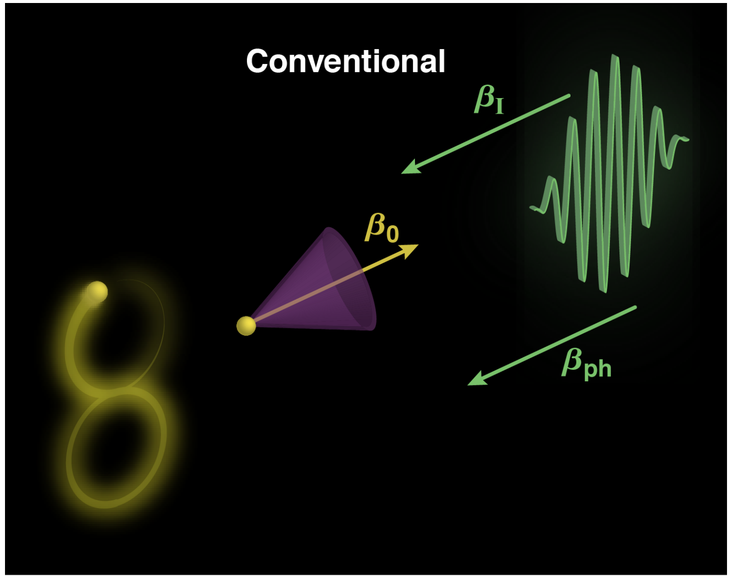
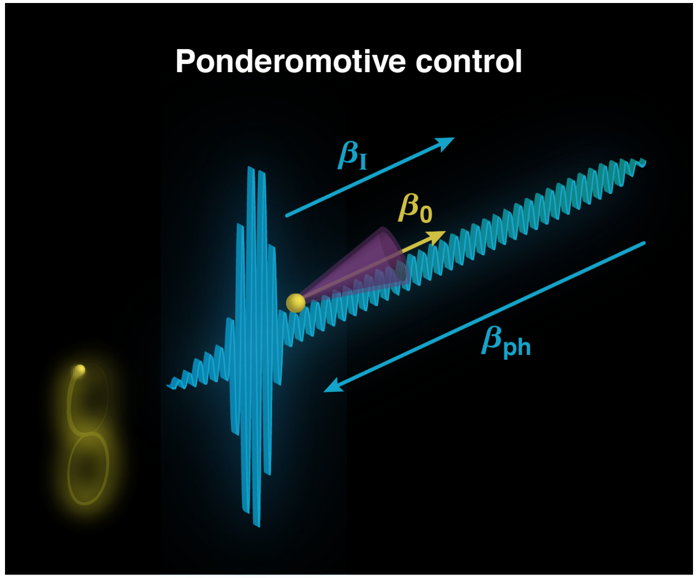
Nonlinear Thomson scattering with ponderomotive control



TC15637c



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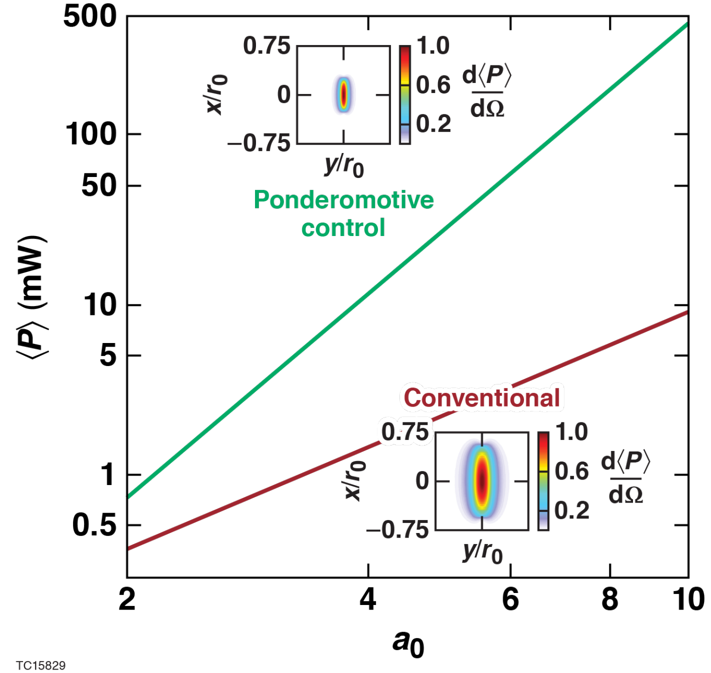

TC15829

John P. Palastro
University of Rochester
Laboratory for Laser Energetics

50th Anomalous Absorption Conference
June, 5th 2022

Collaborators

D. Ramsey, M. Ambat, P. Franke, D.H. Froula, J. Pigeon
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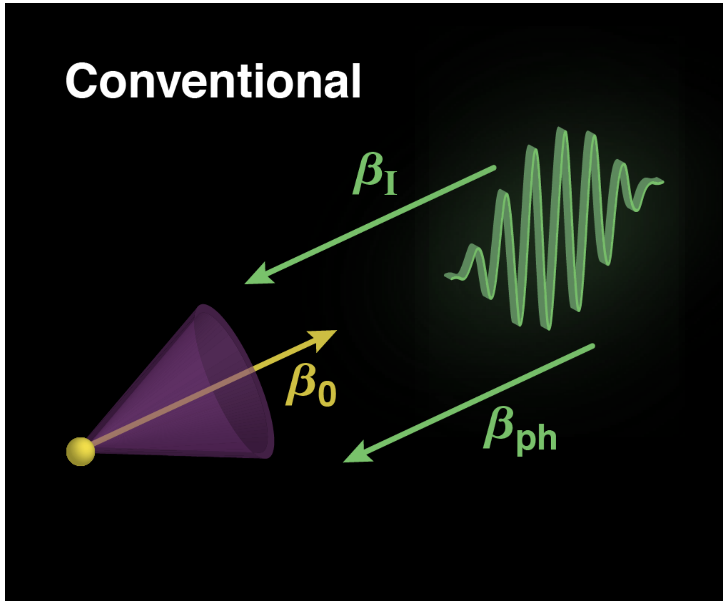
Flying focus pulses enable novel regimes of nonlinear Thomson scattering that enhance the radiation properties

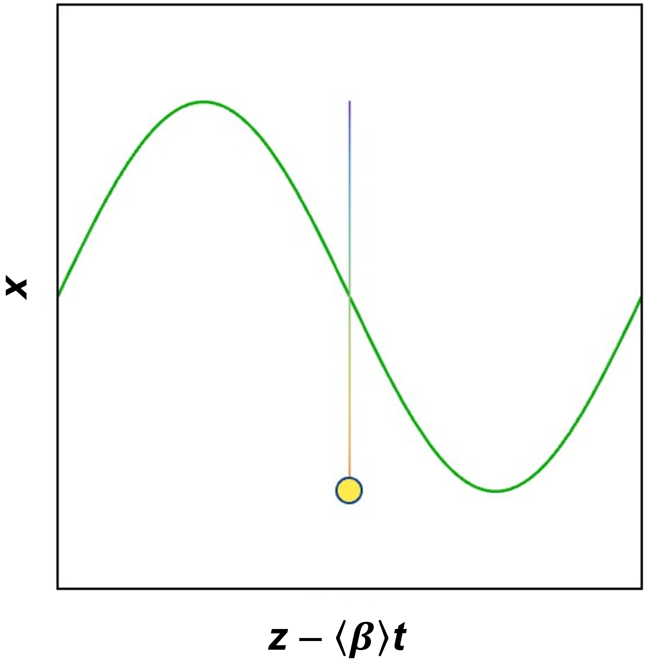
- In nonlinear Thomson scattering (NLTS), a relativistic electron reradiates the photons of an intense laser pulse, converting optical light to x rays
- With a conventional pulse, the ponderomotive force decelerates the electron, introducing tradeoffs between scattered power, spectrum, and emission angle
- Flying focus pulses provide control over the speed and direction of the ponderomotive force
- This force can either directly accelerate or drive a wakefield that accelerates the electron, mitigating the tradeoffs of conventional NLTS

Nonlinear Thomson scattering with ponderomotive control can increase the radiated power by orders of magnitude while reducing the emission angle

When a relativistic electron collides with a counter-propagating laser pulse, it radiates light at an upshifted frequency

Low intensity (I < 2x10^{18} W/cm^2, a_0<1)





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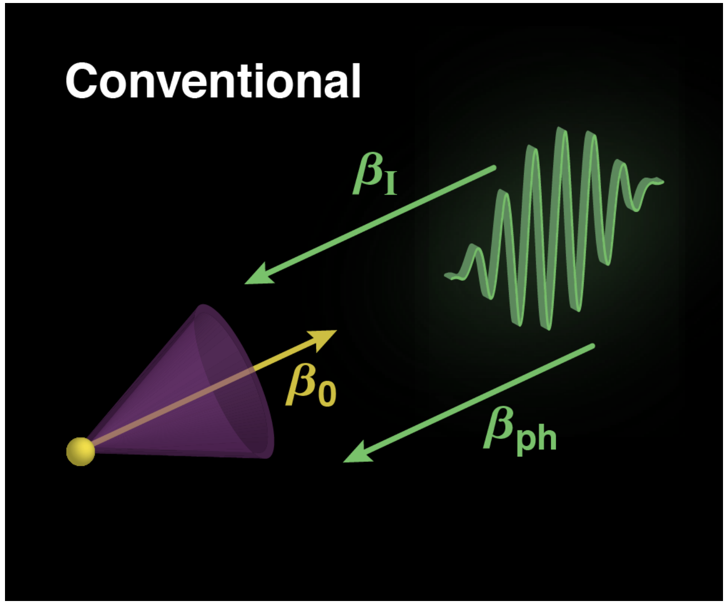
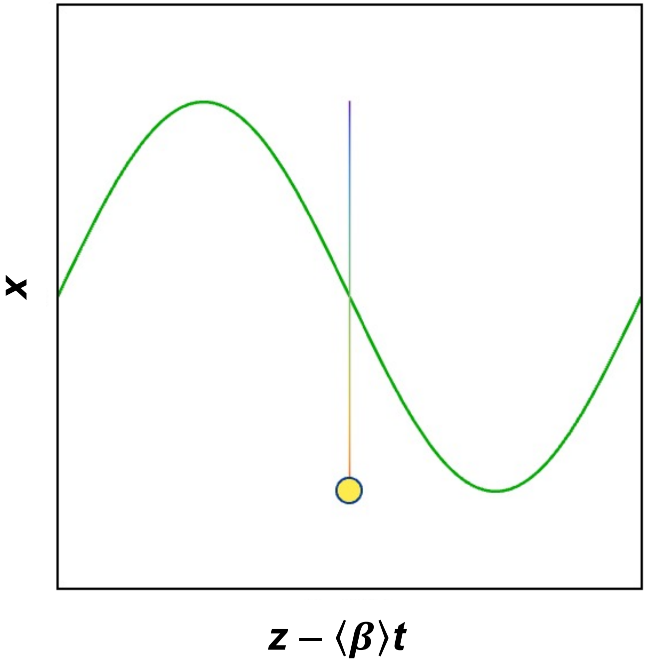
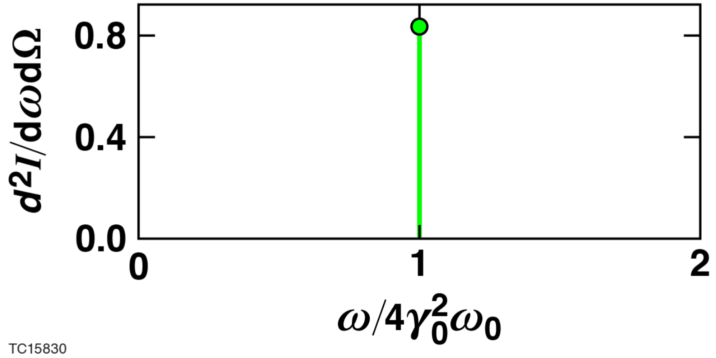
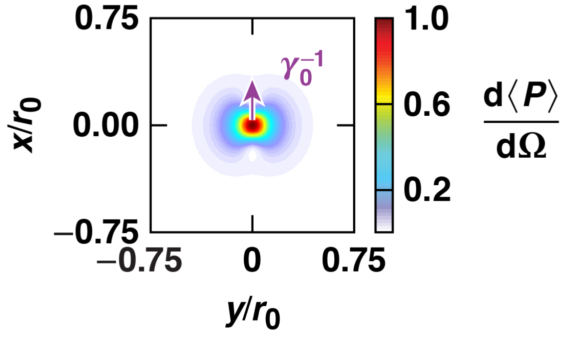




