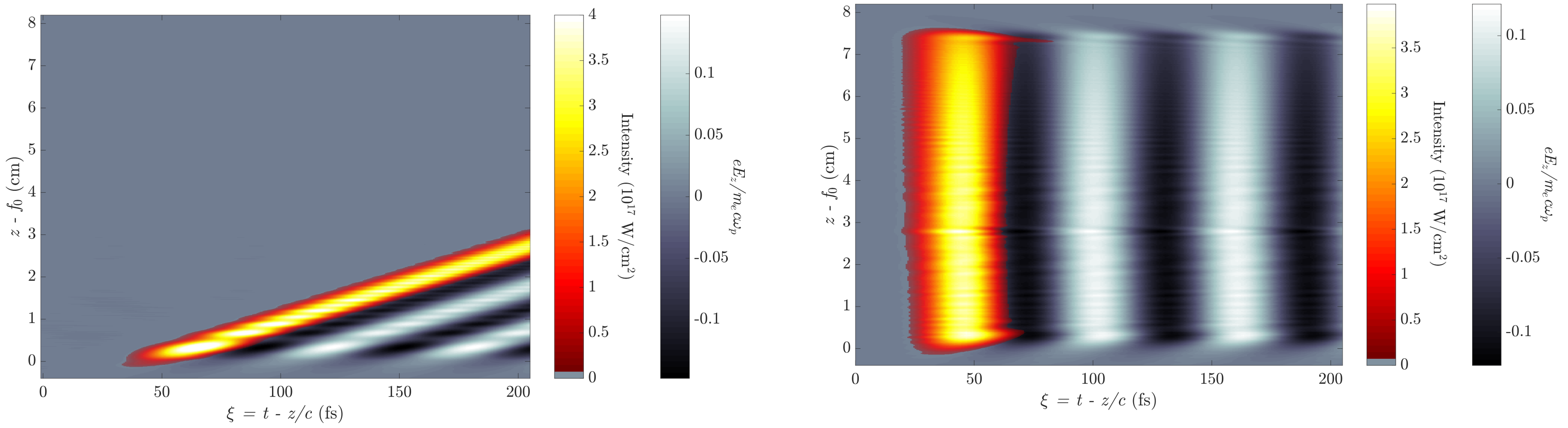
Dephasingless laser wakefield acceleration



J.P. Palastro, J.L. Shaw, D. Ramsey, T.T. Simpson,
P. Franke, S. Ivancic, K. Daub, and D.H. Froula

61st Annual APS DPP Meeting
Fort Lauderdale, FL Oct 23rd 2019

UNIVERSITY of ROCHESTER

An achromatic flying focus* can overcome the dephasing length limitation of laser wakefield accelerators

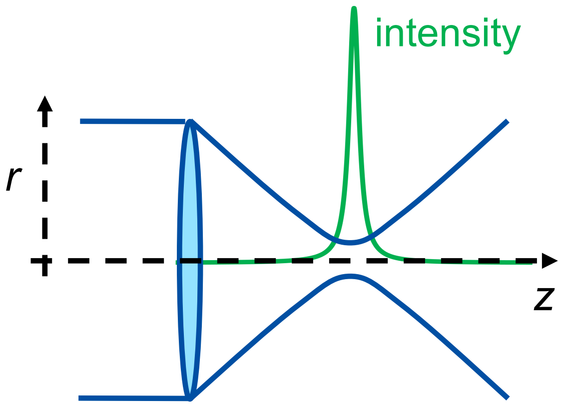
- Traditional laser wakefield accelerators suffer from three limitations: (1) diffraction, (2) depletion, and (3) dephasing
- An axiparabola‡ focuses annuli of a pulse to different locations creating a near-constant intensity over an extended distance
- Coupling the axiparabola to a novel echelon optic provides control over the velocity of the ponderomotive force and eliminates dephasing, depletion, and diffraction

*D. Froula *et al*. Nat. Physics, 12 262 (2018)

‡S. Smartsev *et al*. Opt. Lett., 44 3414 (2019)

Dephasing, diffraction, and depletion limit the energy gain in traditional laser wakefield accelerators

Diffraction



Transverse spreading of the pulse reduce its intensity and the strength of the wake

Depletion

The laser pulse continually loses energy driving the wakefield

Dephasing

Energetic electrons quickly outrun the accelerating phase of the wakefield

Dephasing, diffraction, and depletion limit the energy gain in traditional laser wakefield accelerators

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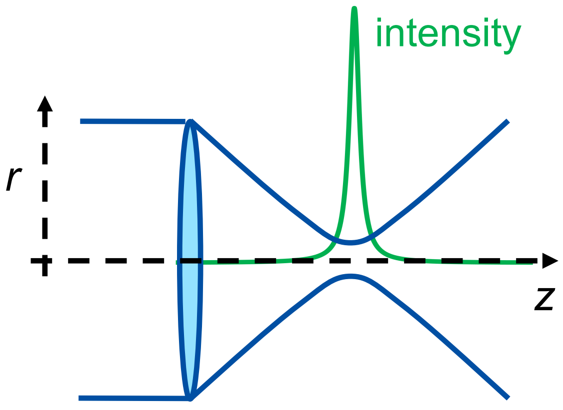

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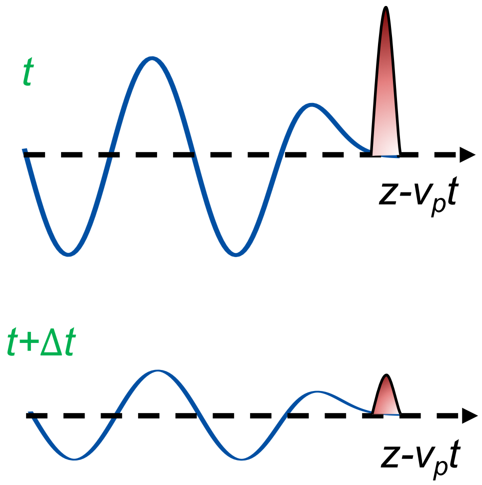

