Hosing in Multi-Pulse Laser Wakefield Accelerators

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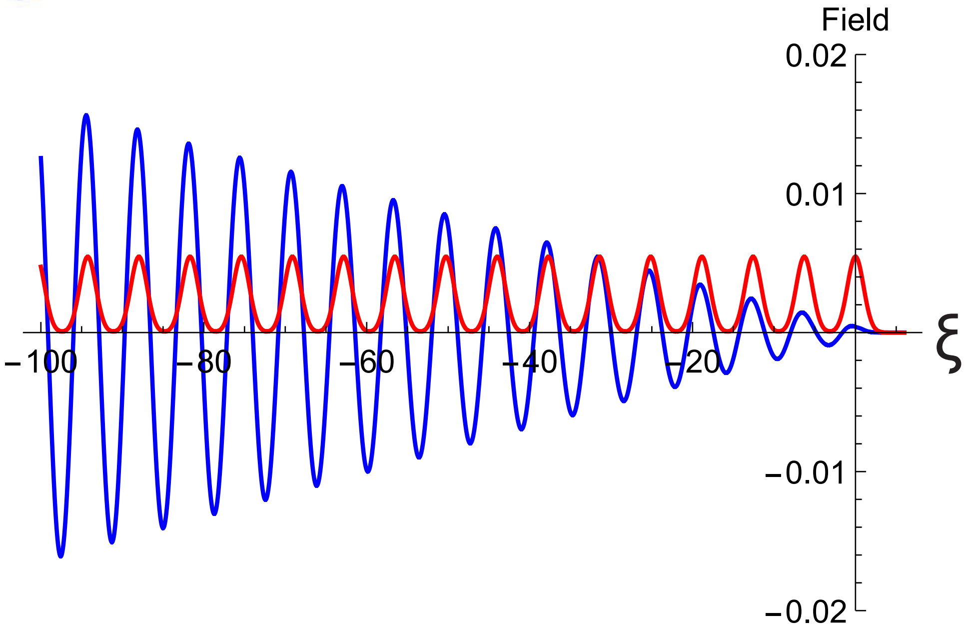
Hosing



Multi-Pulse Laser Wakefield Acceleration
MP-LWFA

- ▶ Fibre and thin-disk lasers for MP-LWFA
- kHz rate
- high efficiency
- excellent spatial quality and pointing
- lower peak power on optics
- compact
- fast feed back diagnostics

▶ Hosing is driven by transverse gradients in the refractive index of the plasma

- by considering the bending of phase fronts due to a transverse plasma density gradient (Mori 1997) the variation of the centroid of a pulse, ρ, can be described by

$$\frac{\partial^2 \rho}{\partial t^2} \simeq -\frac{c^2}{2}\frac{\omega_p^2}{\omega_0^2}\frac{\partial}{\partial r}\left(\frac{\delta n}{n_0}\right) = -\frac{c^2}{2}\frac{\omega_p^2}{\omega_0^2}\partial_r\left(\frac{\delta n}{n_0}\right)$$

- a second pulse trailing in the wake driven by another pulse will follow oscillating or will refract away depending on the sign of $\partial_r(\delta n/n_0)$

Model

considered parameters

► Trains of identical laser pulses: 10 to 120 pulses

Each pulse:

- 10 mJ, FWHM 100 fs, w0 = 40 μm, Gaussian envelope
- a_0 = 0.052, Power/Critical Power = 6×10^{-4}
- plasma density = 1.74×10^{17} cm^{-3} , λ_p = 80 μm, k_p w0 = π
- considered accelerator length = 25 cm

► Nonrelativistic calculations

- analitic solutions of fluid equations in 2D + 1 following Gorbunov and Kirsanov (1987)

► Weakly relativistic calculations

- numerical solutions of fluid equations in 2D +1 following Miano (1990)

