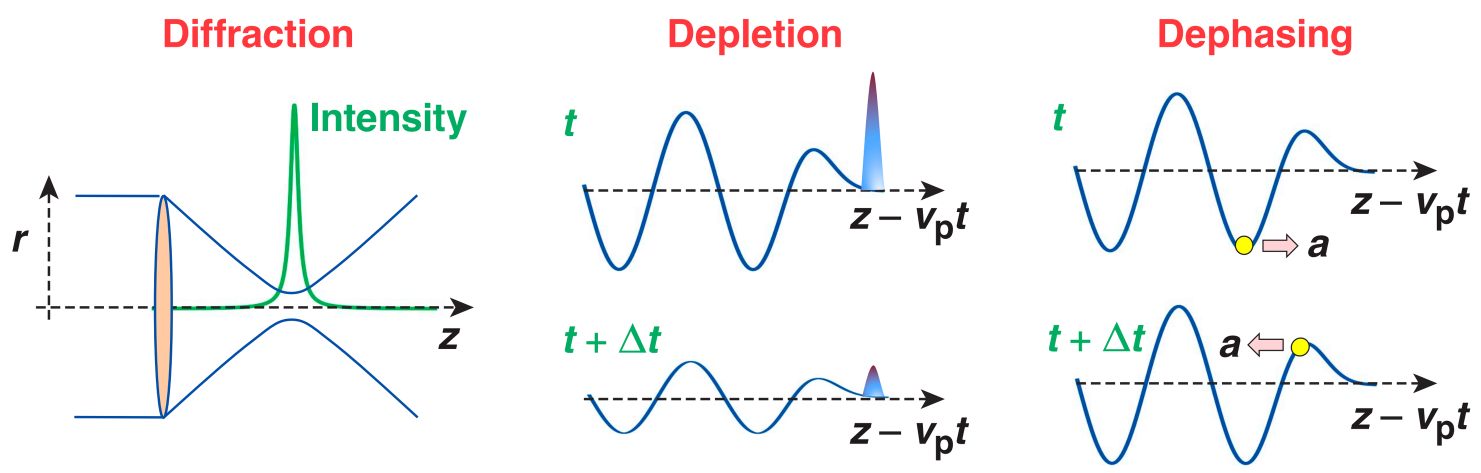
University of Rochester, Laboratory for Laser Energetics

## Introduction

In a laser-wakefield accelerator (LWFA), the ponderomotive force of an intense laser pulse propagating through a plasma excites a large-amplitude plasma wakefield that can trap and accelerate electrons [1].

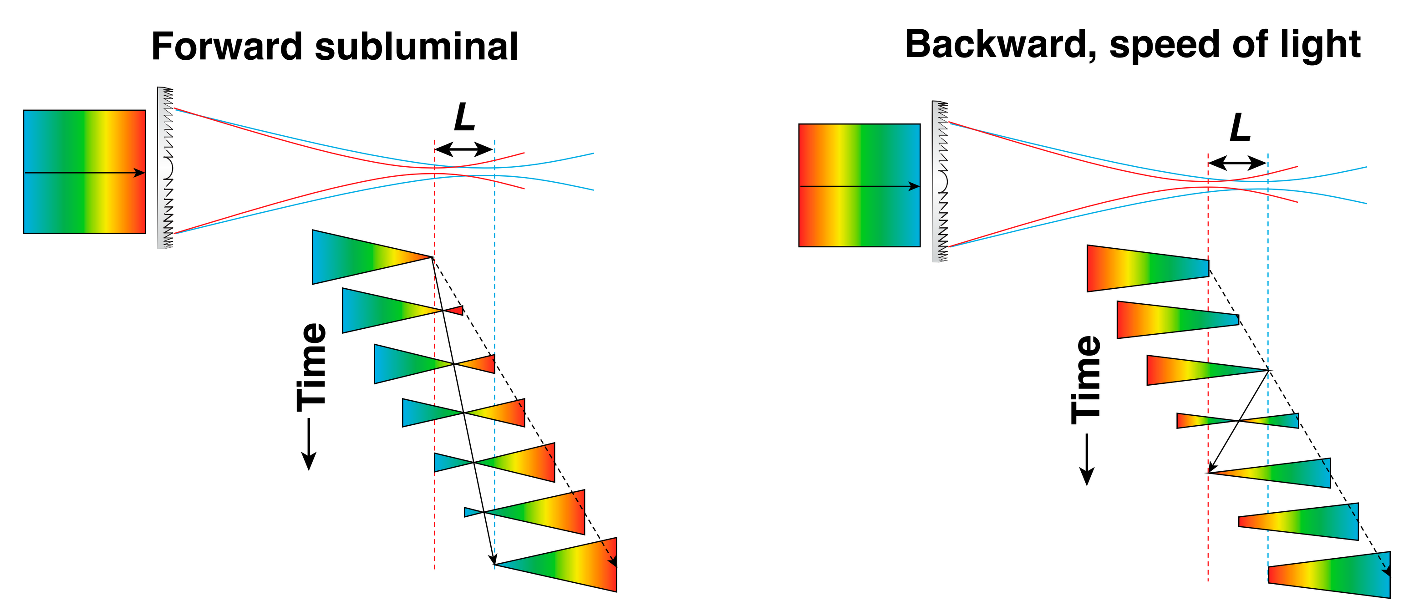
Three fundamental challenges limiting LWFA performance are