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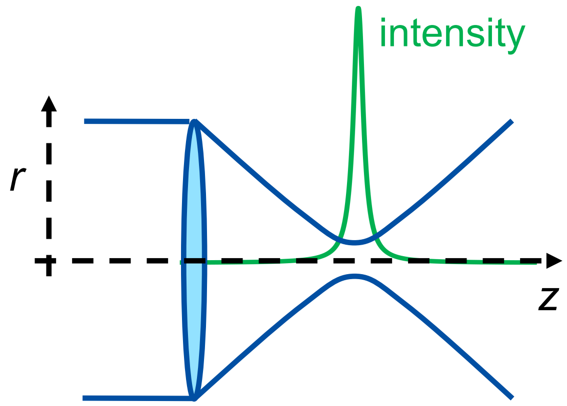

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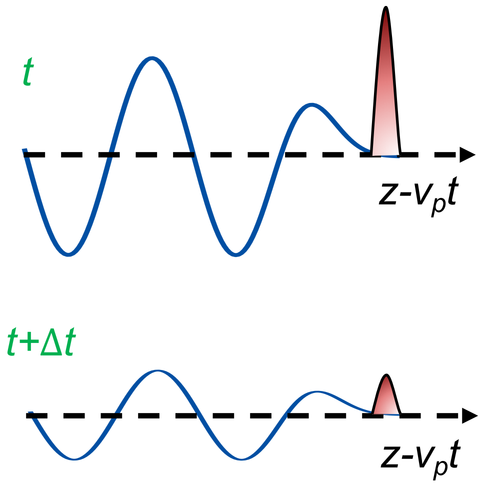

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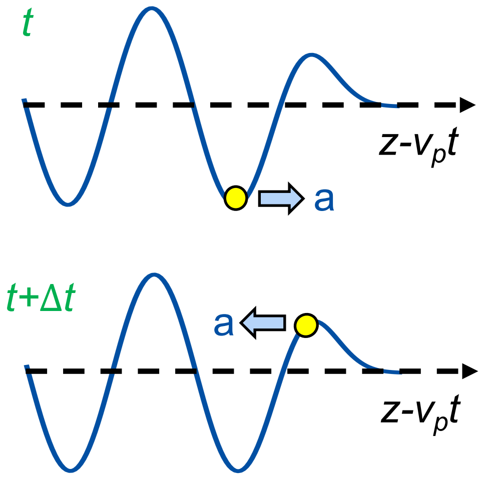

Energetic electrons quickly outrun the accelerating phase of the wakefield

A dephasingless LWFA can accelerate electrons to much higher energies than a traditional LWFA

Traditional LWFA

$$\frac{\Delta E_T}{mc^2} = \frac{\pi^2}{8} a_0^2 \frac{k_0^2}{k_p^2}$$

energy gain

Dephasingless LWFA

$$\frac{\Delta E_D}{mc^2} = \frac{\pi}{8} a_0^2 k_p L$$

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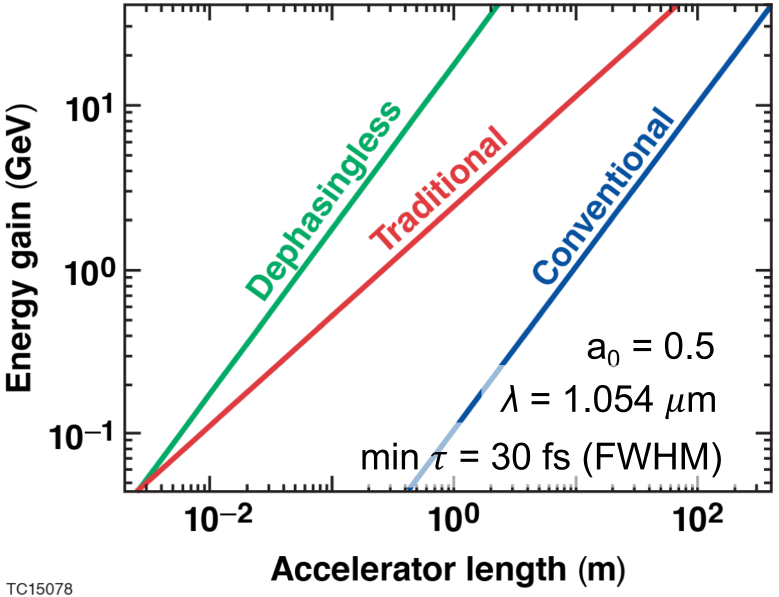

TC15078

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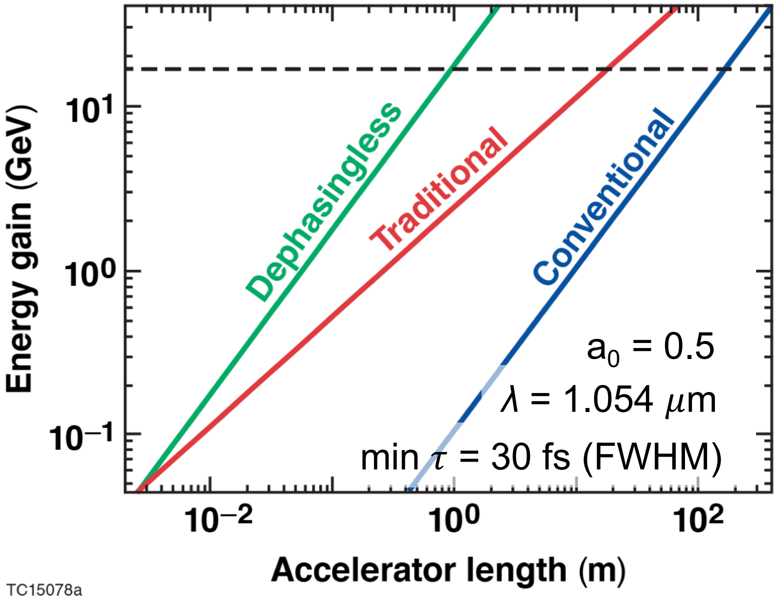
accelerator length