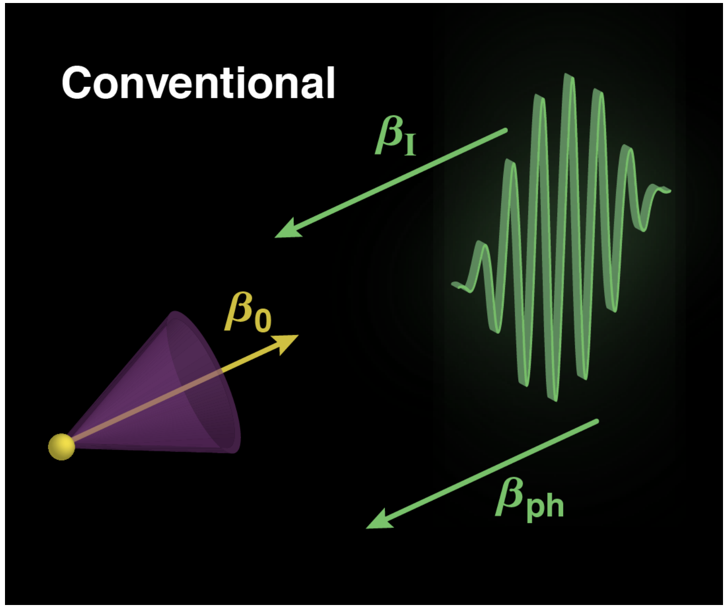


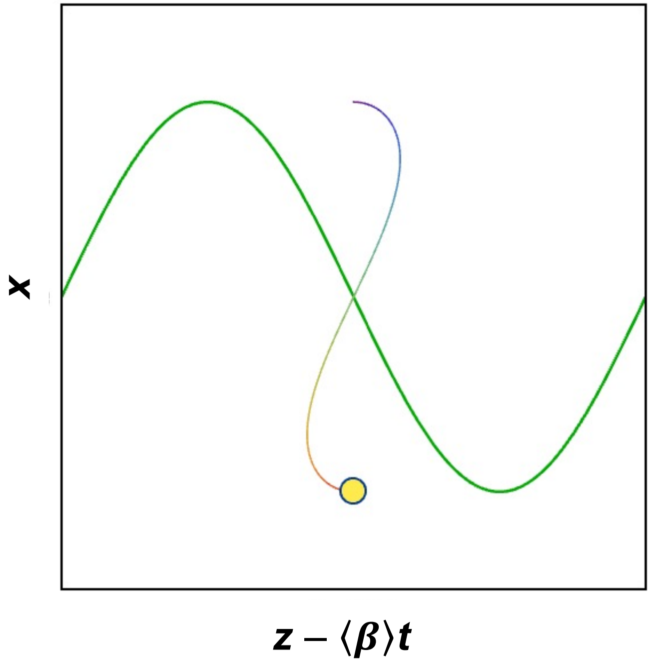


Linear oscillations result in emission at a single frequency and into an angle determined by the electron energy

At high intensity, the electron motion becomes nonlinear, including significant oscillations in the longitudinal direction

High intensity ($I > 2 \times 10^{18}$ W/cm^2, $a_0 > 1$)





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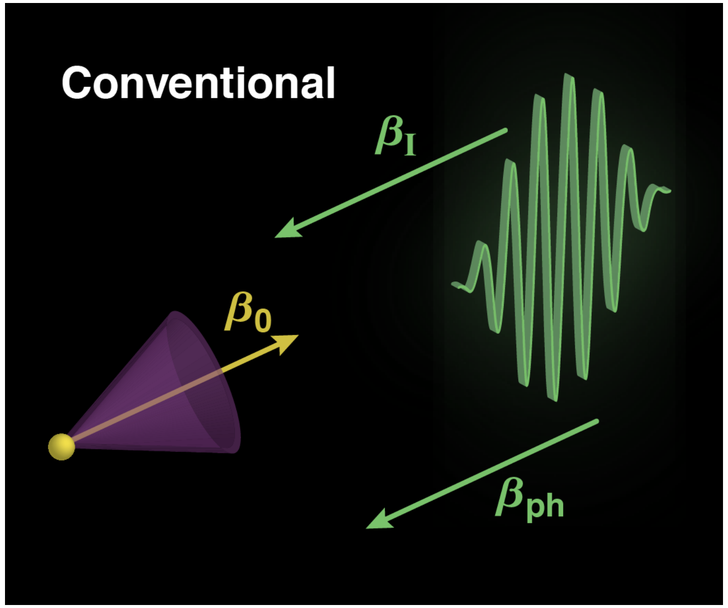
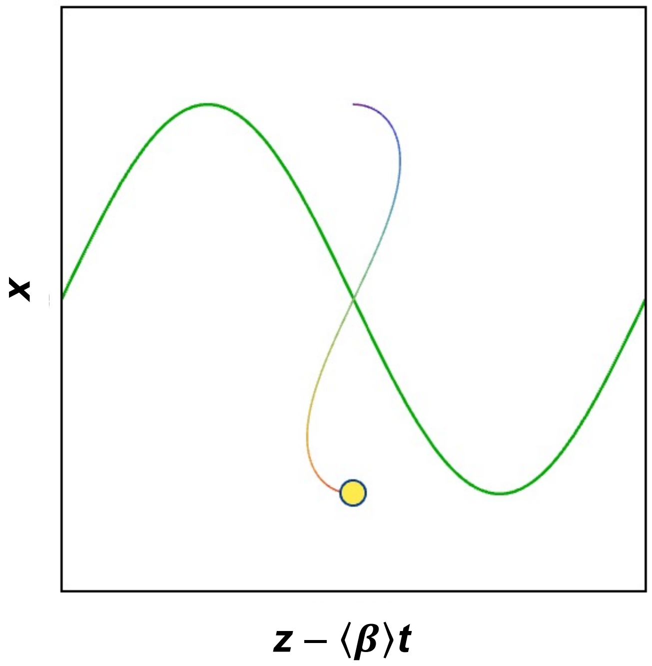
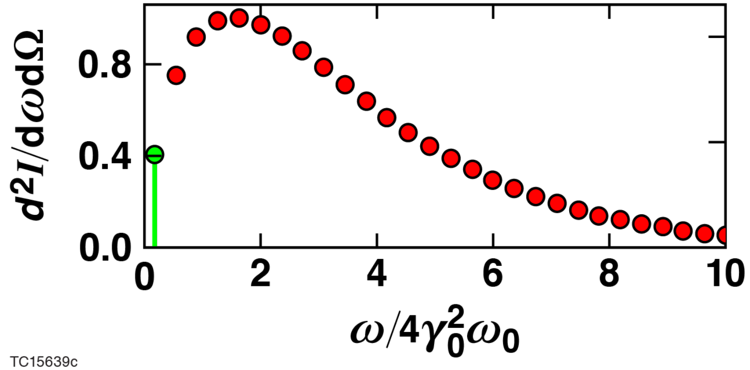
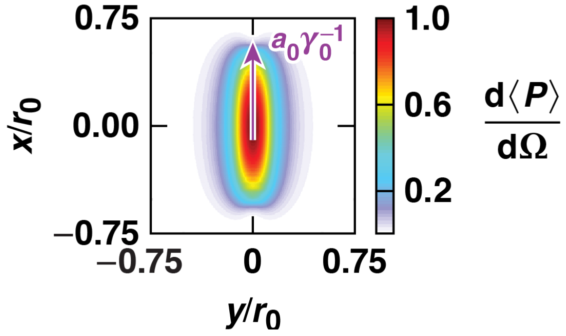




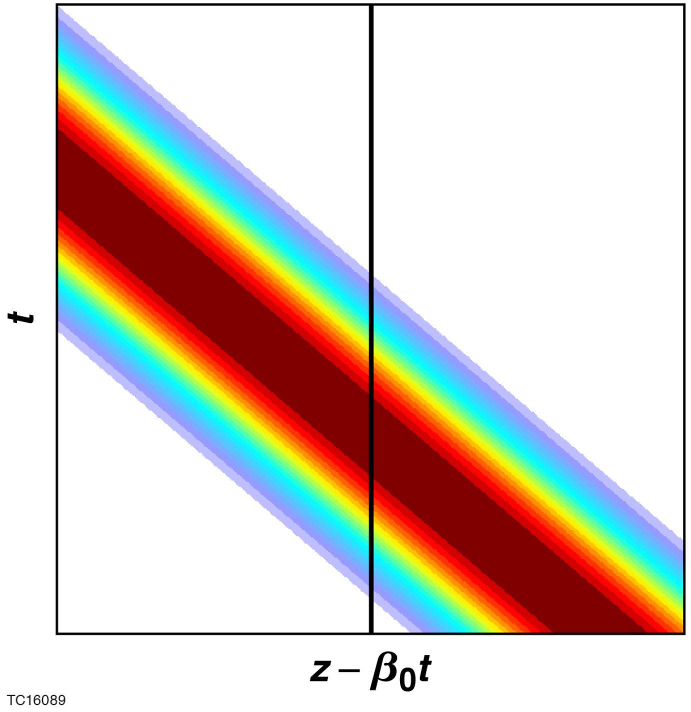




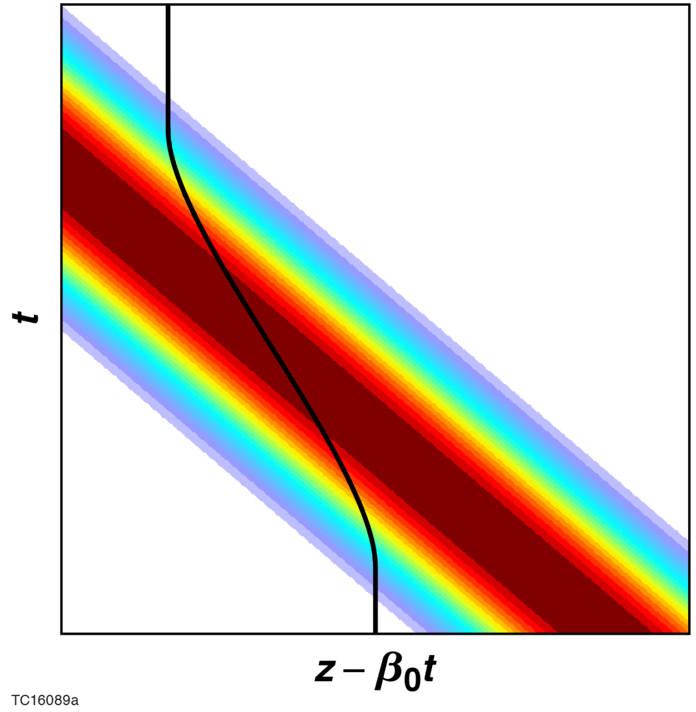
The nonlinear motion results in broadband emission into several harmonics and into a much wider cone

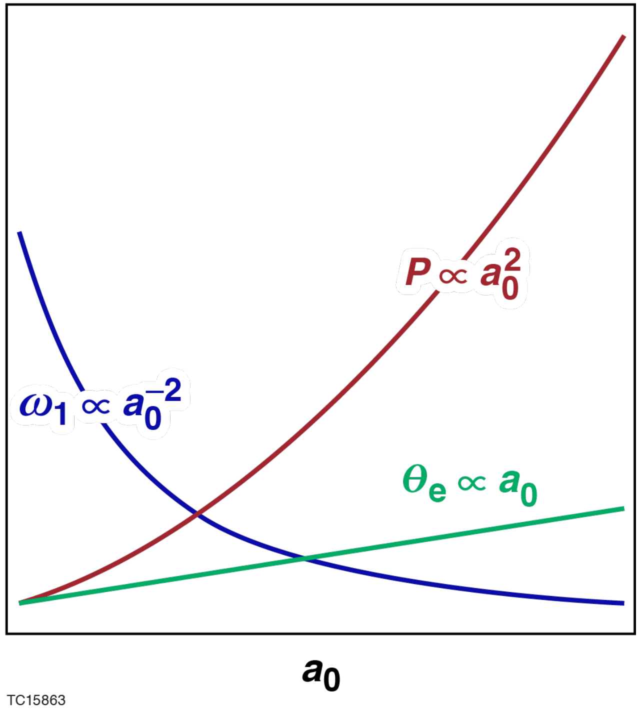
In a high intensity laser pulse, electrons undergo an appreciable ponderomotive deceleration, which modifies the radiation properties

Low intensity ($a_0<1$)



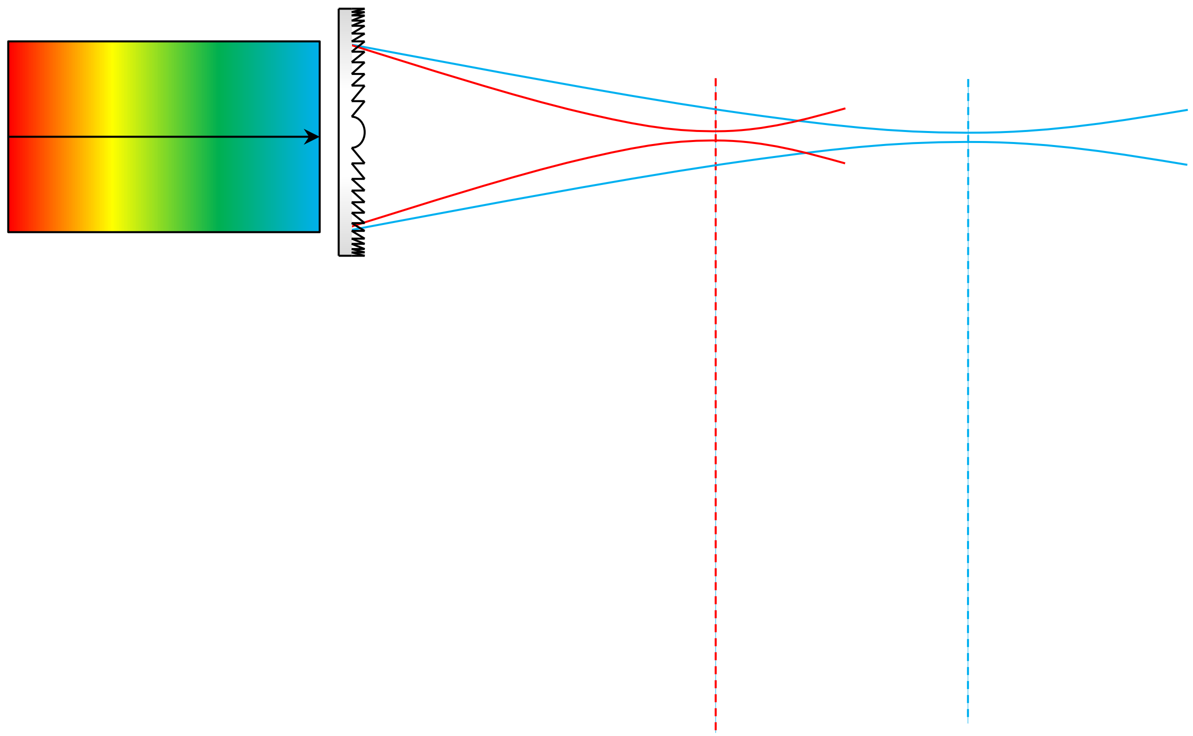
High intensity ($a_0>1$)