- Diffraction: the laser pulse diffracts as it propagates, decreasing its intensity and thus its ability to drive a wake
- Depletion: the laser pulse loses energy to the wakefield, decreasing its intensity
- Dephasing: electrons ($v_z \sim c$) outrun the accelerating phase of the wakefield and are no longer accelerated




## Chromatic Flying Focus

[2]



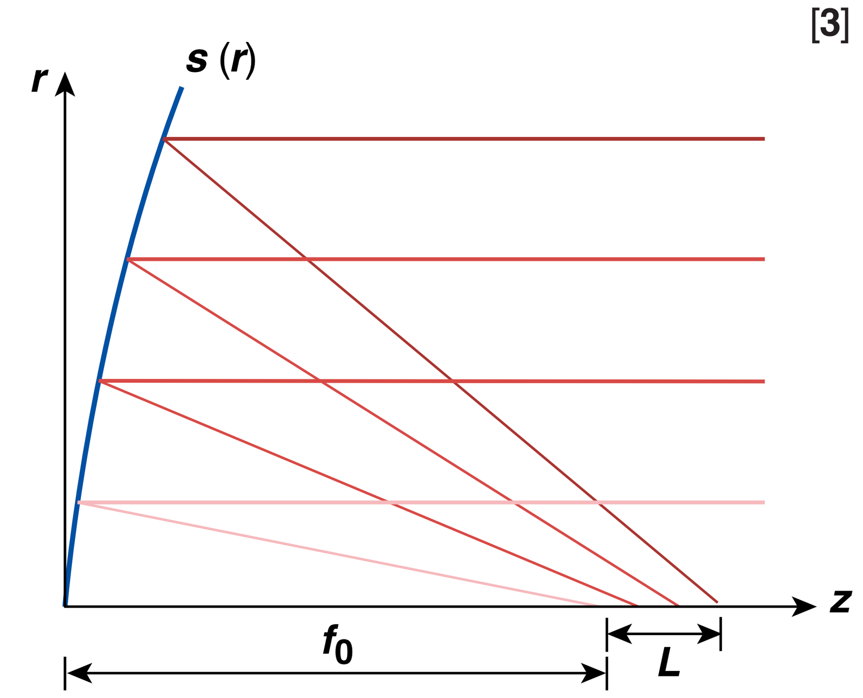

- The original flying focus uses a highly chromatic diffractive focusing optic to focus different colors in a pulse to different axial locations in the far field [2]
- By controlling the chirp of the input pulse, the arrival time of each color to its respective focus can be controlled
- However, since the pulse's bandwidth is spread out over the focal region, the ultrashort pulse duration is lost

## Axiparabola and Radial Group Delay

[3]

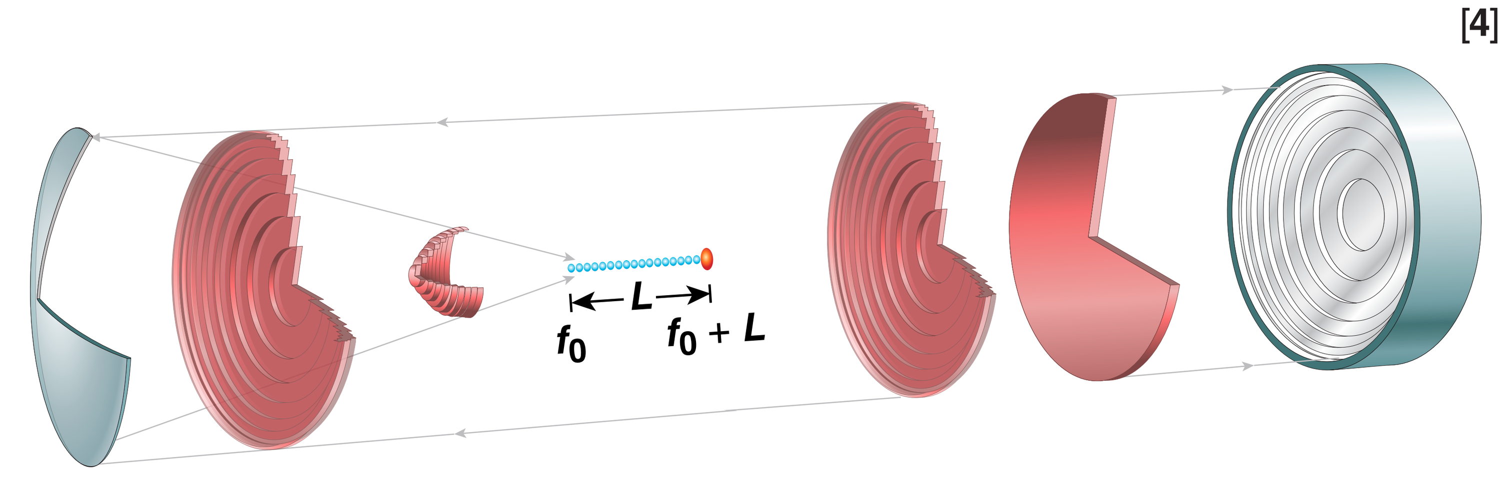
- An axiparabola is a reflective optic that focuses light rays at different radial locations in the near field to different axial locations in the far field [3]
- By controlling the arrival time of each radius at the axiparabola with a tailored radial group delay, an intensity peak can be driven at a desired velocity