For equal energy gain:

$$\frac{U_D}{U_T} = \frac{16}{\pi^3}\left(\frac{2c\tau_m}{L}\right)^{1/2}(\omega_0\tau_m)^2$$

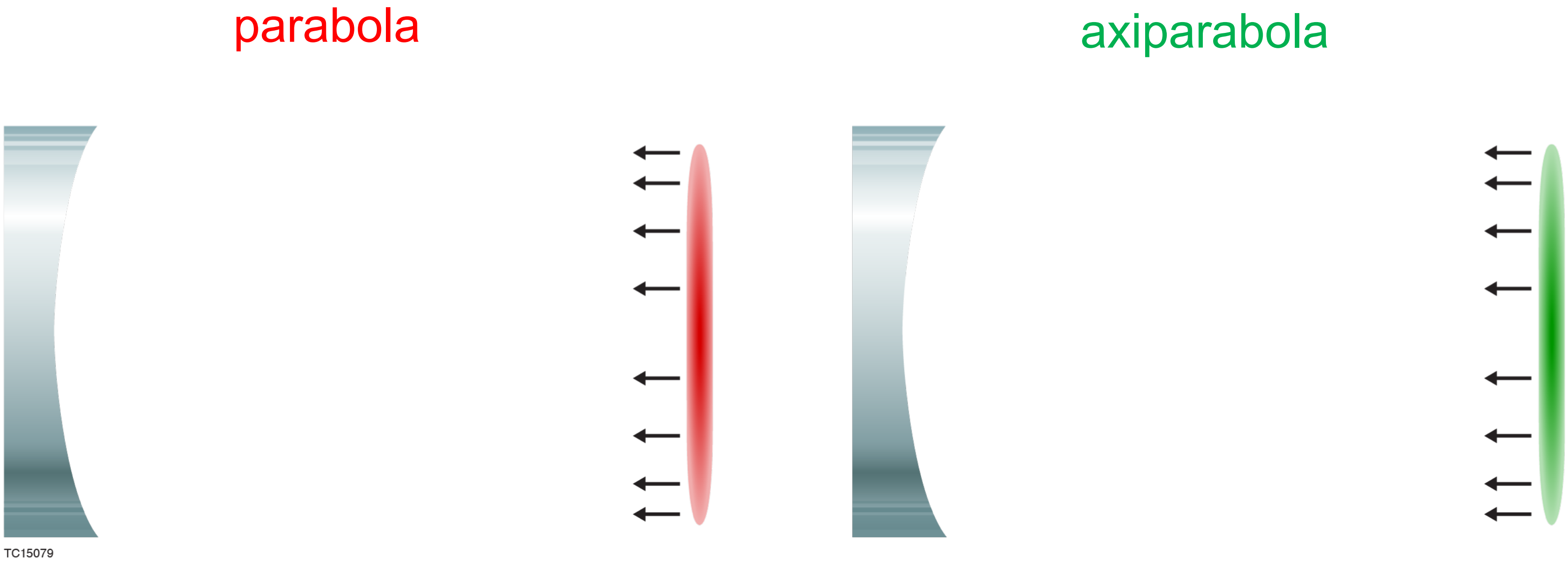
ratio of laser energies

minimum duration



TC15078a

An axiparabola[‡] focuses annuli of a pulse to different locations creating a near-constant intensity over an extended distance



‡S. Smartsev *et al*. Opt. Lett., 44 3414 (2019)

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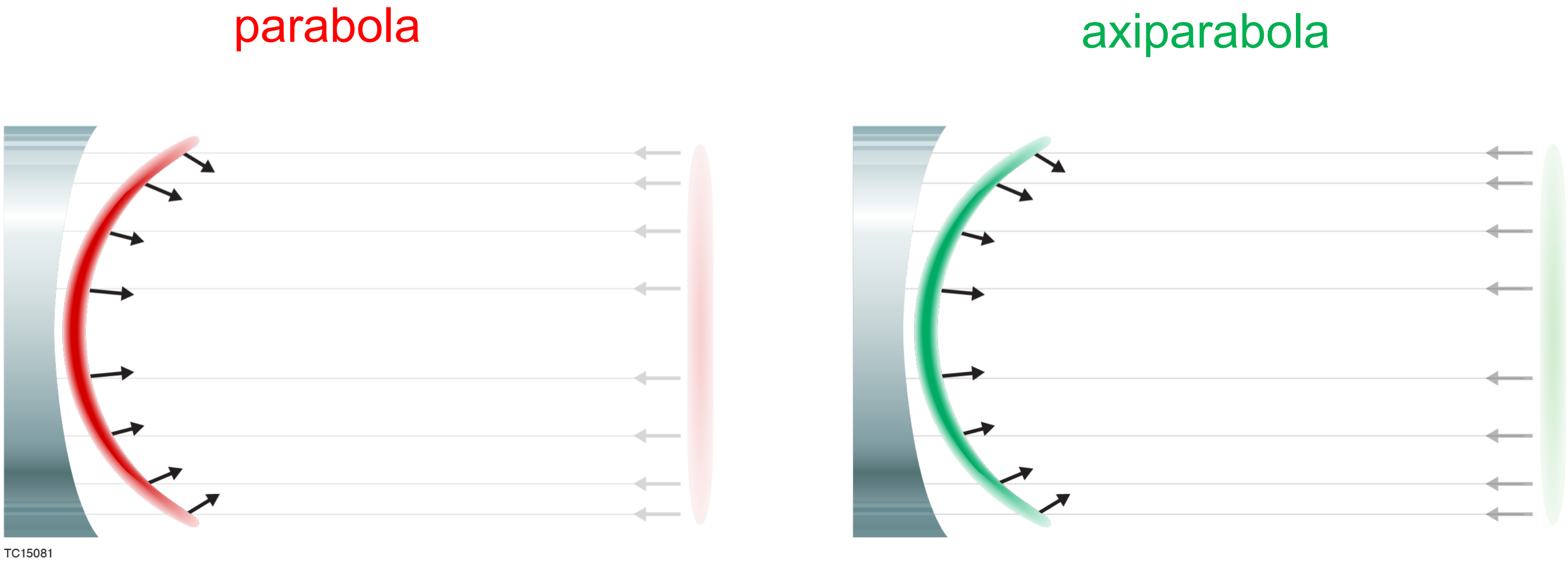