A higher intensity provides more radiated power, but significantly redshifts the harmonic frequencies and increases the emission angle

The intensity peak of a flying focus pulse can travel in the opposite direction as its phase fronts



D. Froula *et al.* Nature Photonics (2018)

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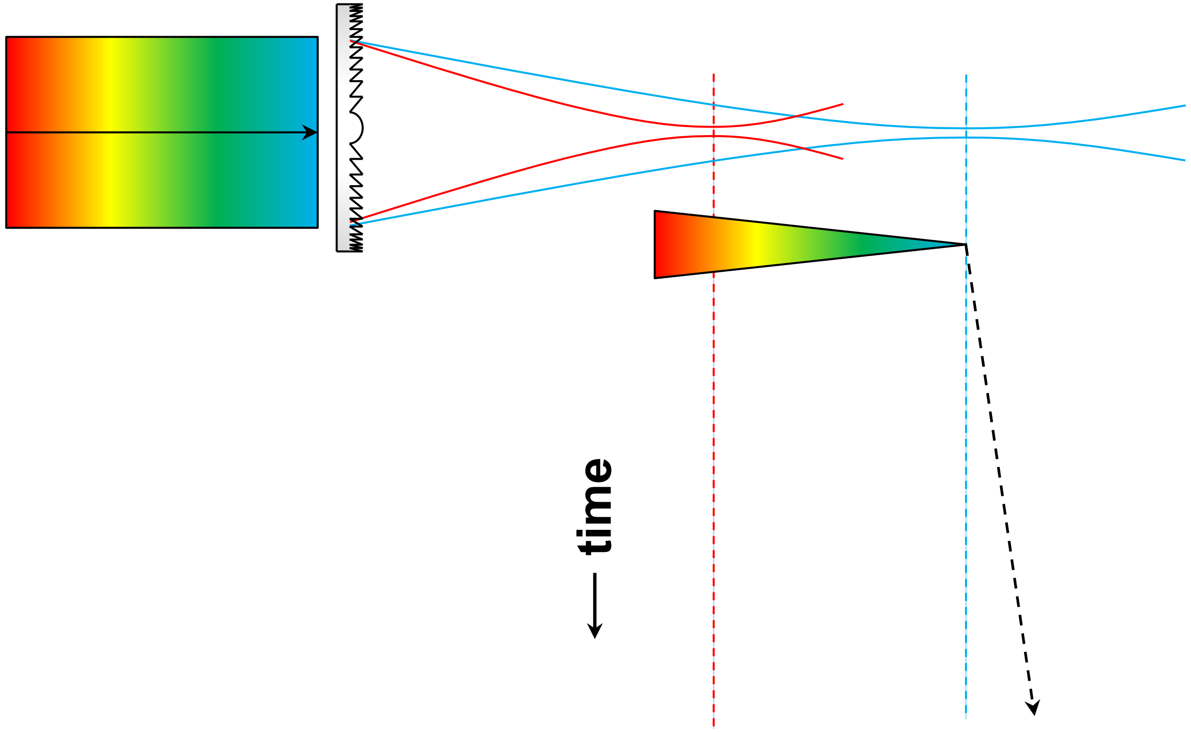

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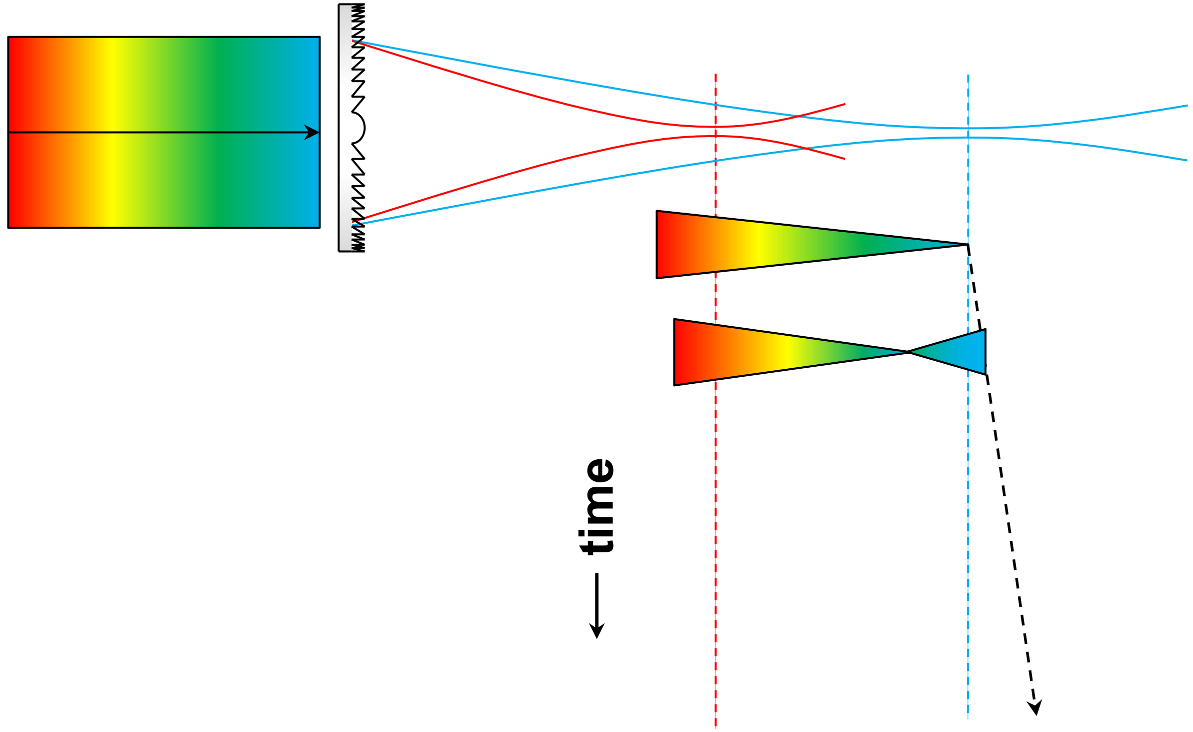

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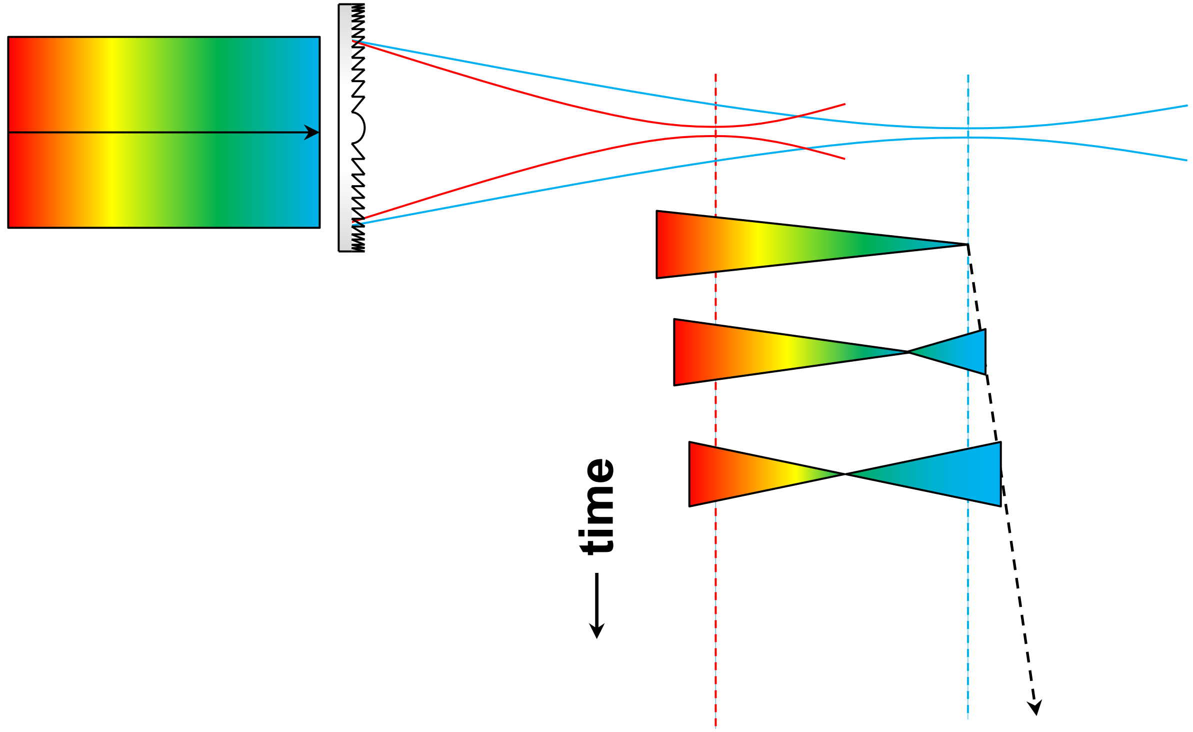

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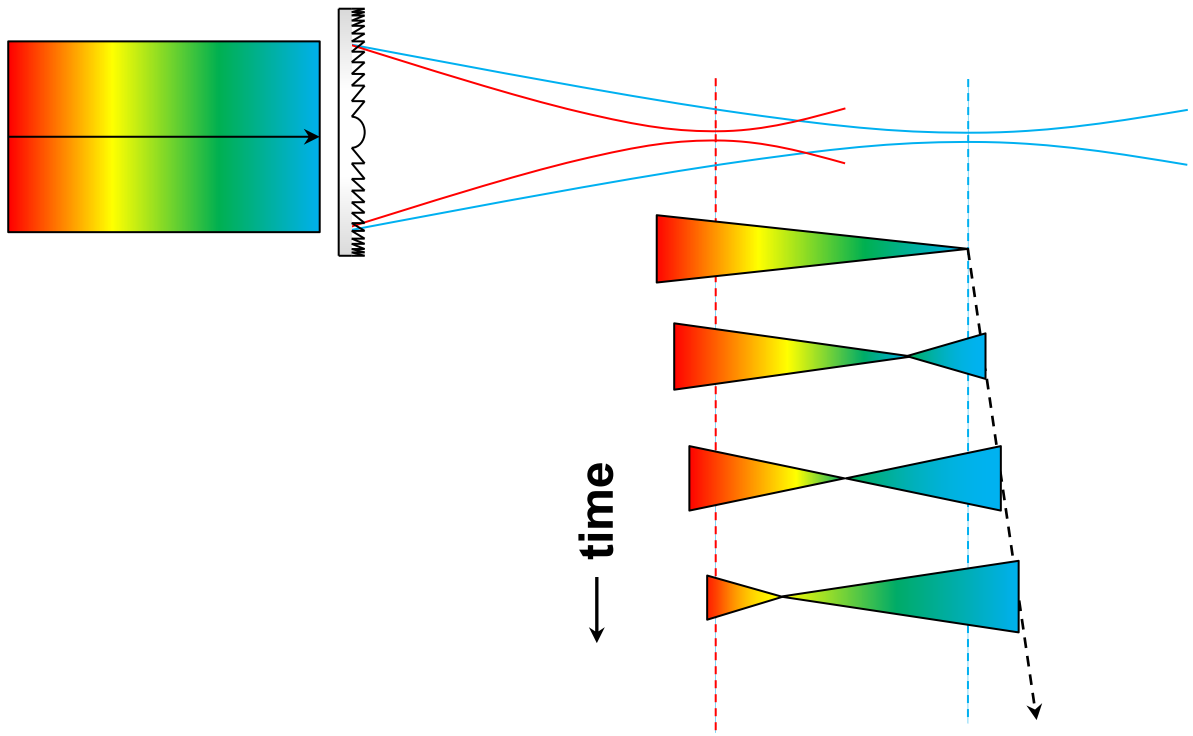