$r$ – radial coordinate
$z$ – longitudinal coordinate
$s(r)$ – axiparabola sag function
$f_0$ – focal length offset
$L$ – focal depth

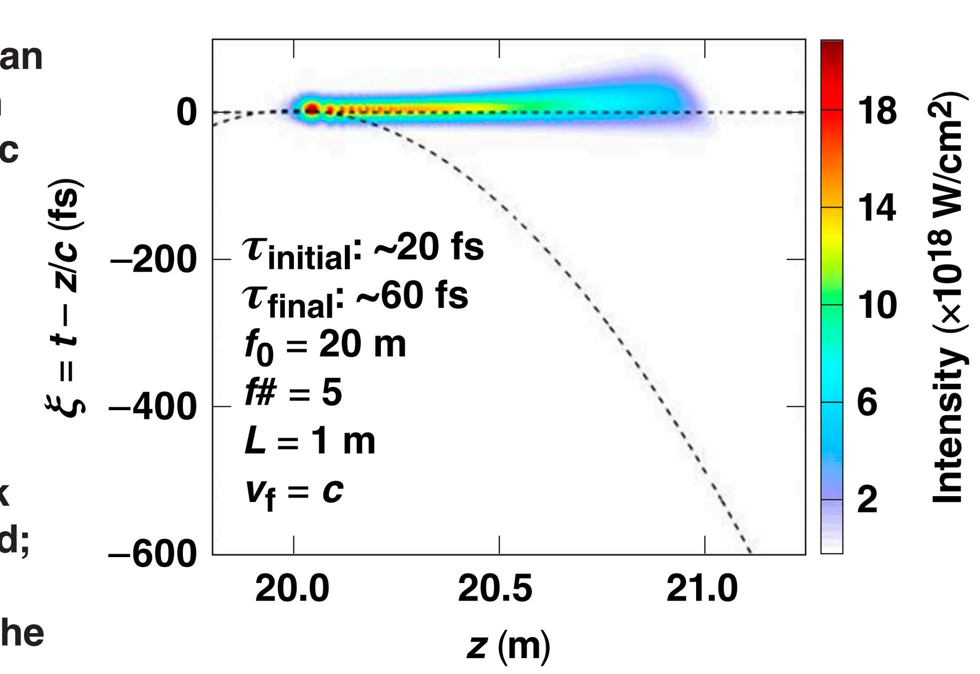



## Axiparabola and Reflective Echelon

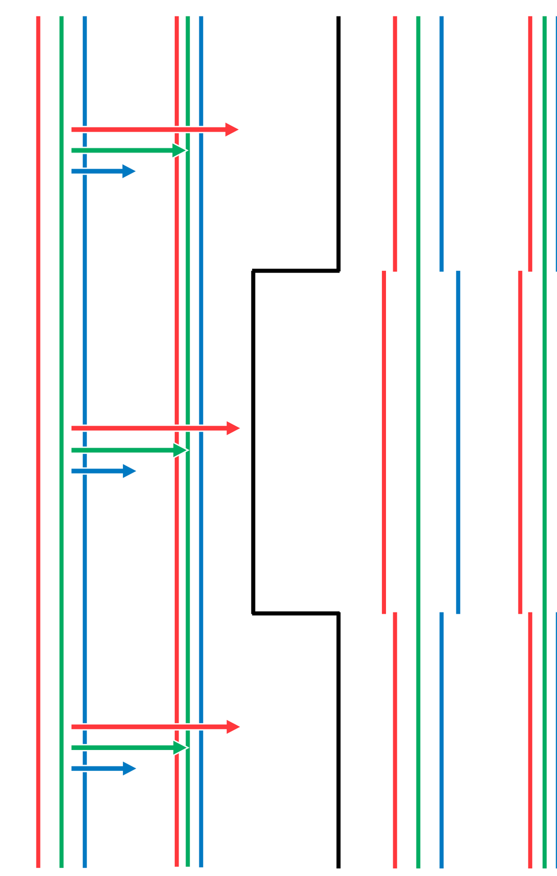
[4]




- A reflective echelon (1) separates a pulse into concentric rings, (2) imparts a stepped radial group delay to the pulse to control the arrival time of each ring to the axiparabola, and (3) circumvents chromatic aberration inherent in refractive optics [4]
- Within each echelon step, the pulse front (surface coinciding with the peak intensity of the pulse) and phase front (surface of constant phase) are flat
- Despite using reflective optics, simulations suggest an increase in pulse duration in the far field akin to chromatic aberration; this is shown in the figure to the right by the broadening of the pulse in $\xi$ as the pulse propagates
- The dashed horizontal line shows a constant focal velocity of the intensity peak when the echelon is included; the dashed curve shows an increasing focal velocity of the intensity peak without the echelon




## Quasi-Chromatic Aberration in the Reflective Echelon



- Consider a single-step echelon with $\lambda_0$/2-deep steps (black lines) modeled in "transmission"
- Input rays have flat phase fronts (colored lines)
- Immediately after reflecting from the inner step, the phase fronts are still flat
- However, since the echelon steps are fixed at $\lambda_0$/2-deep, the phase fronts of different wavelengths have different step-to-step phase differences