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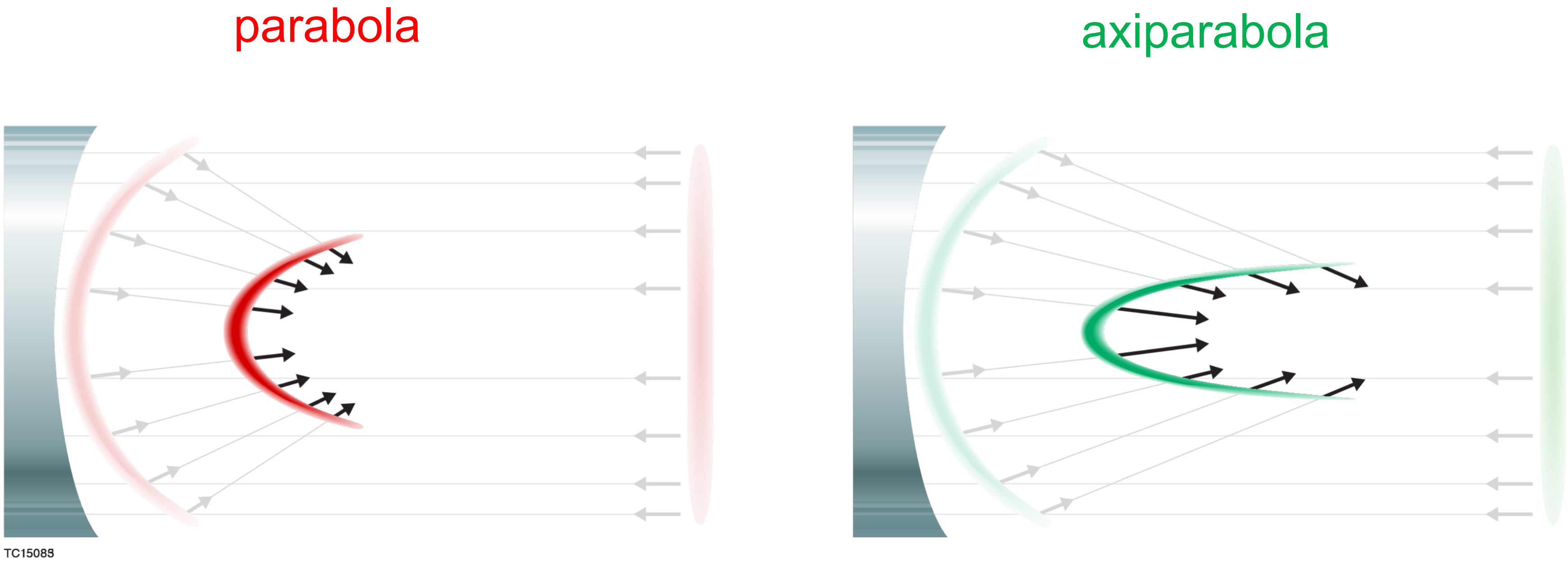

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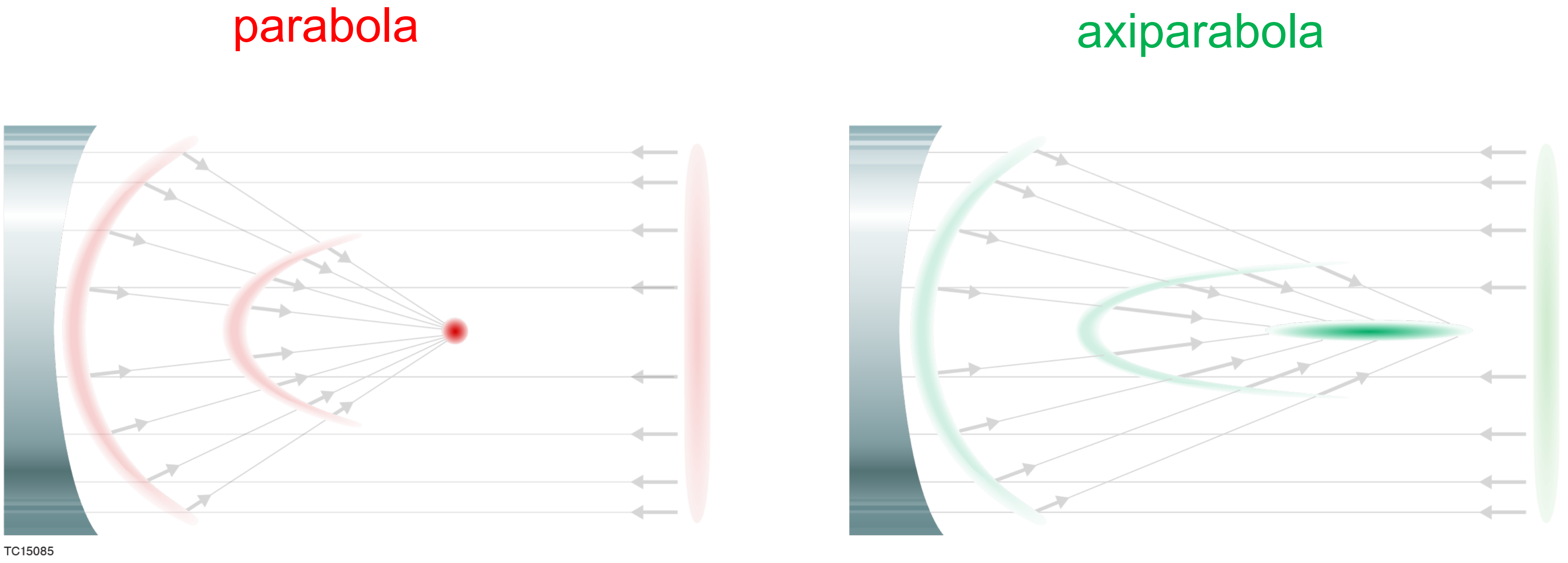