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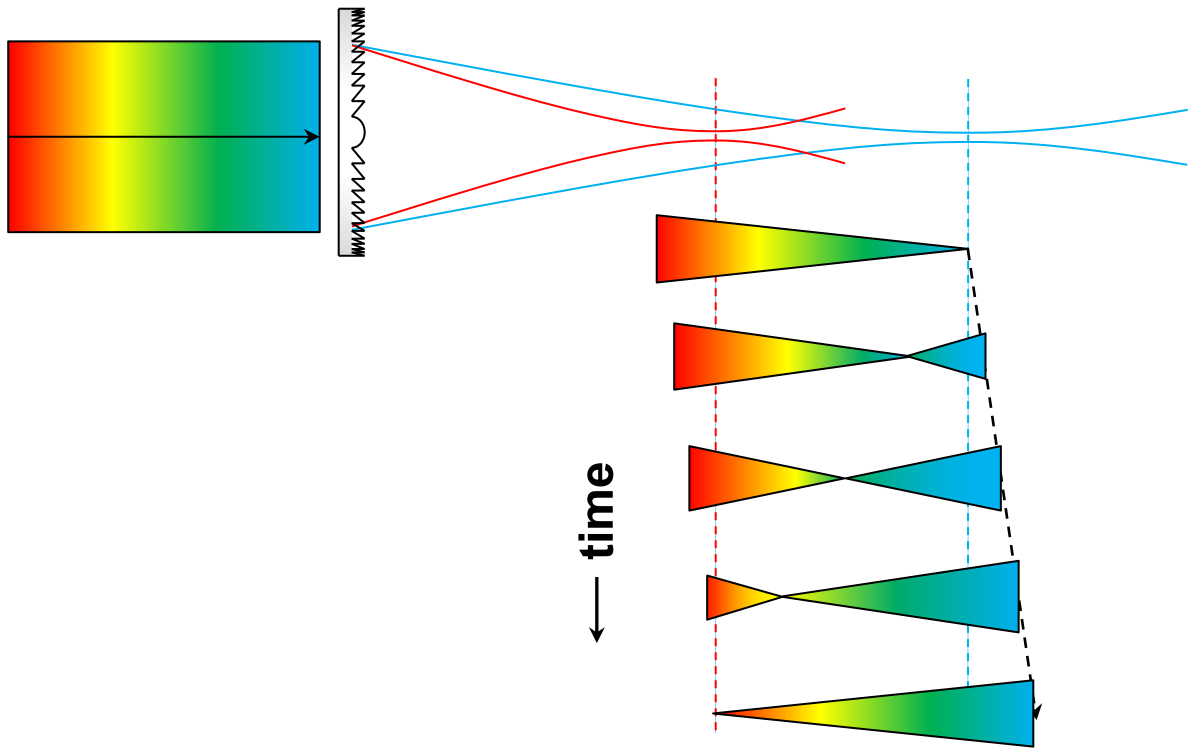

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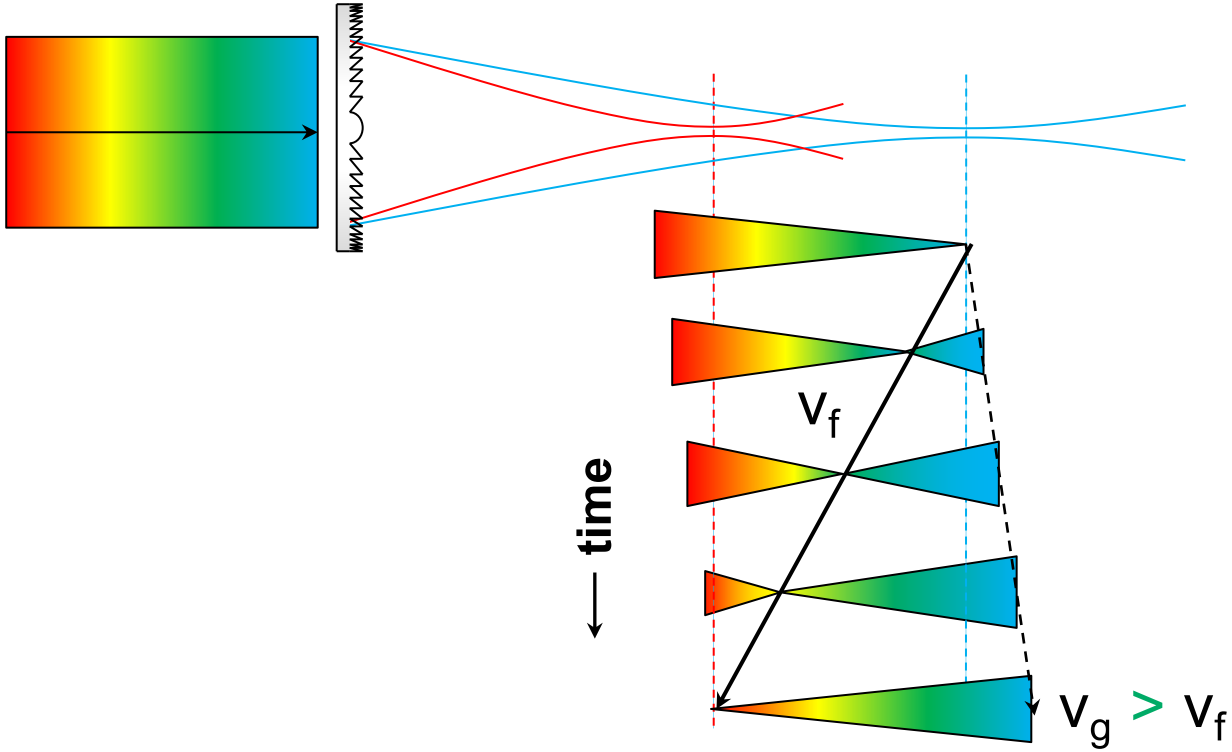

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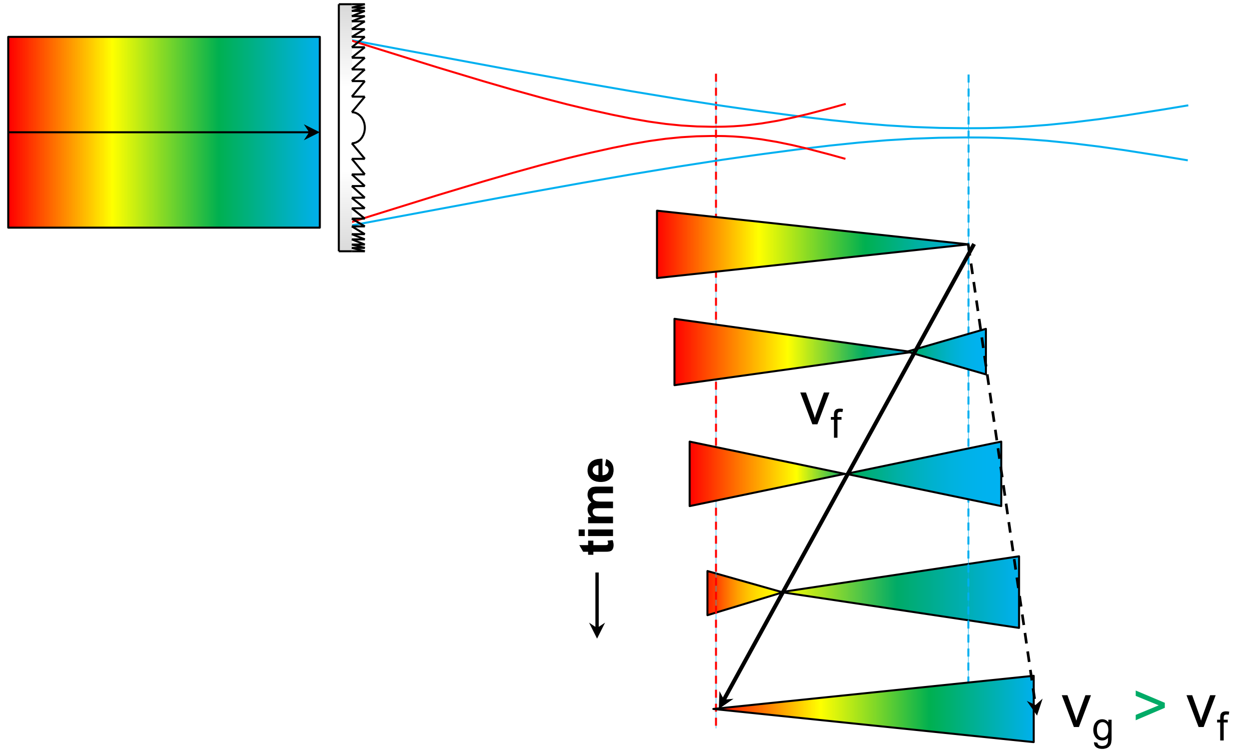
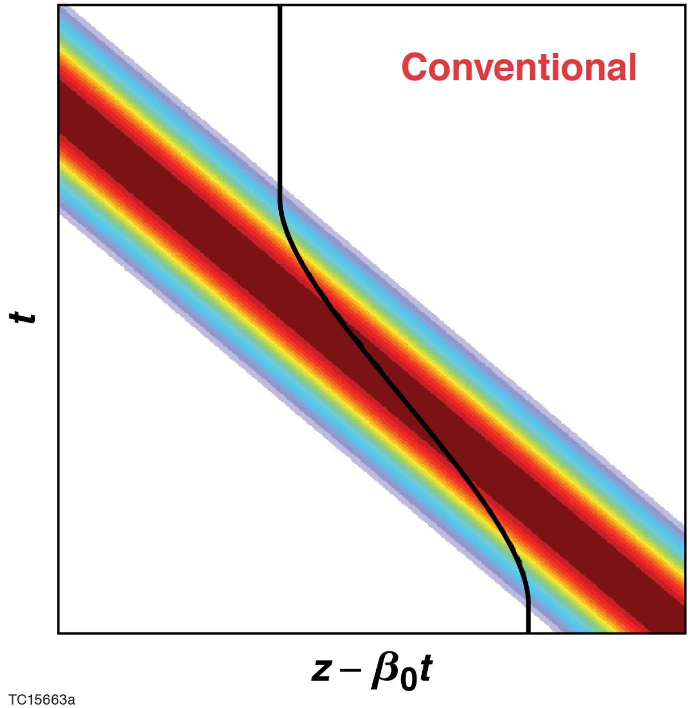


The backwards travelling intensity peak can ponderomotively accelerate electrons in the opposite direction of its phase fronts

D. Ramsey *et al.* Phys. Rev. E (2020)

The programmable velocity of the intensity peak provides control over the electron trajectory

v=-c



TC15663a

A counter-travelling intensity peak decelerates the electron

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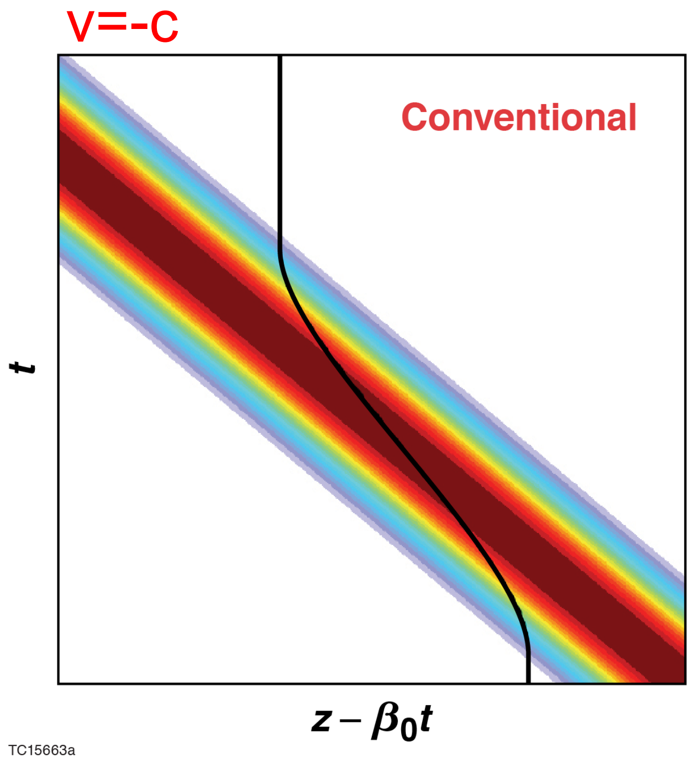

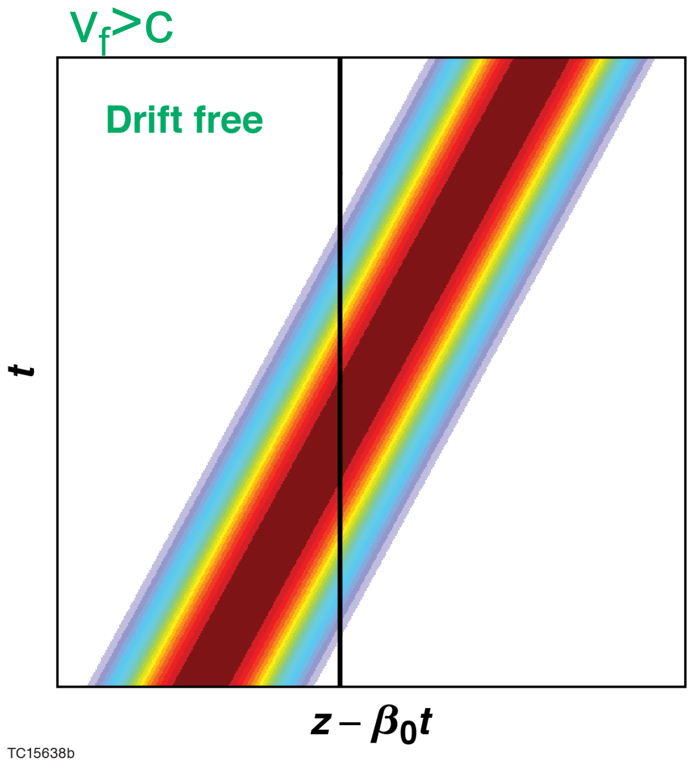

A counter-travelling intensity peak decelerates the electron

A **super**luminal, co-travelling intensity peak leaves the electron velocity unaffected