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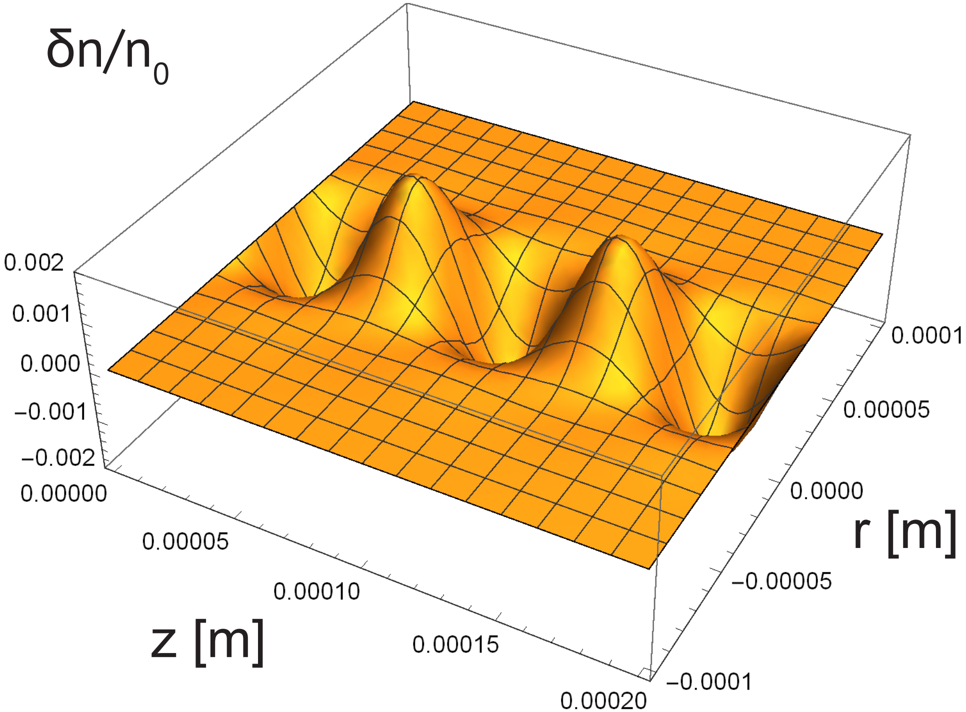
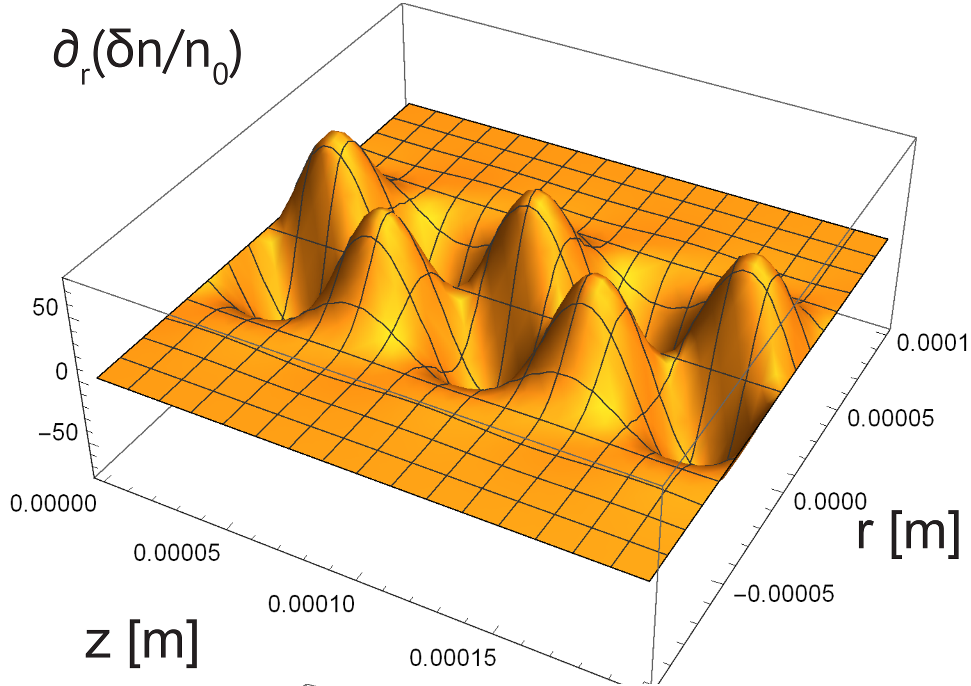