[‡]S. Smartsev *et al*. Opt. Lett., 44 3414 (2019)

Coupling the axiparabola to a novel echelon optic provides control over the velocity of the ponderomotive force

TC15087

The echelon imparts a delay to each radius without introducing angular dispersion or chromatic focusing errors

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TC15088

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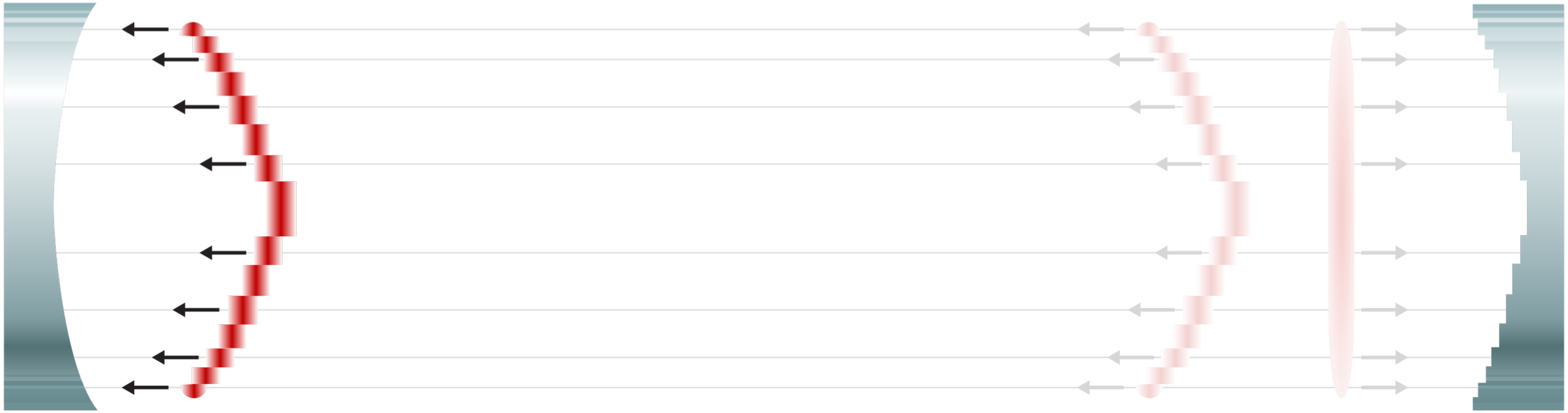

TC15088a

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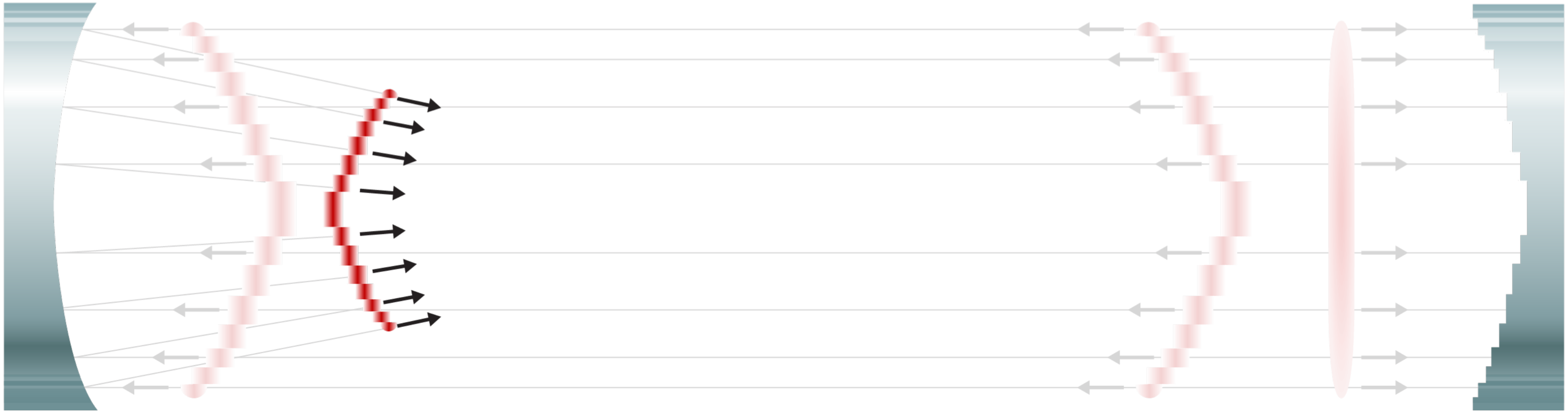

TC15089

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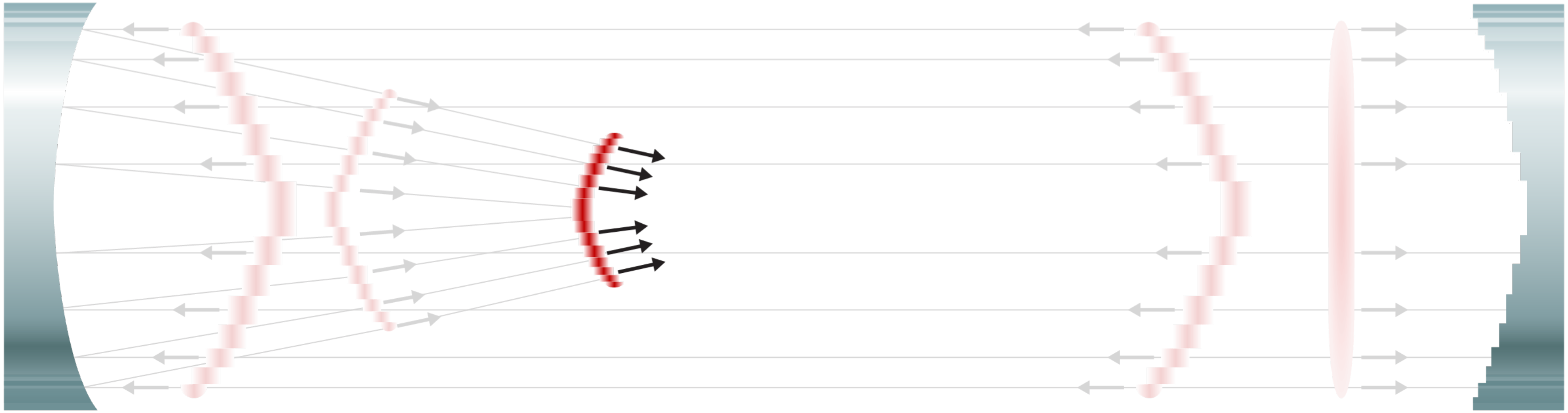