D. Ramsey *et al.* Phys. Rev. E (2022)

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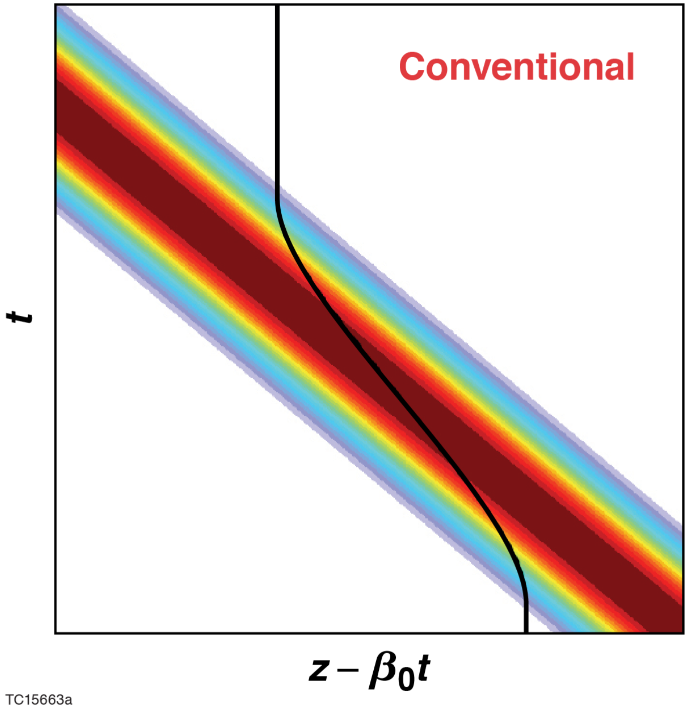
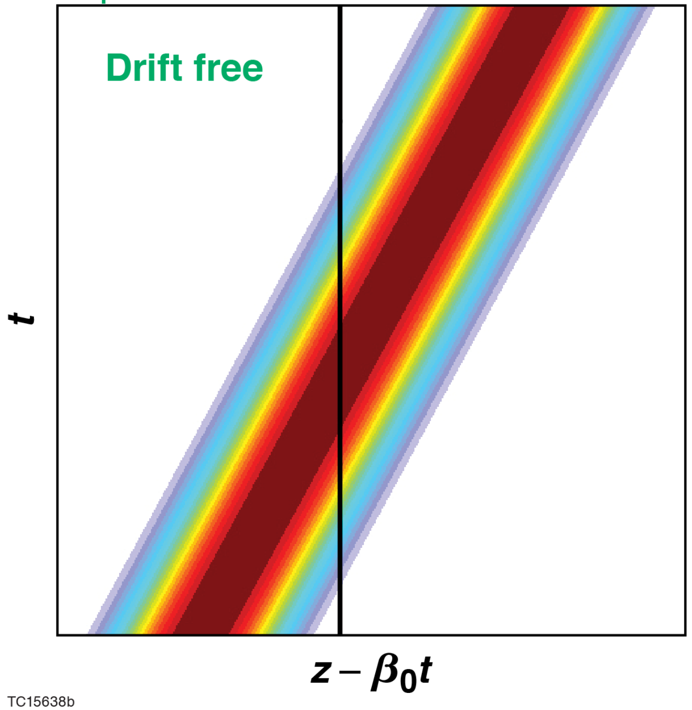


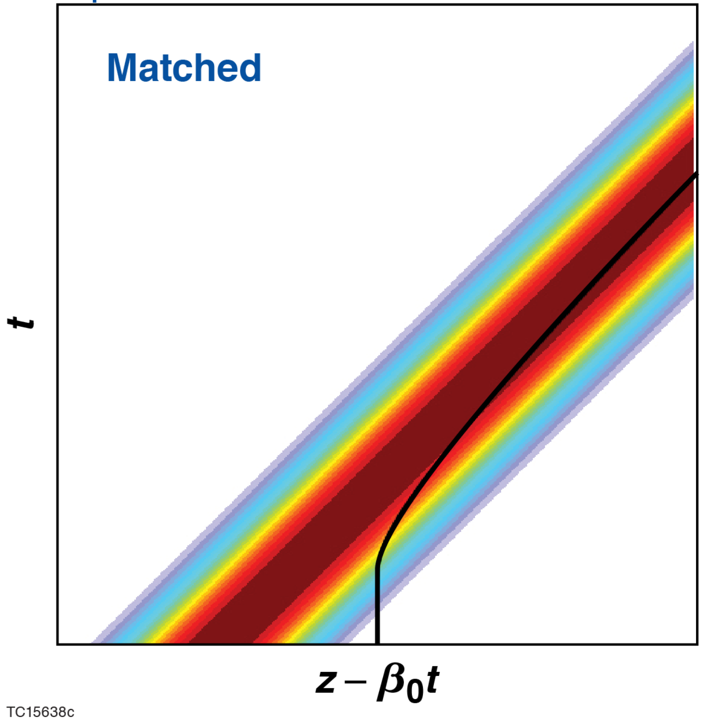
TC15663a

$v_f>c$



TC15638b

$v_f<c$



TC15638c

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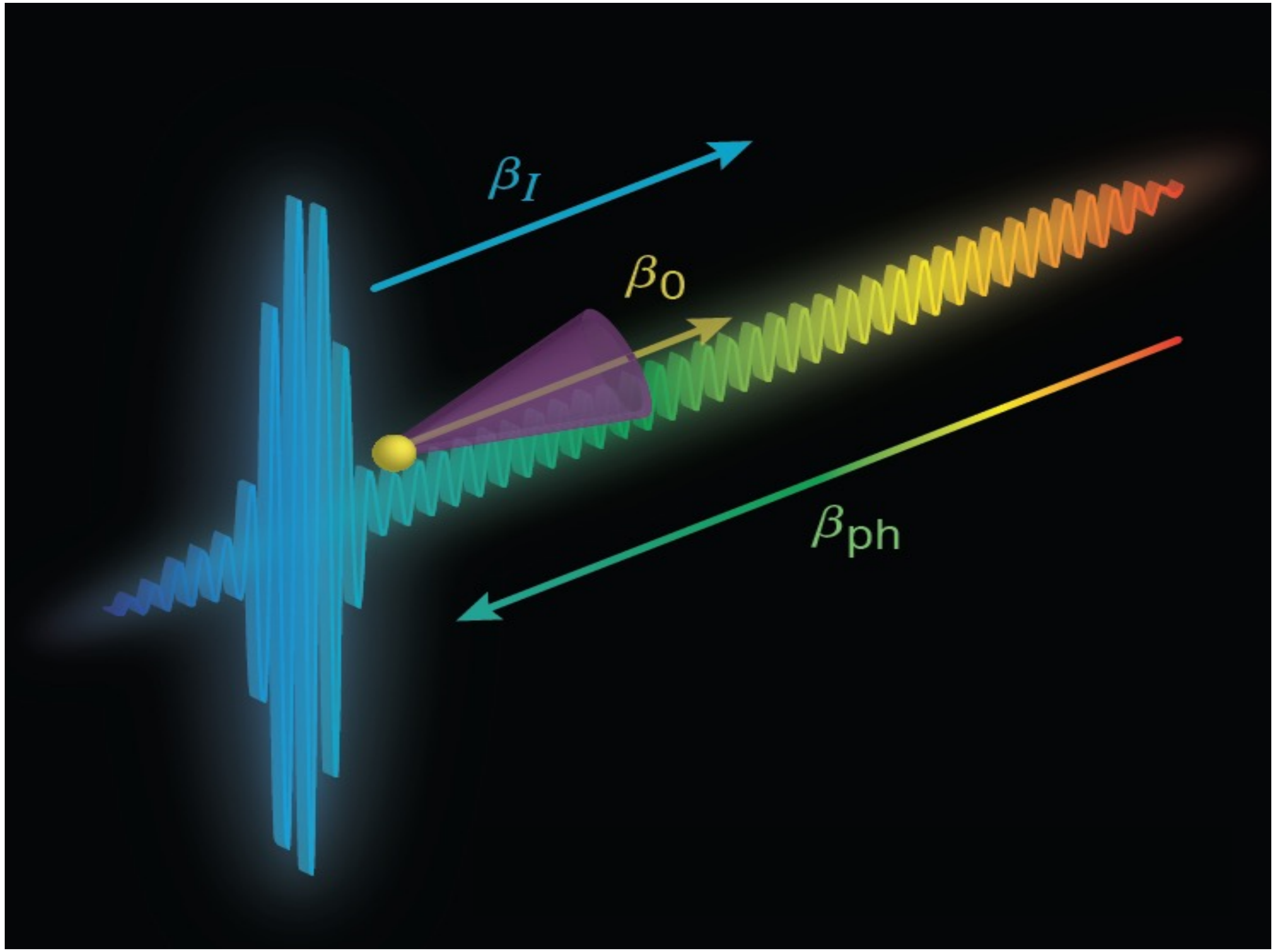
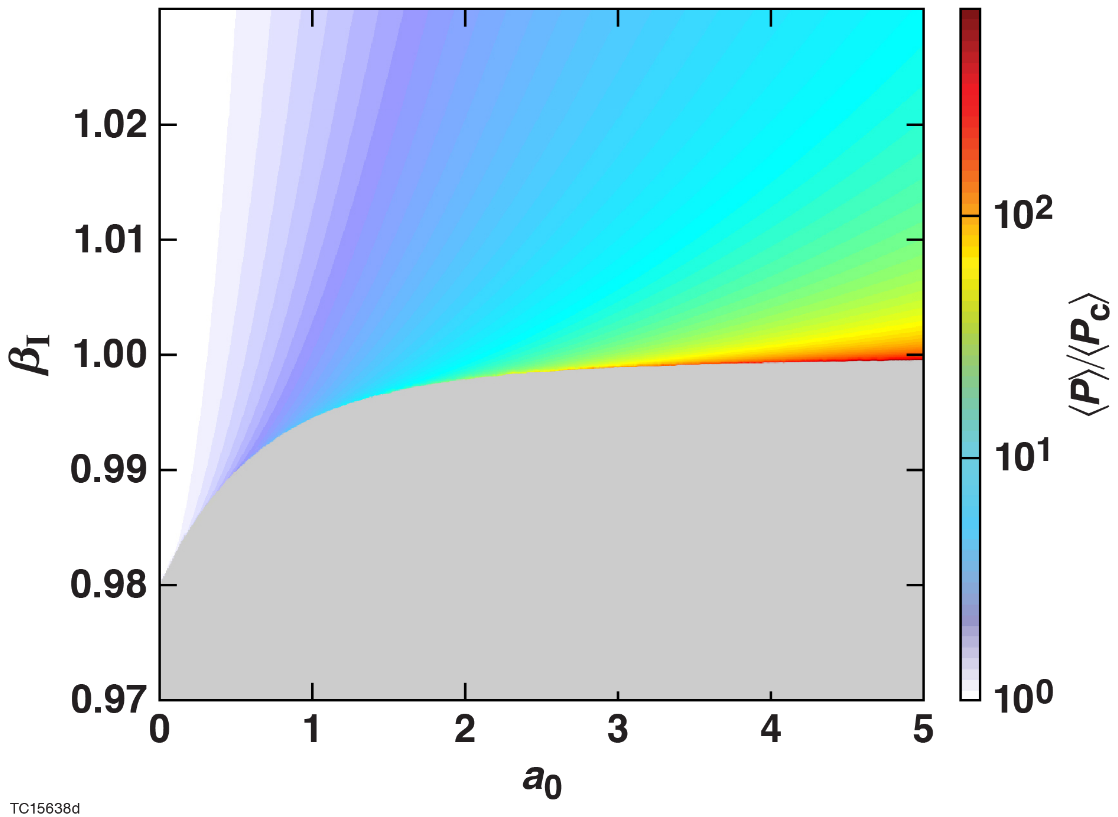
A **super**luminal, co-travelling intensity peak leaves the electron velocity unaffected

A **sub**luminal, co-travelling intensity peak accelerates the electron up to its velocity

Nonlinear Thomson scattering with ponderomotive control (NPC) takes advantage of the trajectory control afforded by flying focus pulses



NPC increases the radiated power by orders of magnitude while decreasing the emission angle



TC15638d

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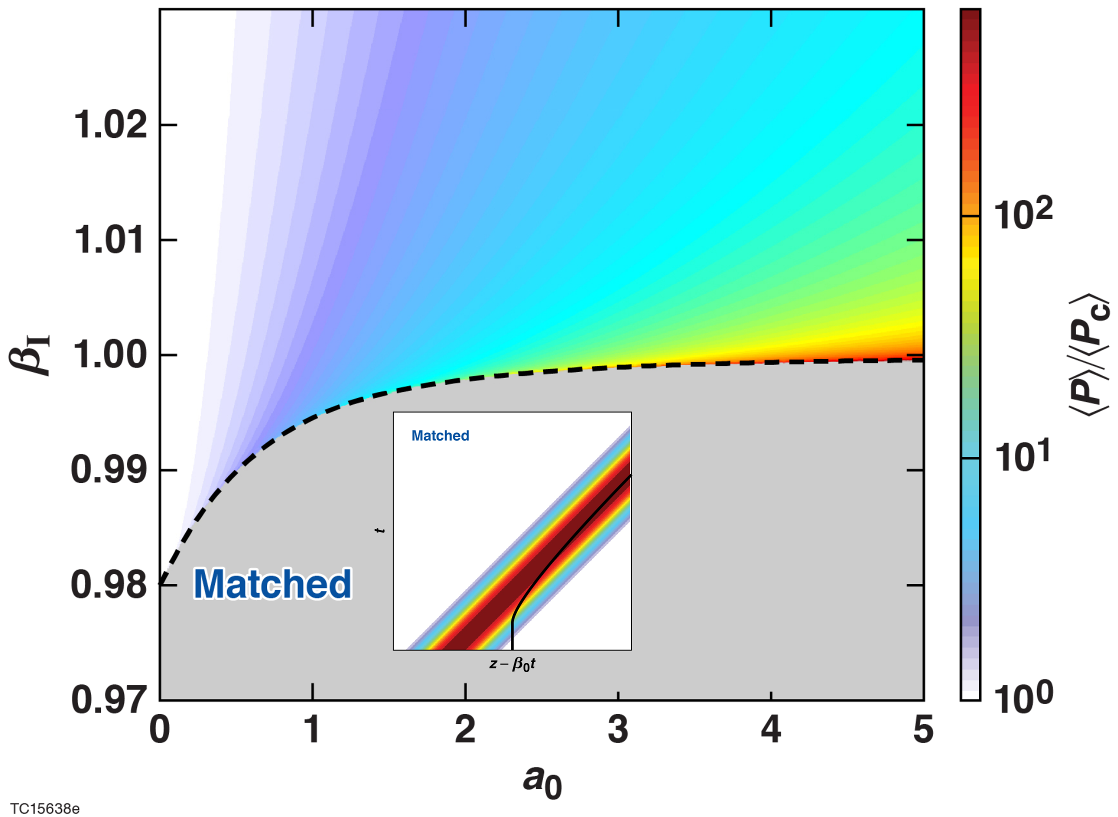