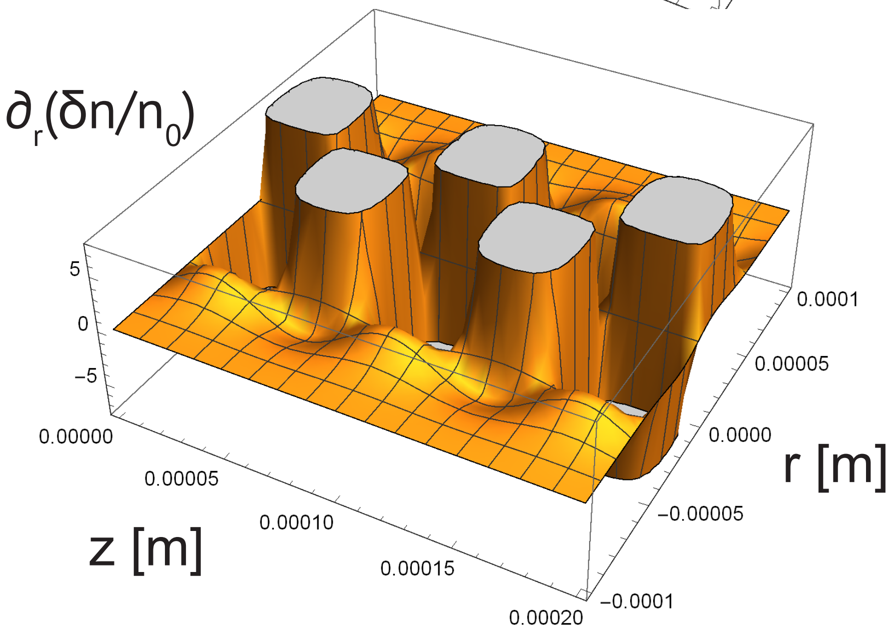
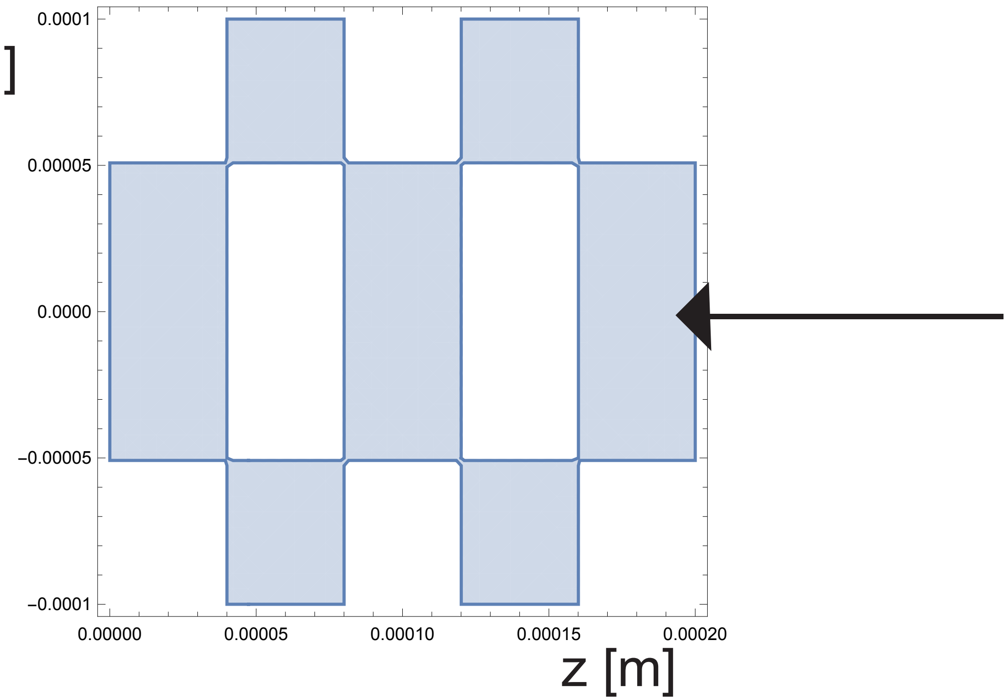
1 pulse