$\Delta\phi_{max} < \Delta\phi_0$
$\Delta\phi_{min} > \Delta\phi_0$

$\lambda_0$: central wavelength
$\lambda_{max} = \lambda_0 + d\lambda/2$: maximum wavelength
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- This leads to longitudinal chromatism and thus pulse broadening in the far field

## Conclusions

- A reflective echelon can impart a stepped radial group delay to a pulse prior to its creation of a flying focus with an axiparabola
- Far-field chromatic-like aberrations arise because the echelon steps are fixed at a depth defined by the central wavelength, therefore other wavelengths in the pulse no longer maintain the same fixed-phase relation from step to step
- Simulations suggest this quasi-chromatic aberration is noticeable for long axiparabola focal lengths (~1 m) but insignificant for lengths relevant for dephasingless laser wakefield acceleration (~10 cm)

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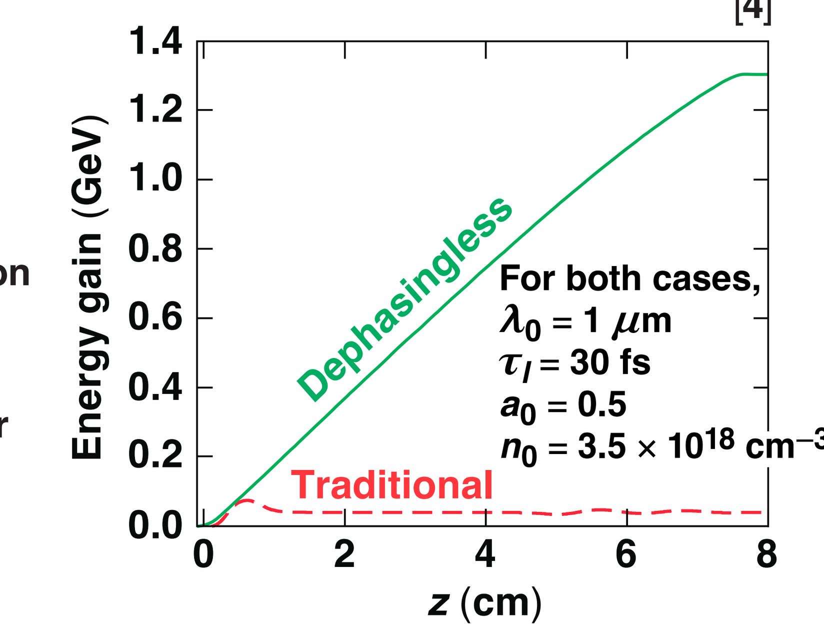


- In the DLWFA, the electron gains 1.3 GeV over 16 dephasing lengths, while in the traditional LWFA, the electron outruns the laser pulse and only gains a maximum of 75 MeV energy over a single dephasing length [4]

## References

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## Acknowledgements

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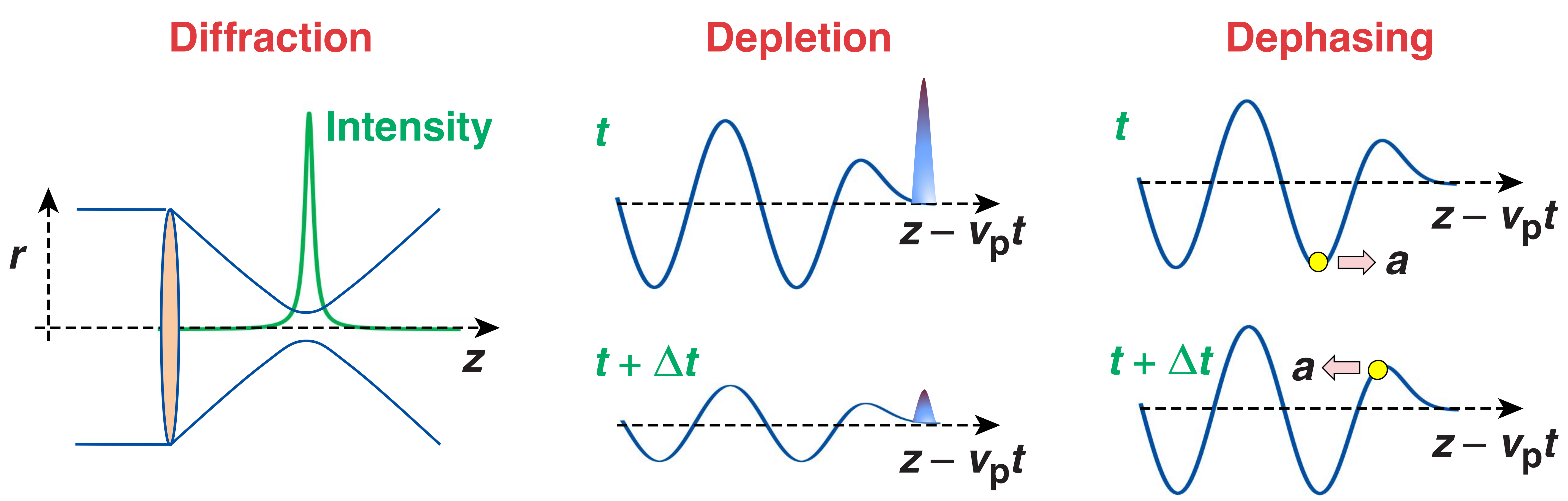