TC15091

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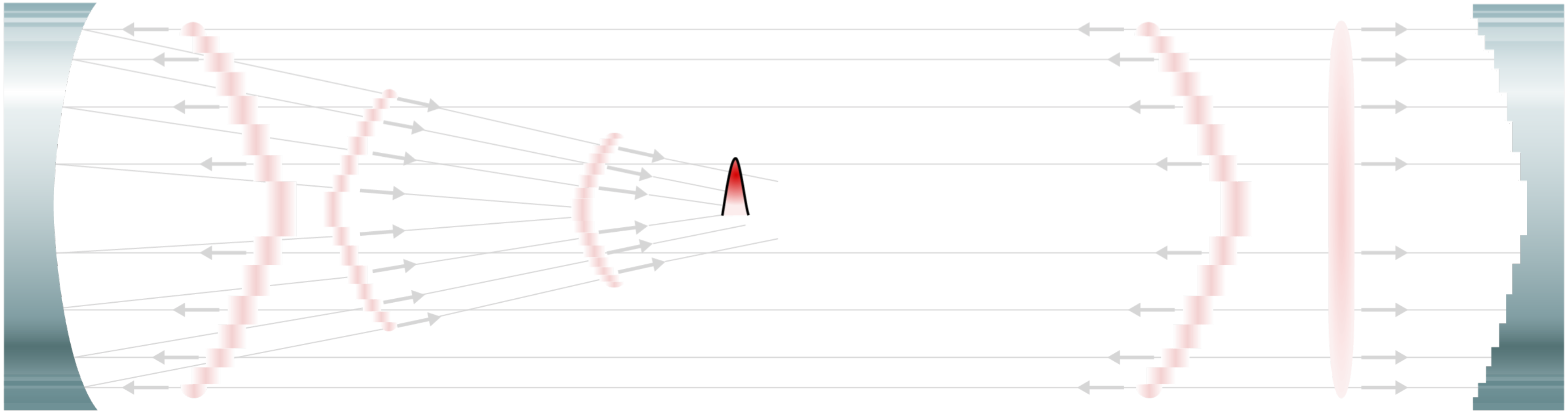

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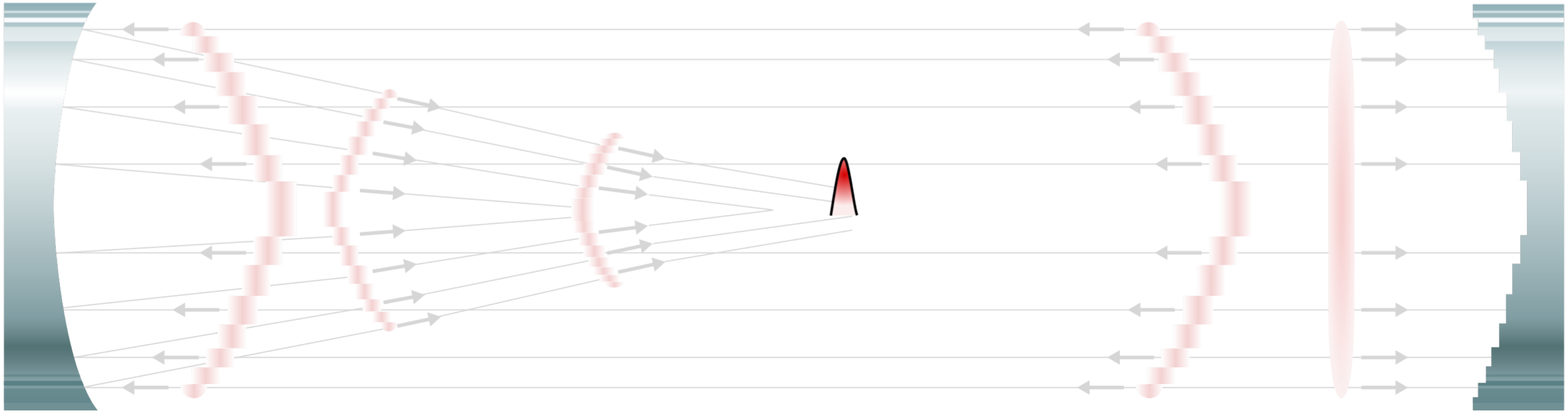

TC15093

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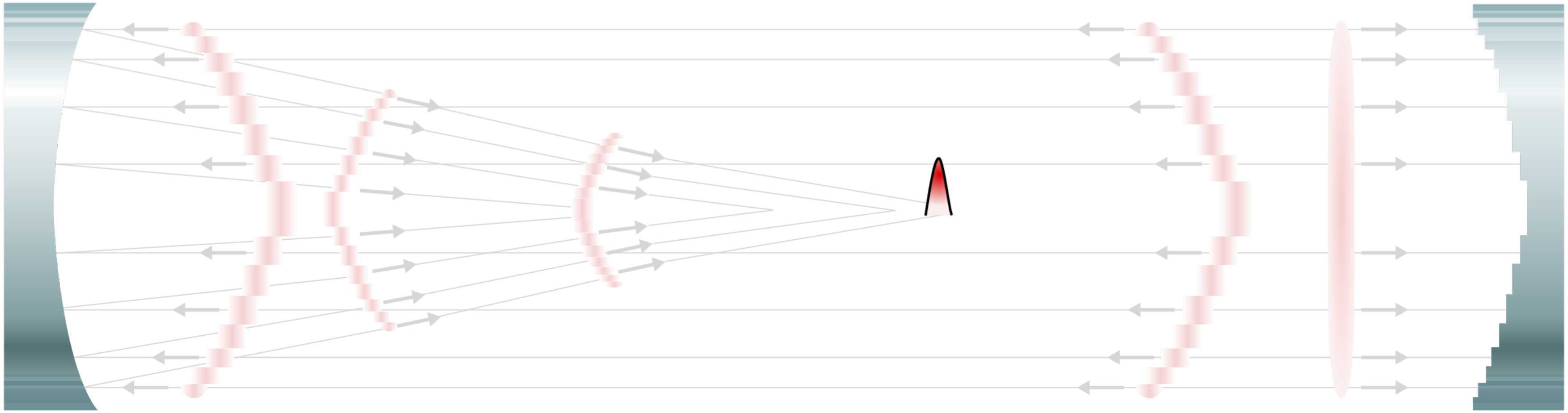