Focusing



focusing part

one expects: f λ_p , f = 0.5 available

for example:
n pulses uniformly spaced by $(1 - \alpha)\,\lambda_p$
=> $(n - 1)(1 - \alpha)\,\lambda_p$ is the distance between the first and last pulse in the train which needs to be not smaller than the nominal length of the train = $(n - 1)\,\lambda_p$ from which the size of the focusing part, f λ_p, is subtracted:
=> $(n - 1)(1 - \alpha)\,\lambda_p > (n - 1)\,\lambda_p - f\,\lambda_p$ is required
=> $\alpha < f/(n - 1)$
But pulses spaced by a fraction of λ_p would modify the wake =>
=> f might be smaller than 0.5

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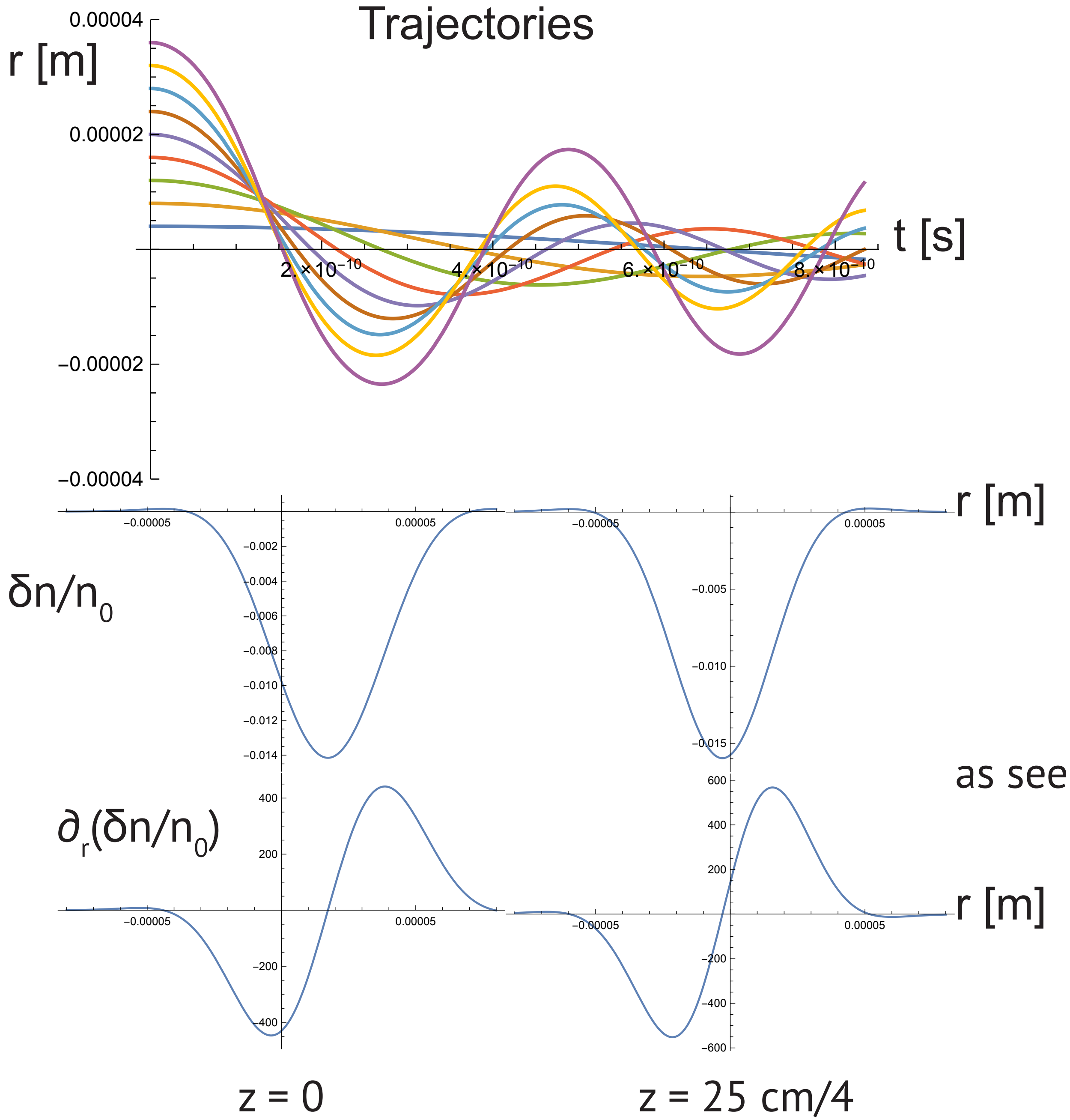
10 pulses α = 0.02