TC15638e

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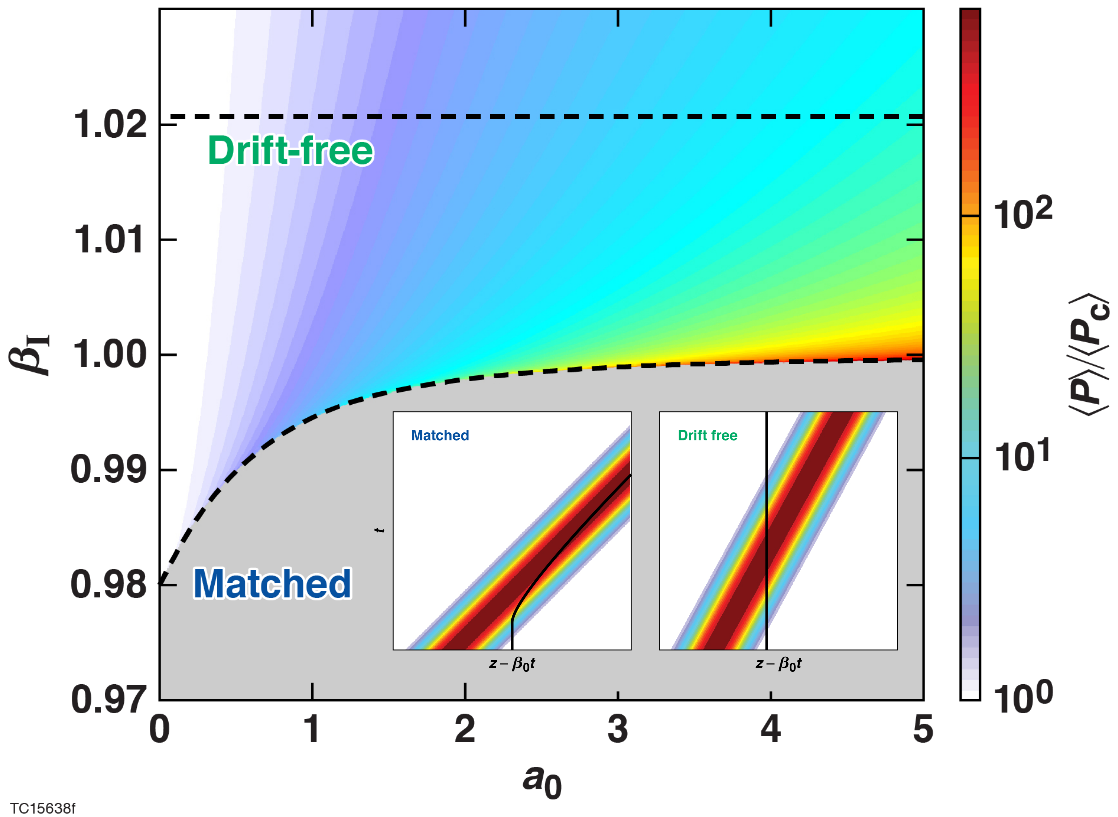

TC15638f

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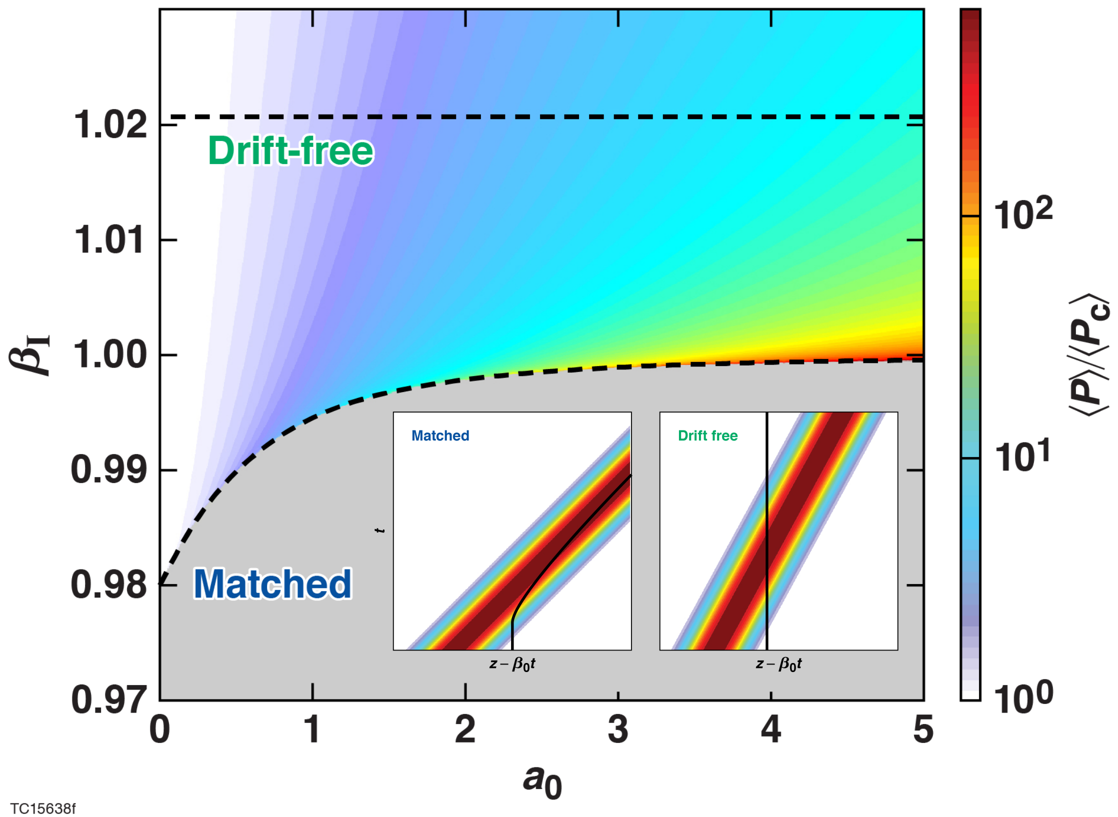
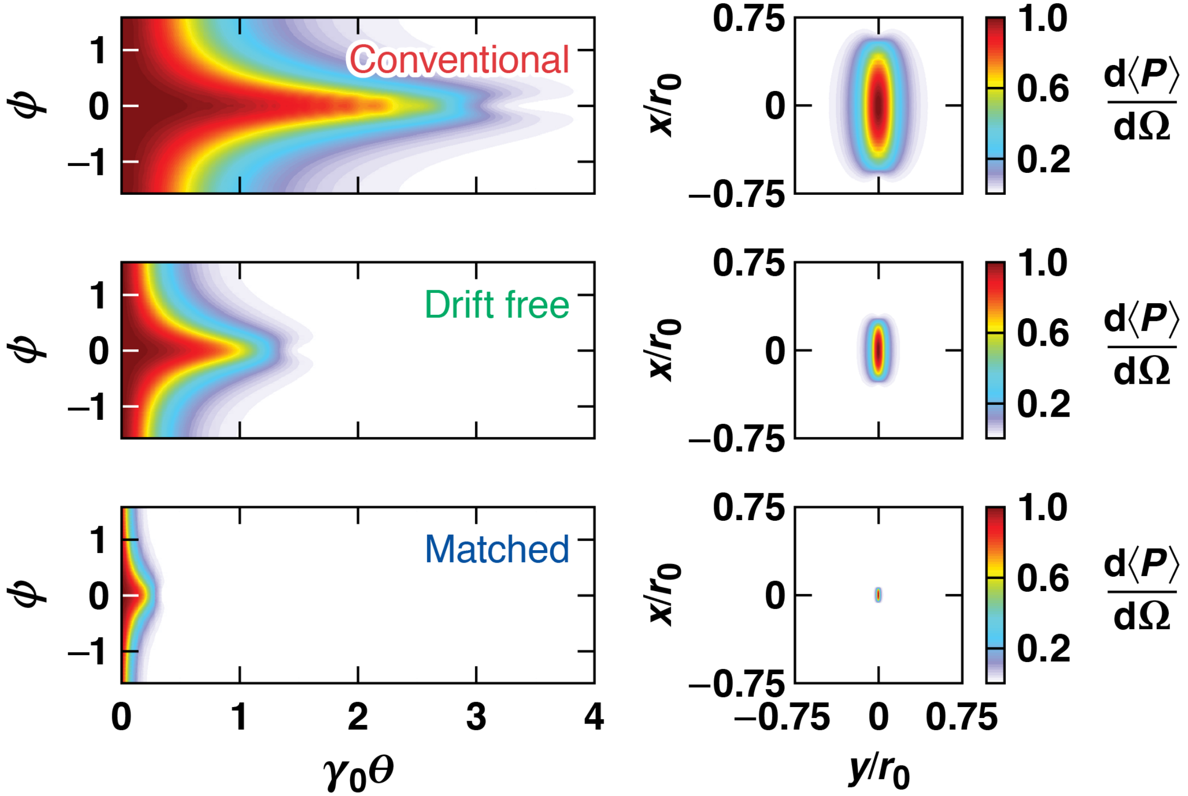
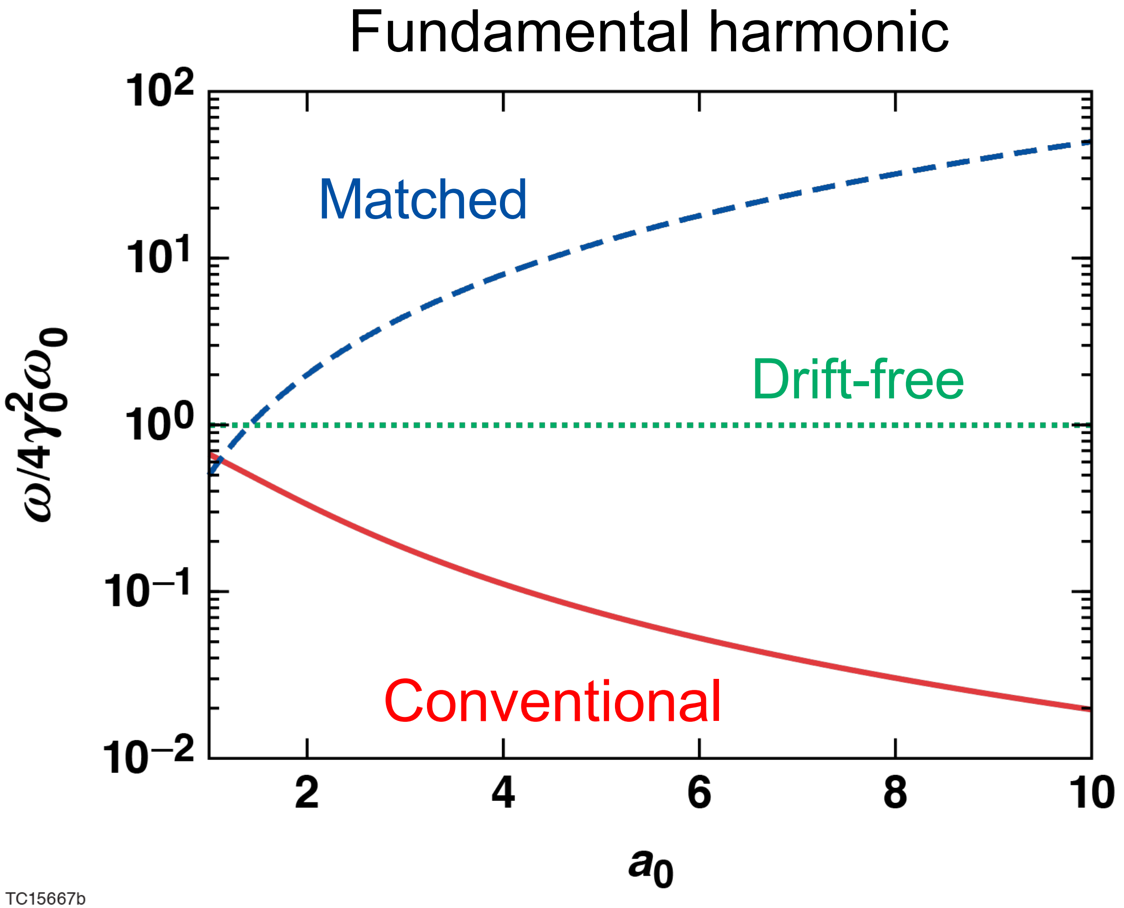