TC15094

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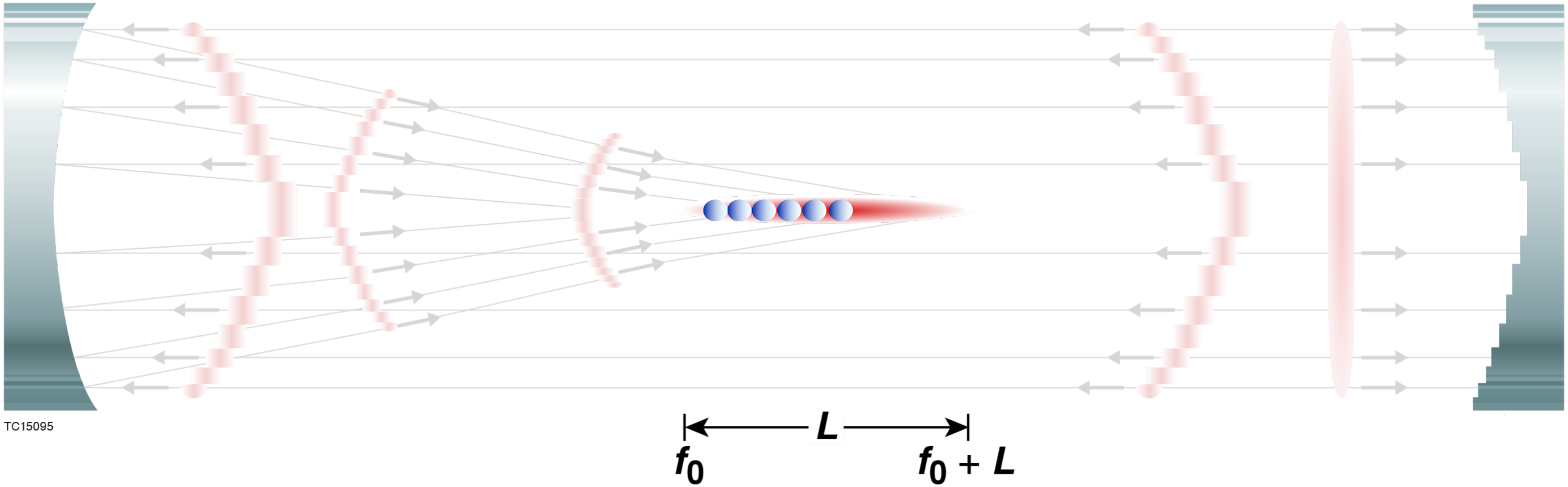


TC15095

The echelon imparts a delay to each radius without introducing angular dispersion or chromatic focusing errors

A dephasingless wakefield accelerator was simulated in the linear regime for parameters consistent with the LLE MTW laser

Laser parameters

λ = 1.054 nm

τ = 30 fs (FWHM)