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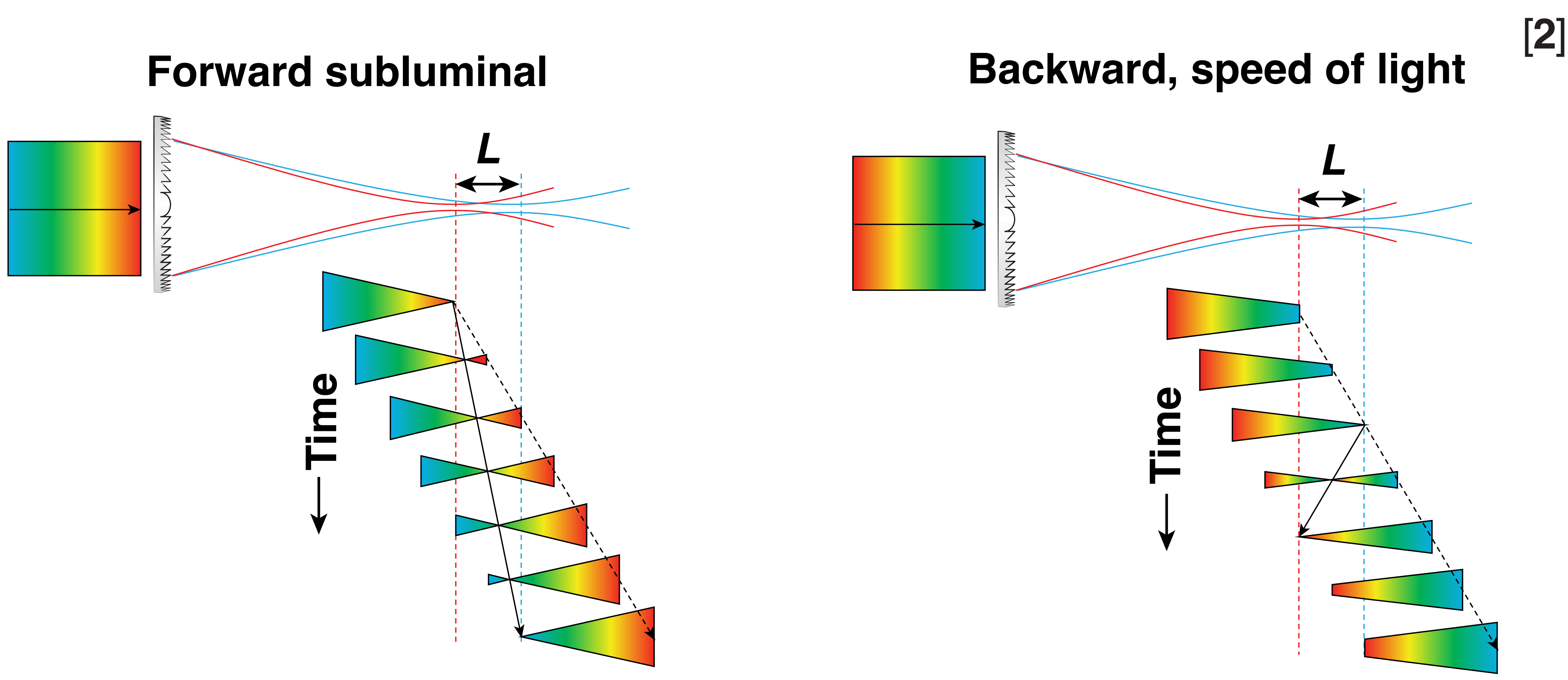