TC15638f

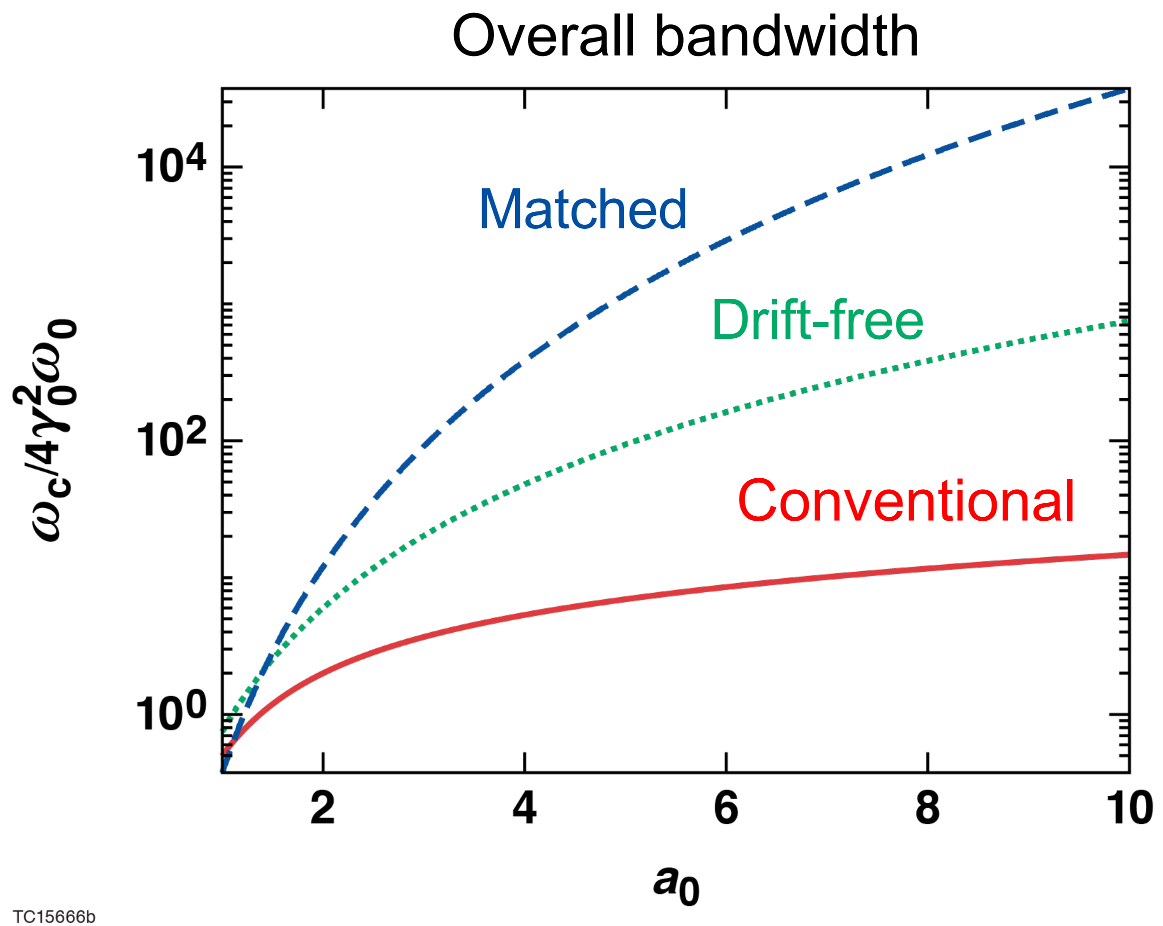


TC15639b

Both the harmonic frequency and bandwidth have a more favorable scaling with intensity in flying focus pulses

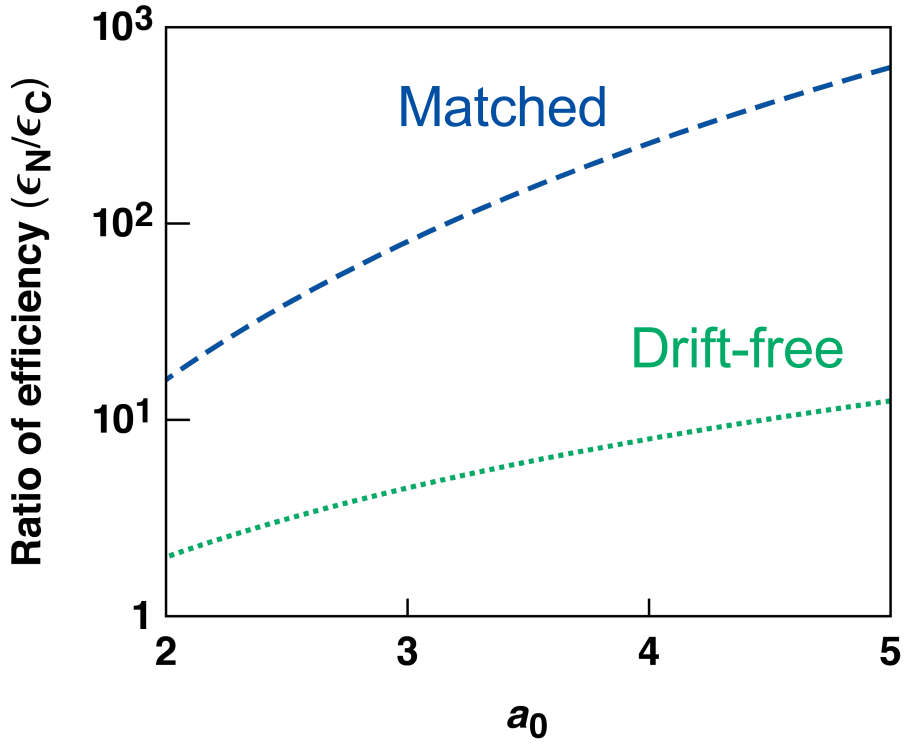


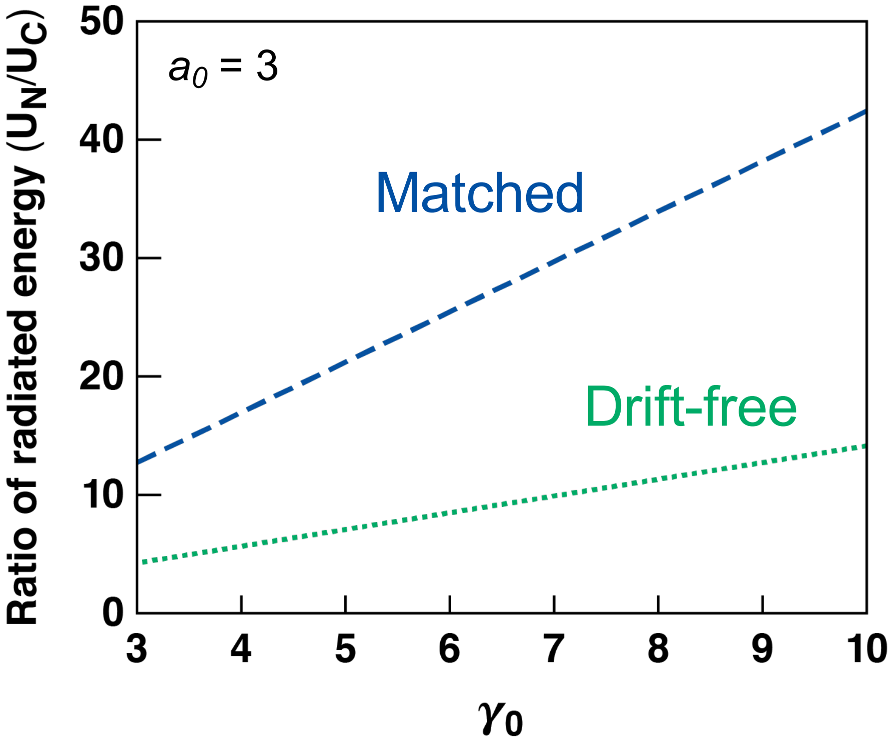
TC15667b



TC15666b

NPC compares favorably with conventional NLTS at either fixed intensity or fixed pulse energy



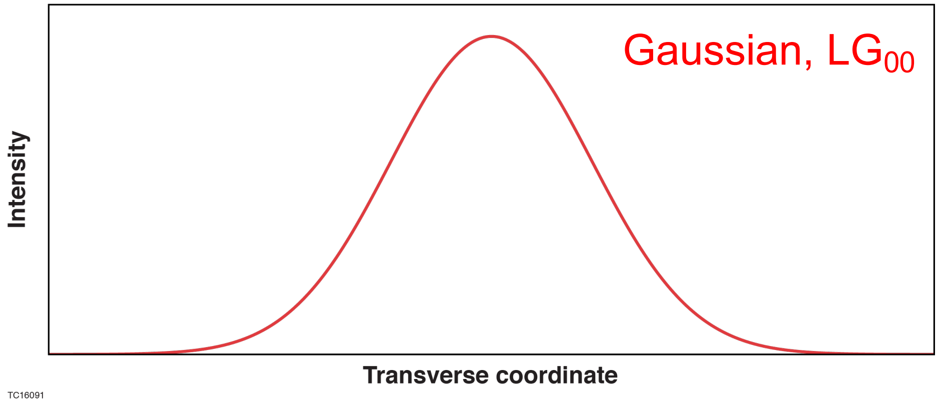


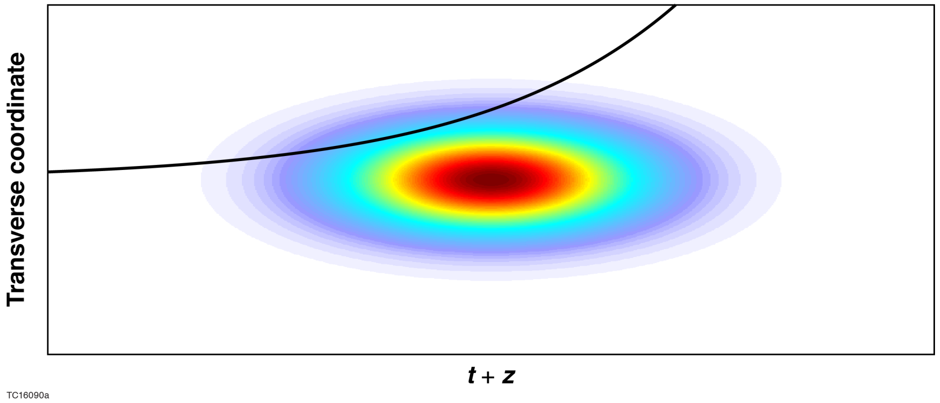
At the same **intensity**, NPC requires more pulse energy, but has much higher efficiency

At the same pulse **energy**, NPC produces much more radiated energy than conventional NLTS

The extended interaction lengths in NPC require transverse shaping of the ponderomotive force to prevent electron deflection

Conventional NLTS





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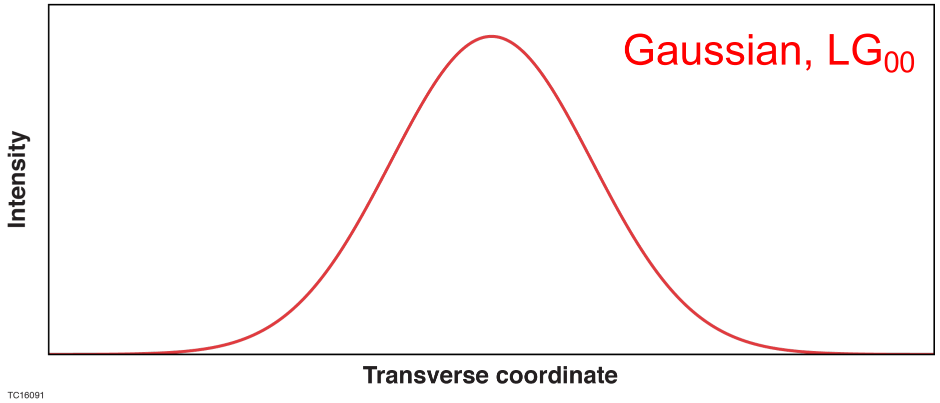
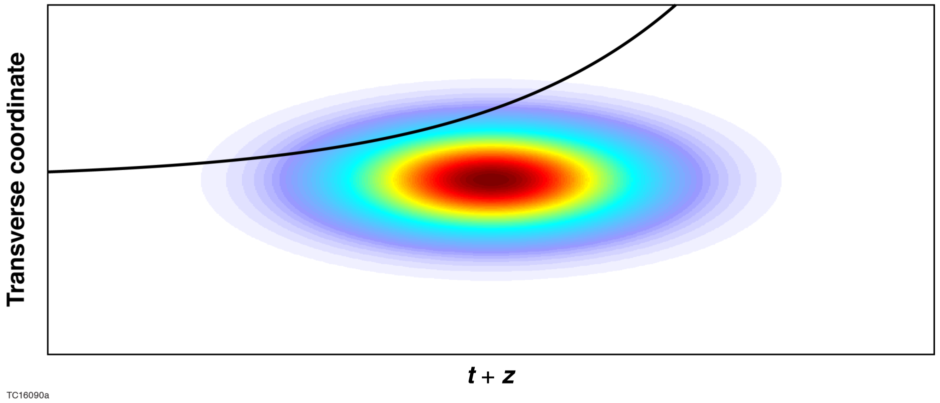
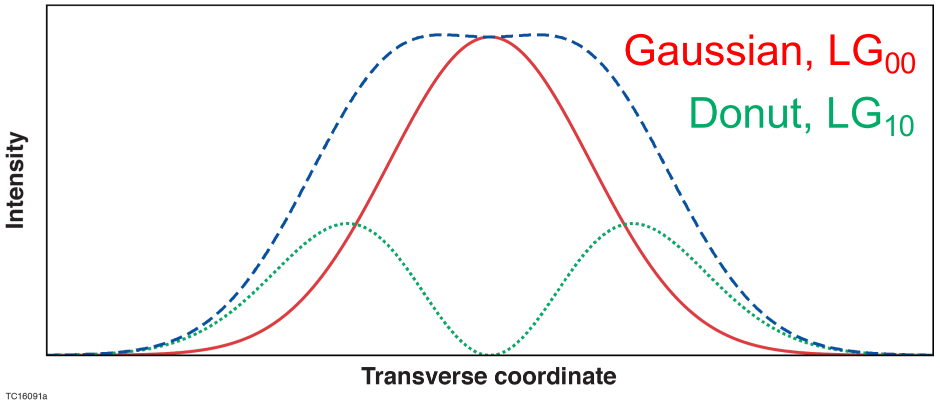
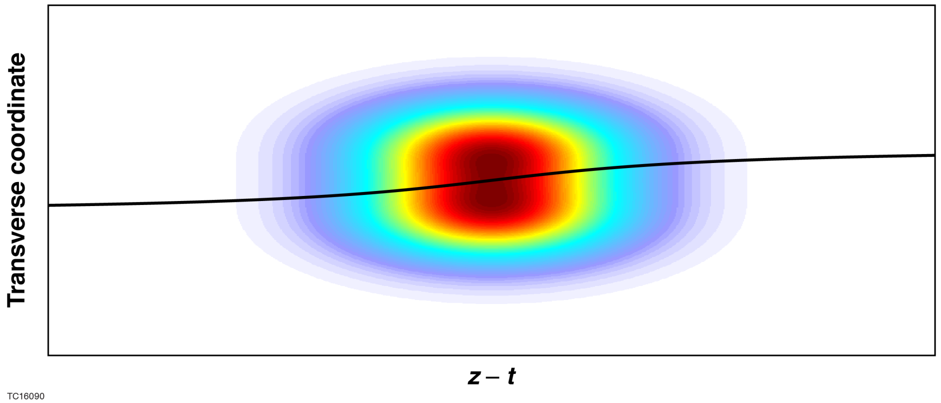