$f_{\#}$ = 5

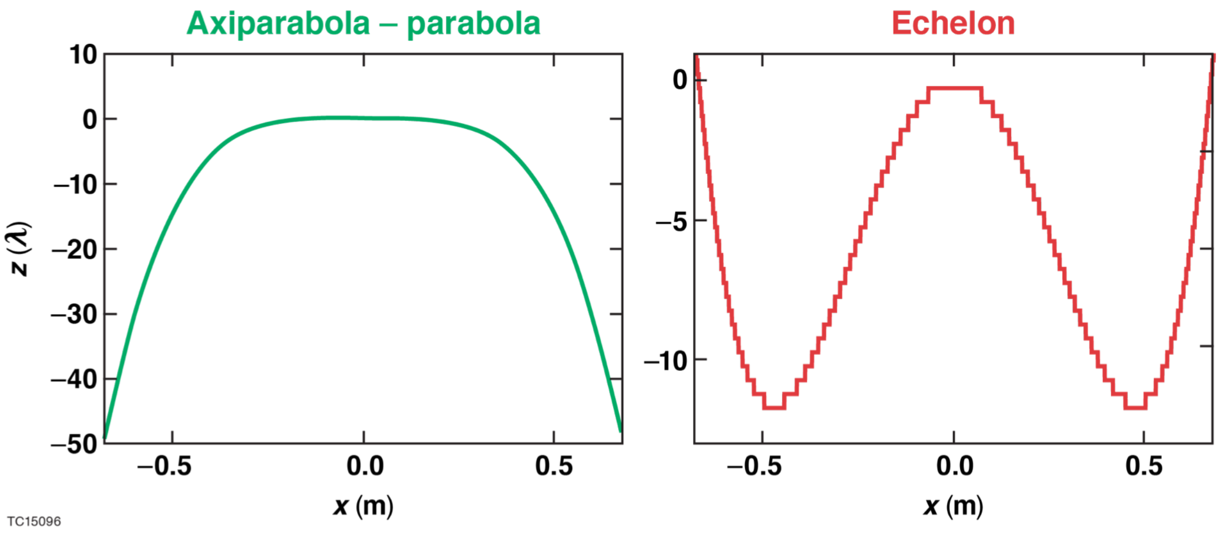
Δf = 8 cm

a_0 = 0.5

Plasma parameters

n_e = 3.5x10^{18} cm^{-3}

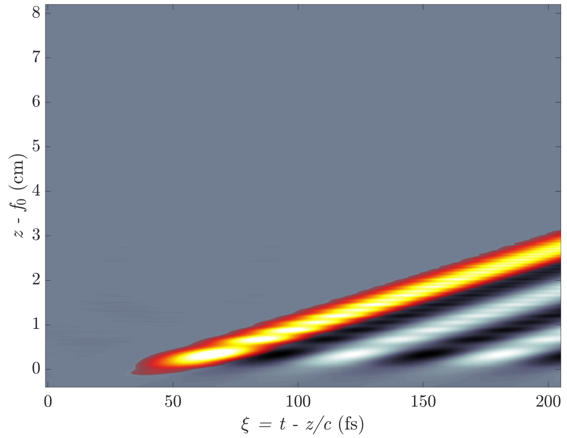
length = 12 cm



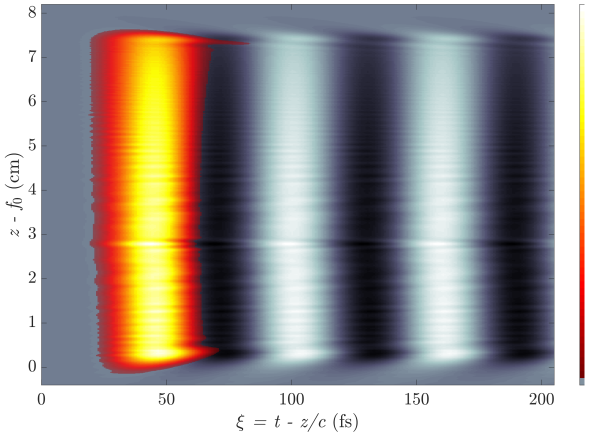
The axiparabola essentially adds spherical aberration to extend the focal region

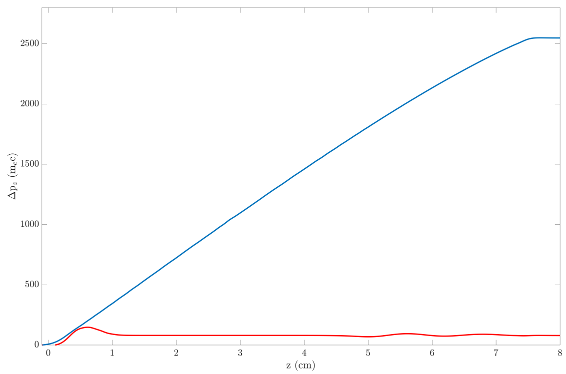
The dephasingless wakefield accelerates electrons to >10 more energy than a traditional LWFA

$v_f = v_g$



$v_f = c$





Scaling laws* predict that dephasingless LWFA is even more promising in the bubble regime

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energy gain

Dephasingless LWFA

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accelerator length

For equal energy gain:

$$\frac{U_D}{U_T} = \frac{32}{(3a_0^2)^{3/2}} \left(\frac{c\tau_m}{L}\right)^{1/2} (\omega_0 \tau_m)^2$$

ratio of laser energies

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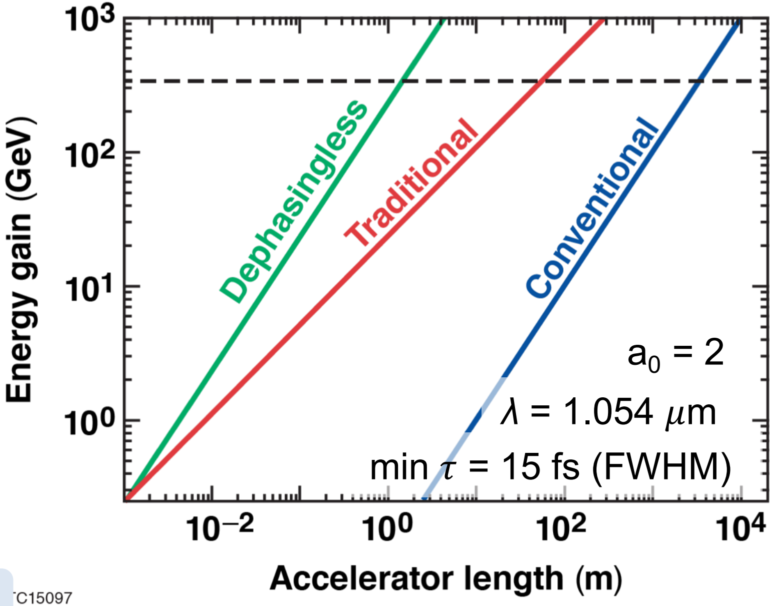

TC15097

*W. Lu *et al*. PRSTAB, 10 061301 (2007)

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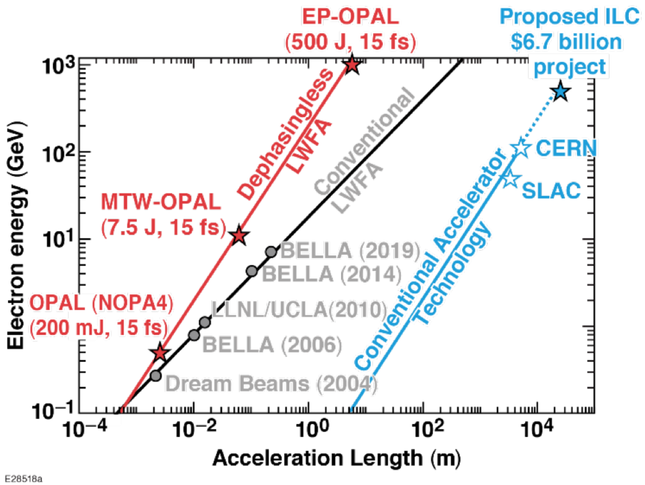

- Two ways to compare:

1. Equal energy over N traditional stages: $U_D = (k_p^3 L / \pi k_0^2) U_T$

2. Equal intensity: $U_D = (8 k_p^2 L / \pi^3 k_0) U_T$