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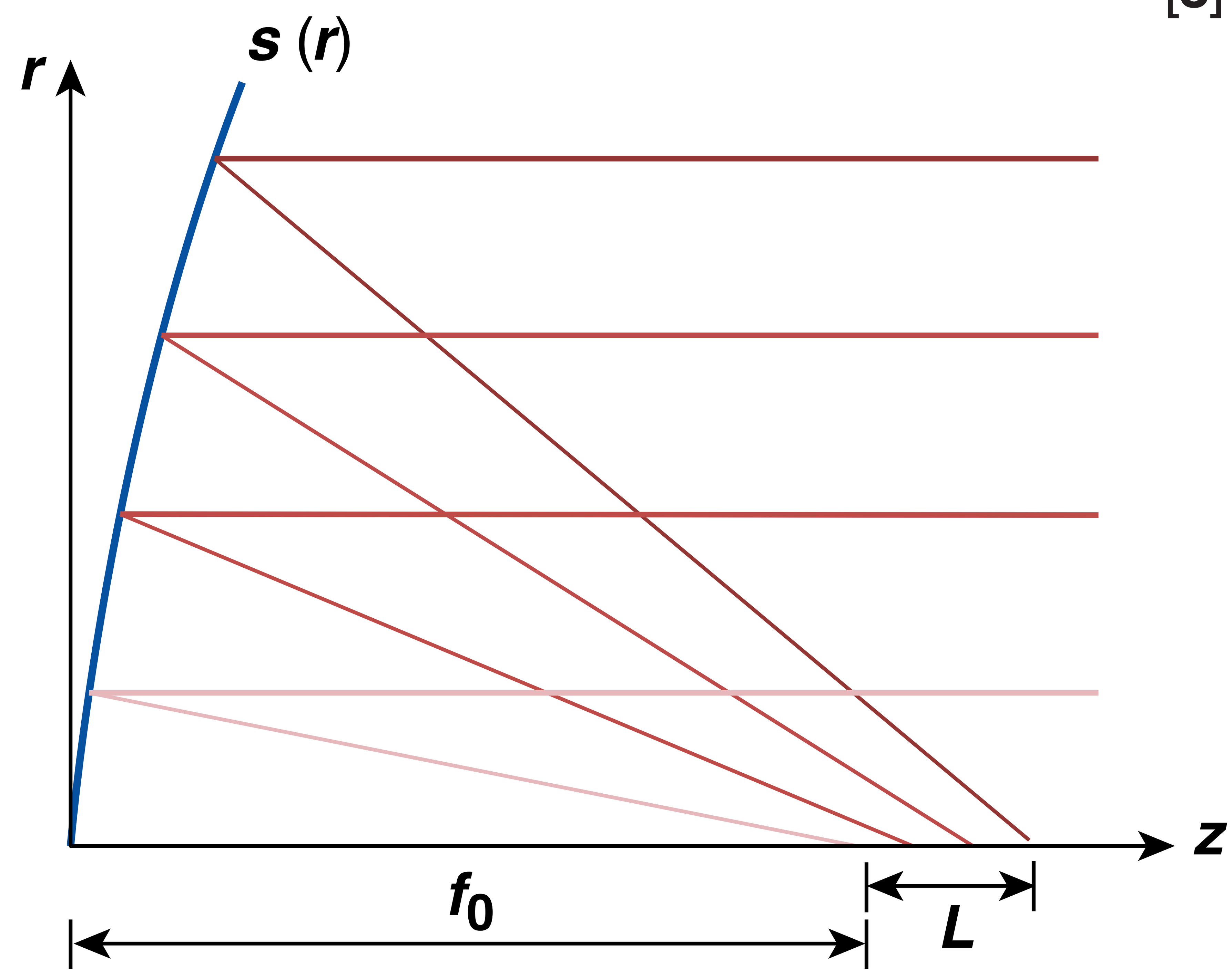


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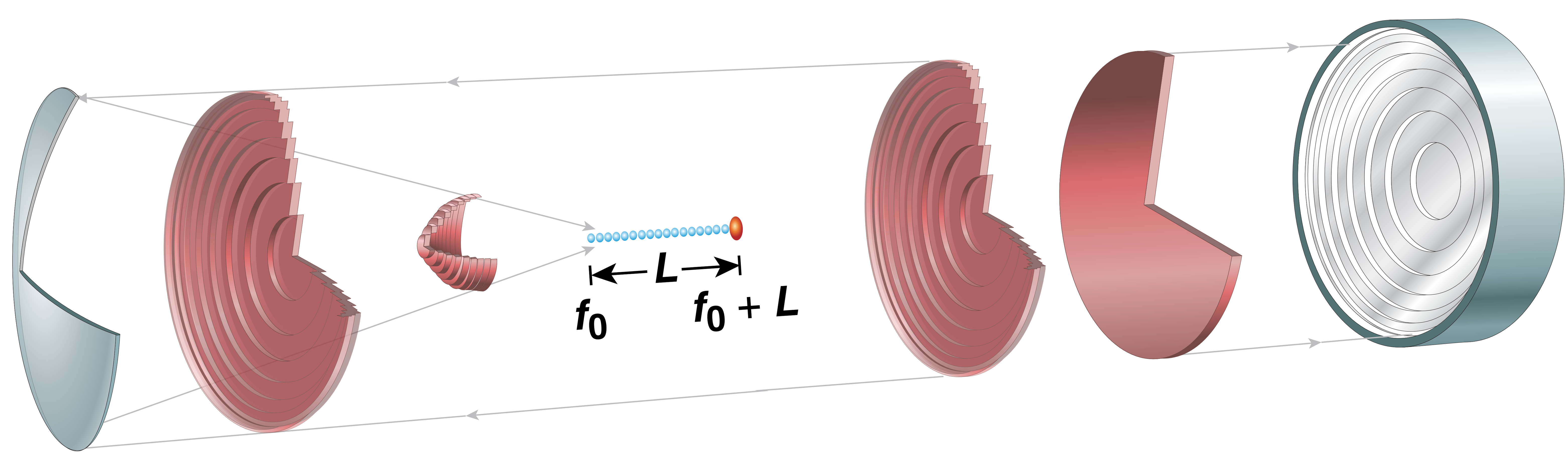