10 pulses with
spacing: α = 0.02
vertical spacing = $w_0/10$

as seen by the pulse 10

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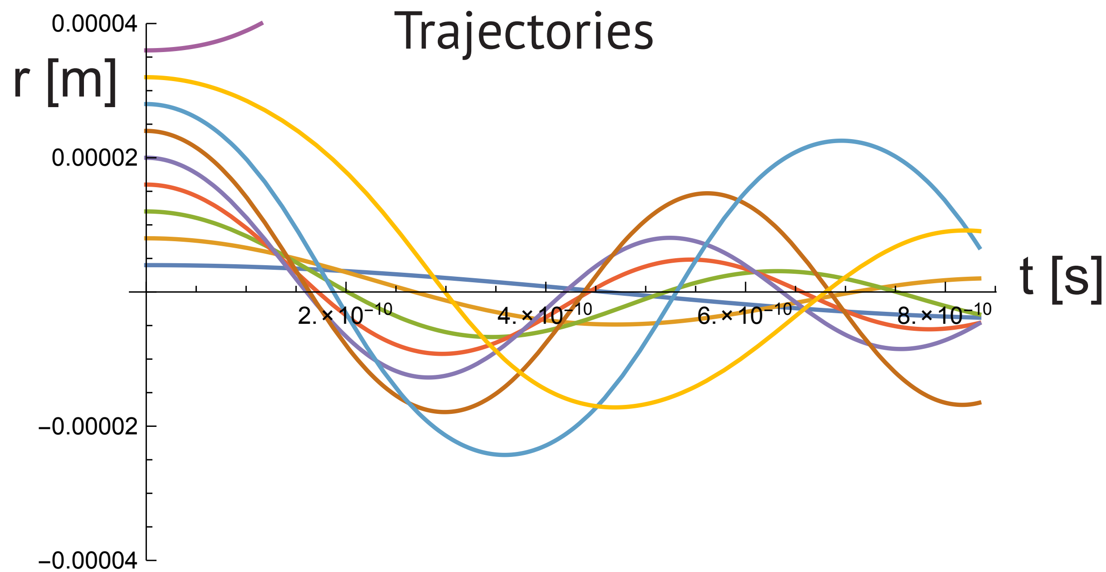
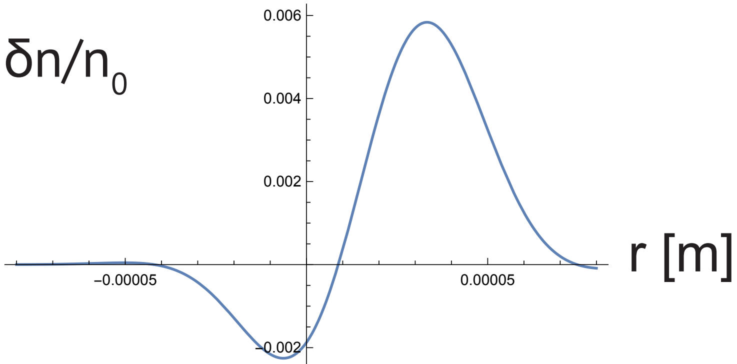
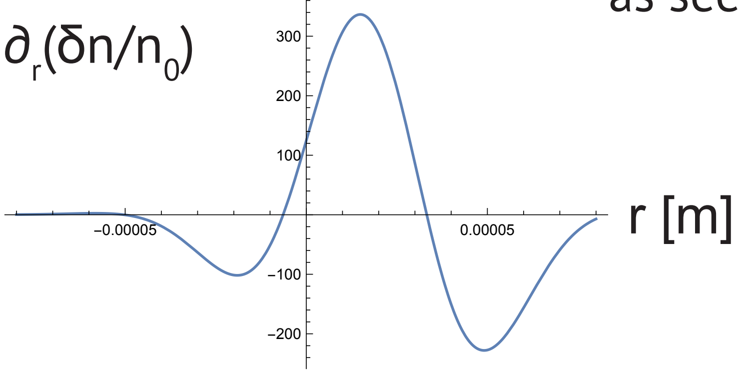
10 pulses α = 0.04