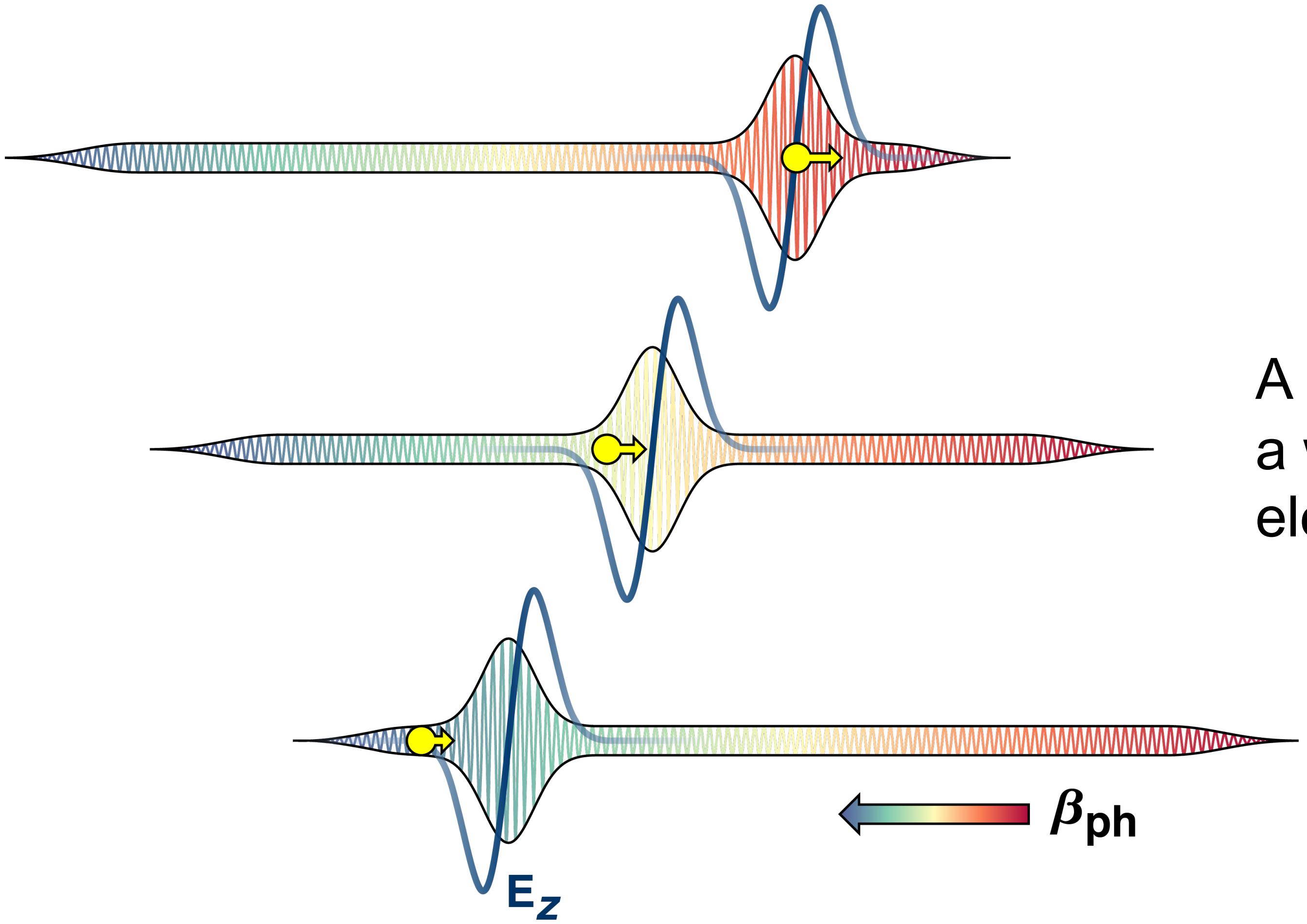


NPC





The presence of a plasma can overcome many of the limitations of vacuum NPC

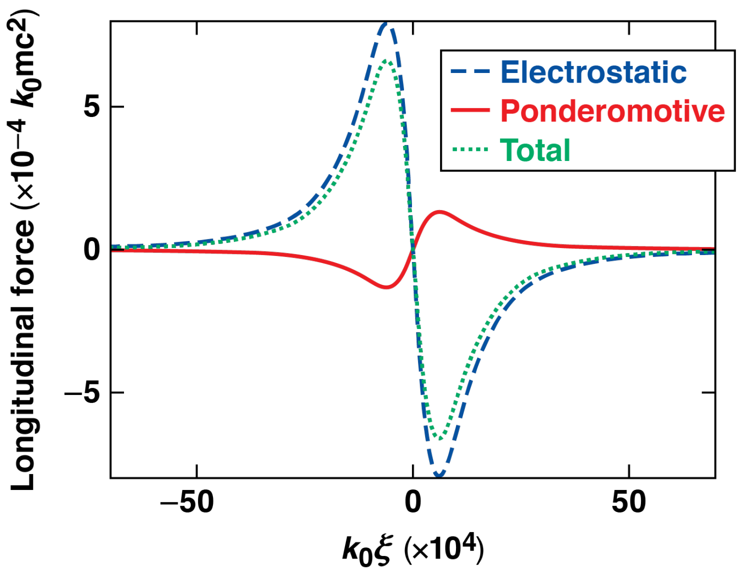


A counter-travelling intensity peak drives a wakefield that accelerates relativistic electrons against the laser phase fronts

TC16128

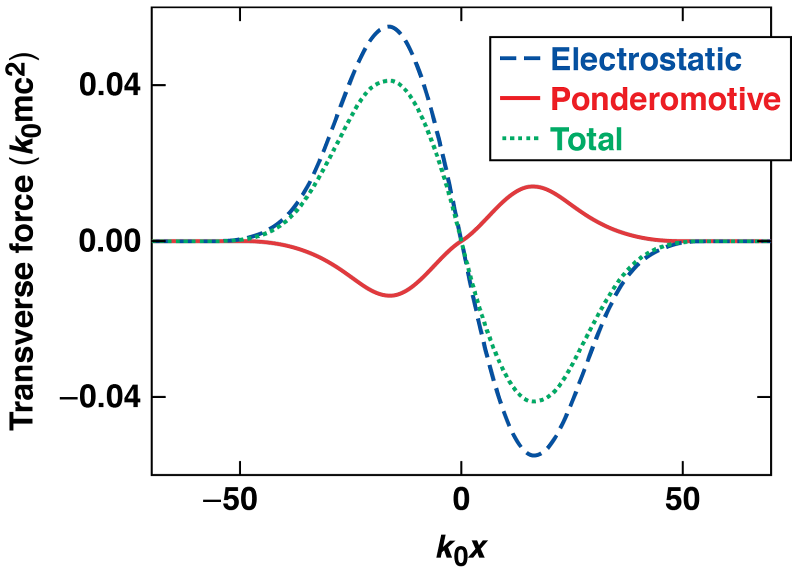
A counterpropagating wakefield provides a stronger accelerating force and obviates the need for transverse intensity shaping

Acceleration



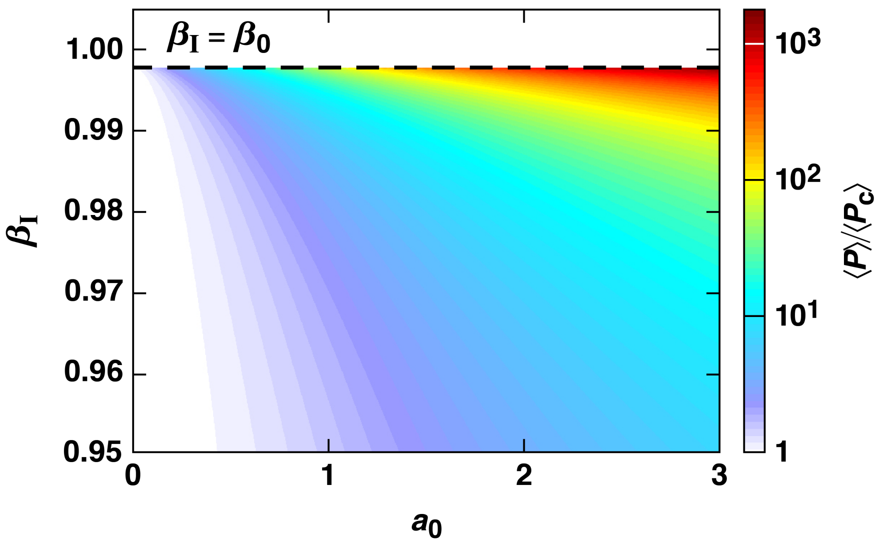
The electrostatic force is much larger than the ponderomotive force

Focusing



The near-linear focusing keeps the electrons well collimated

Power



The radiated power is orders of magnitude larger than conventional NLTS

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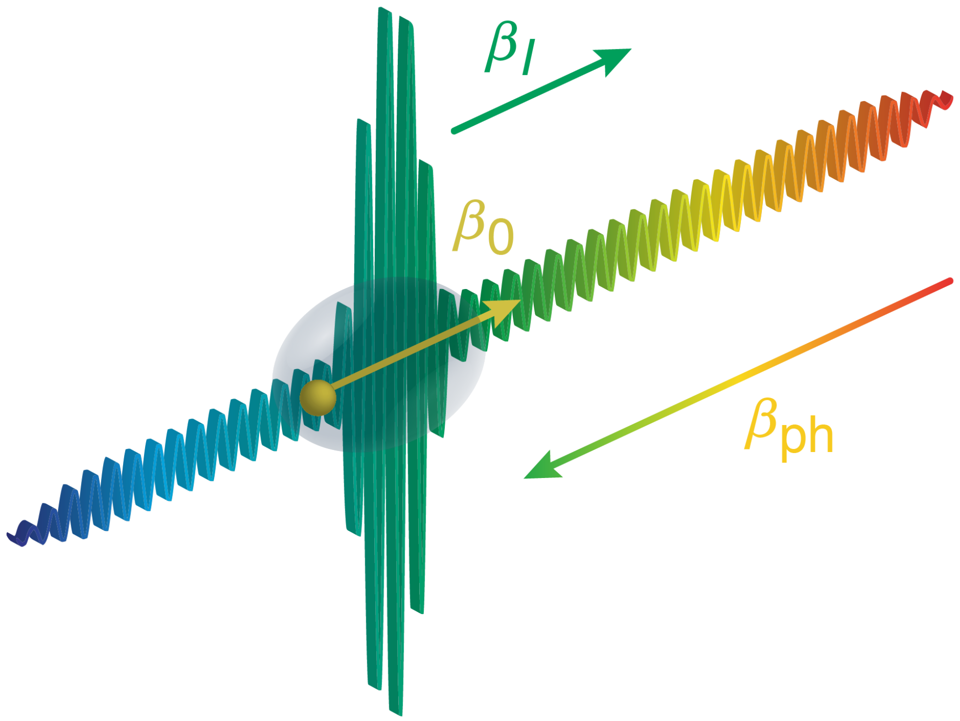

TC15637g

Nonlinear Thomson scattering with ponderomotive control (NPC) takes advantage of the trajectory control afforded by flying focus pulses