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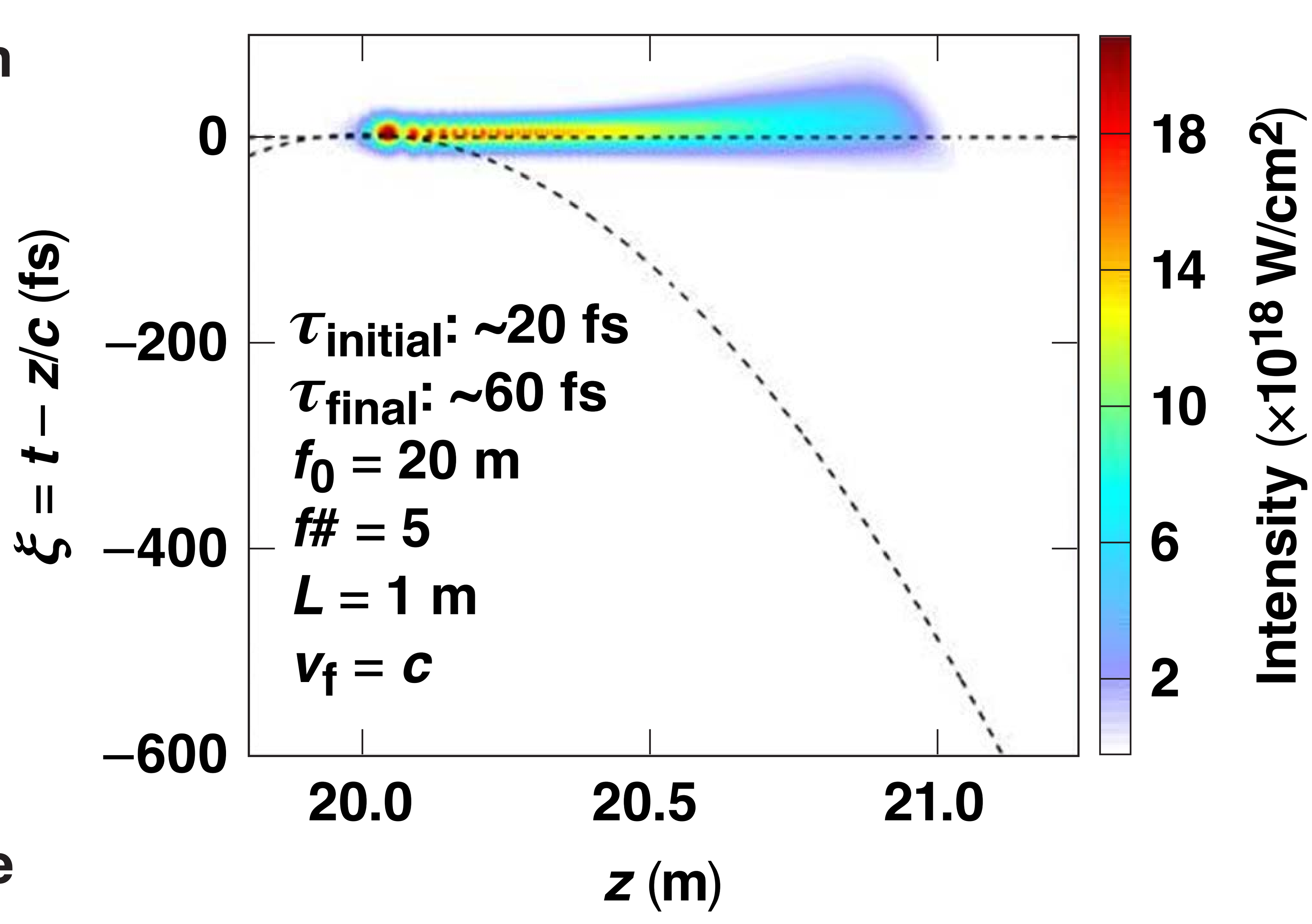

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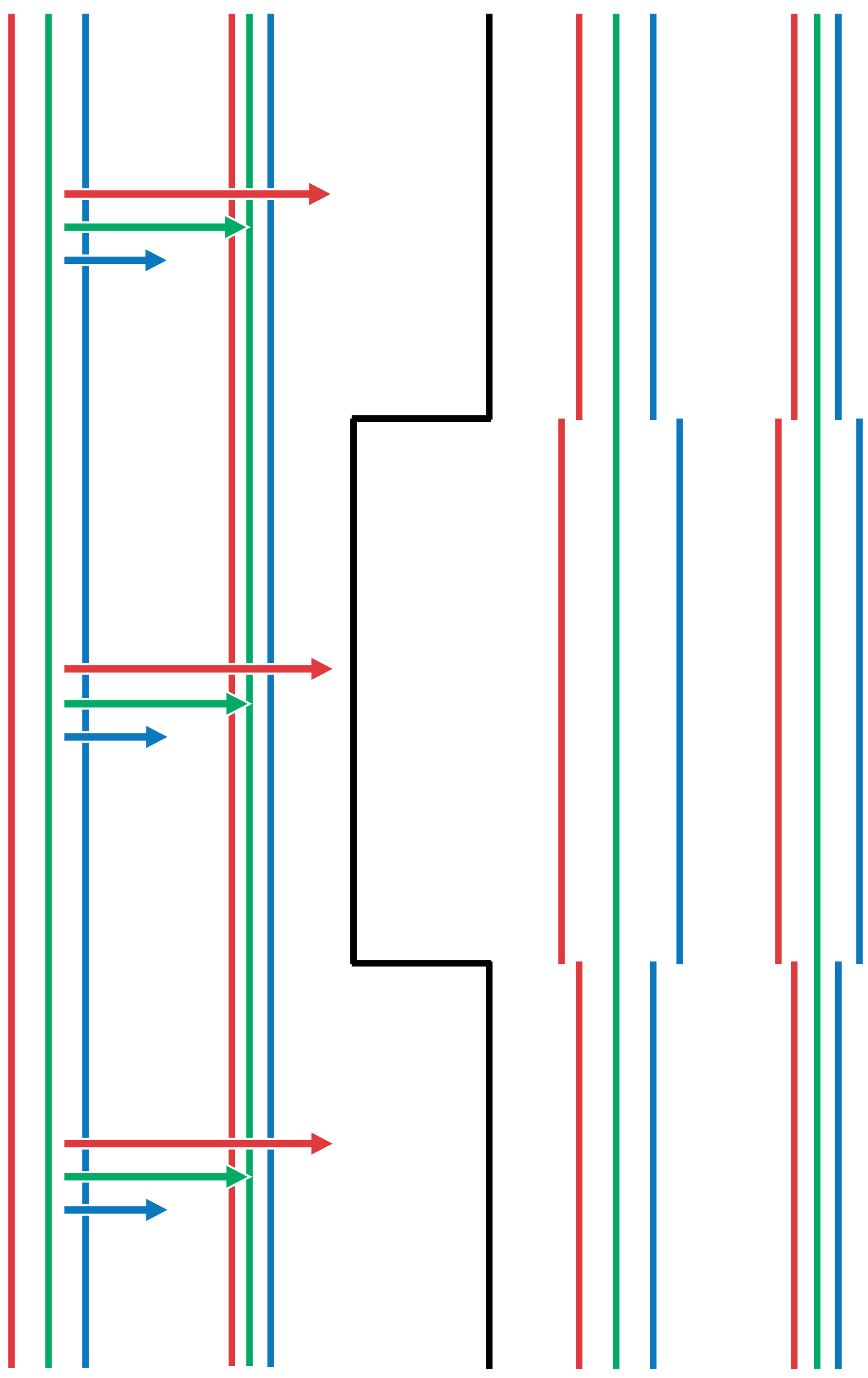