10 pulses with
spacing: α = 0.04
vertical spacing = $w_0/10$

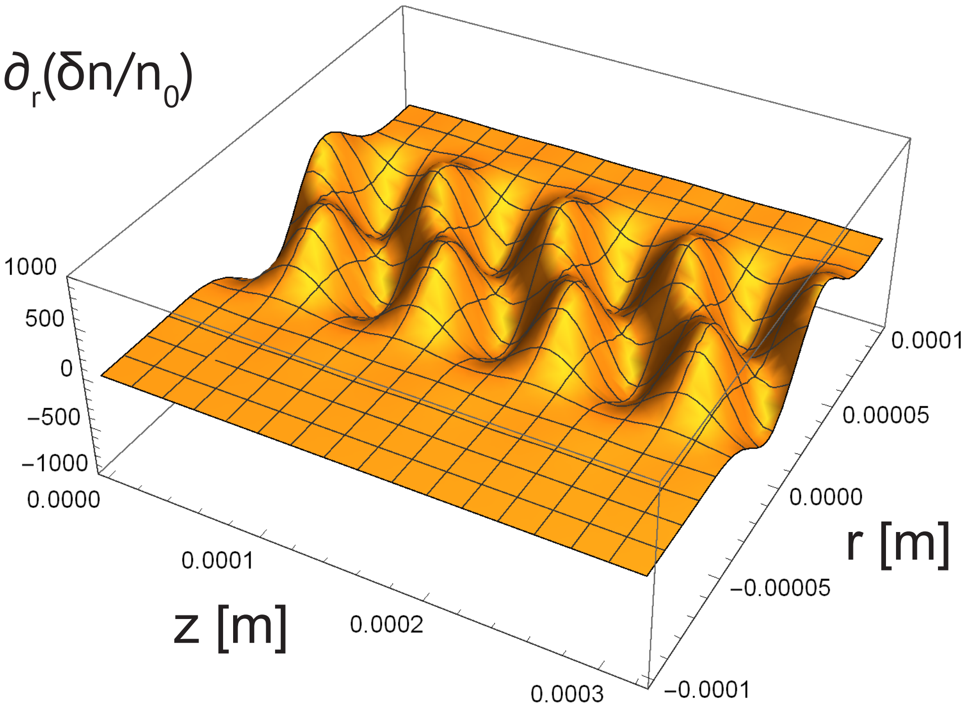


as seen by the pulse 10 at z = 0

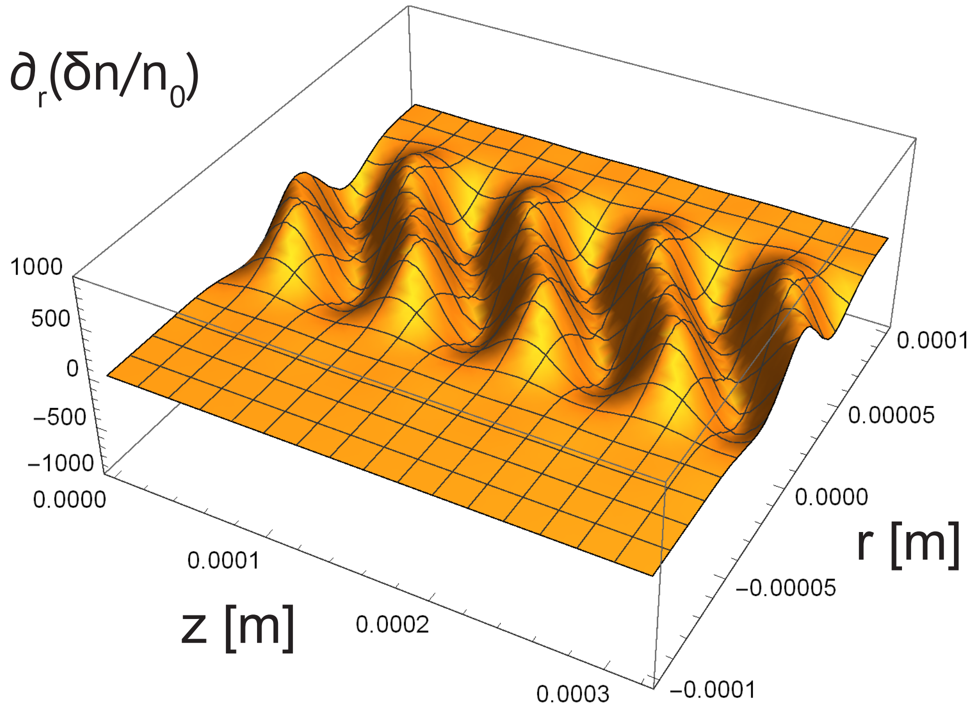