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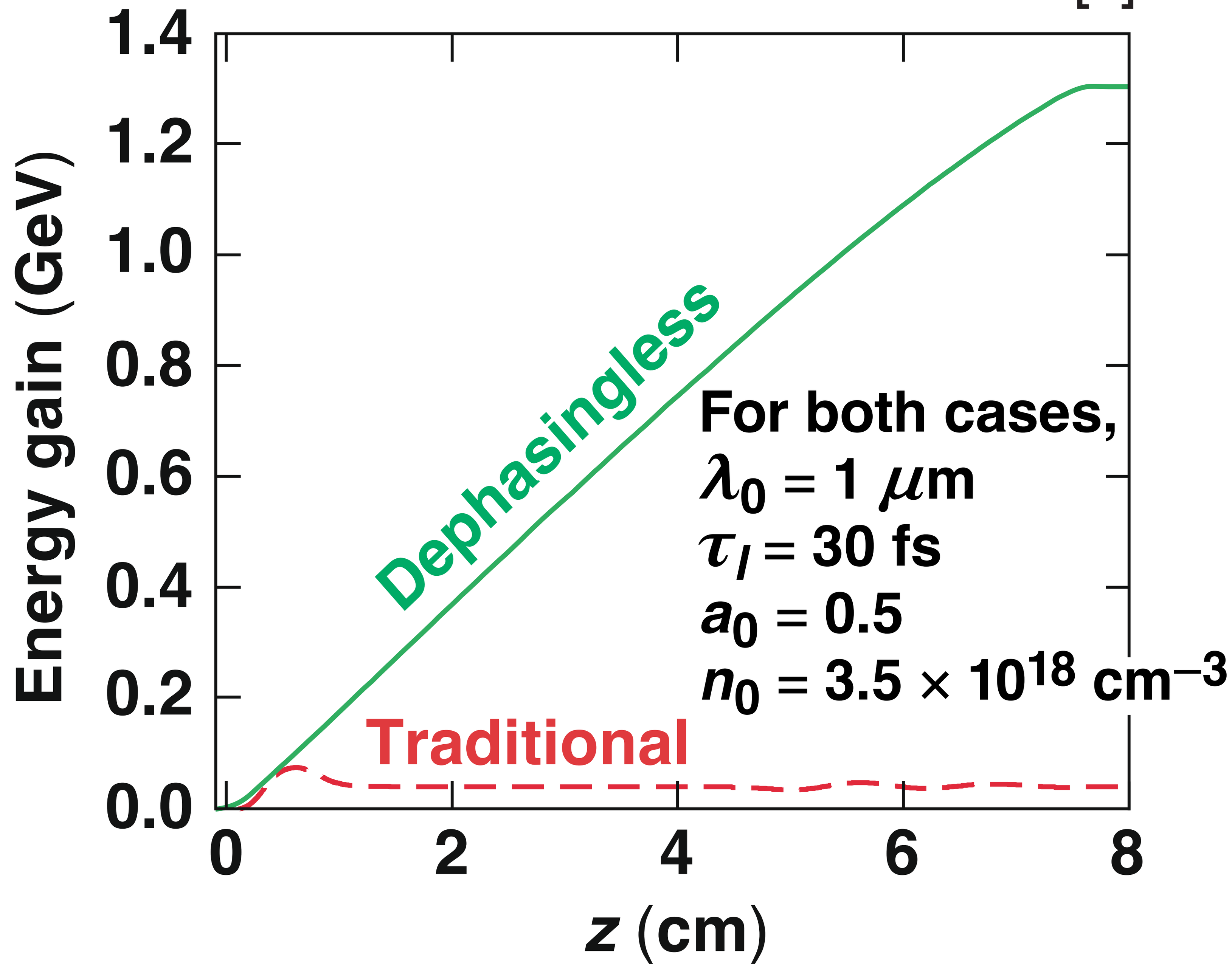


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