10 pulses α = 0.04 is too big

spacing: α = 0.02



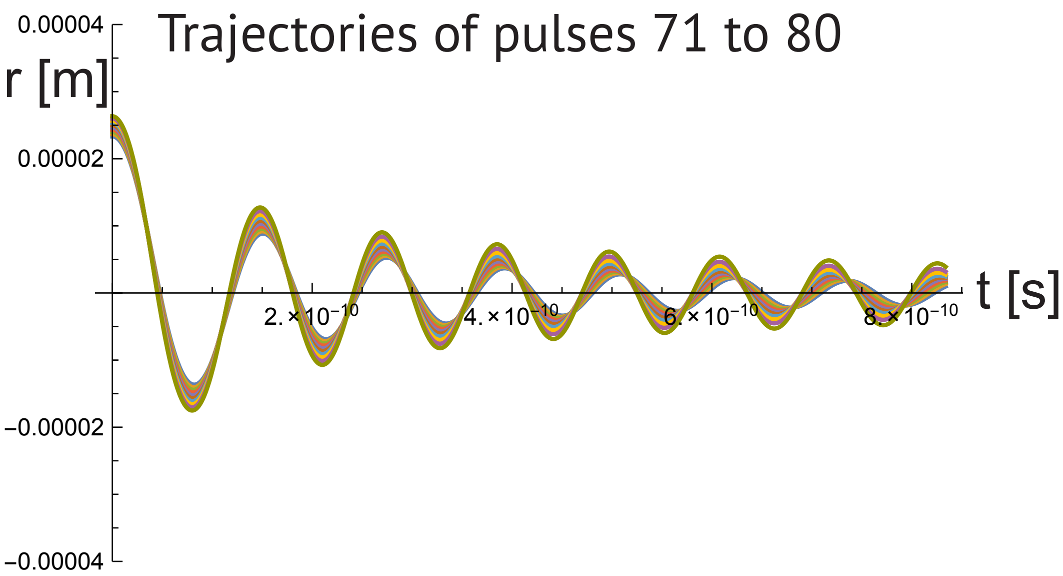
spacing: α = 0.04

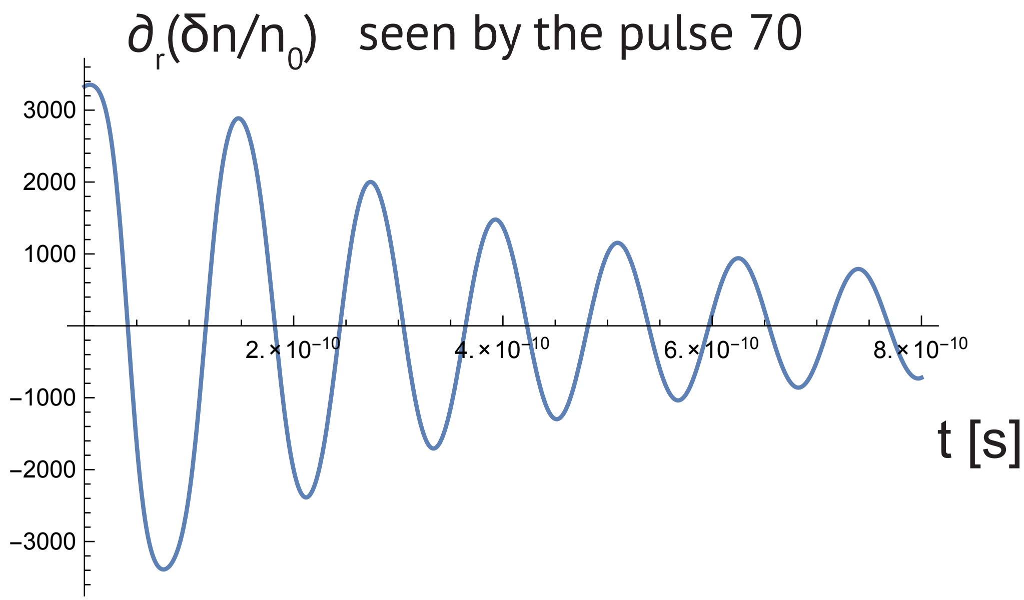


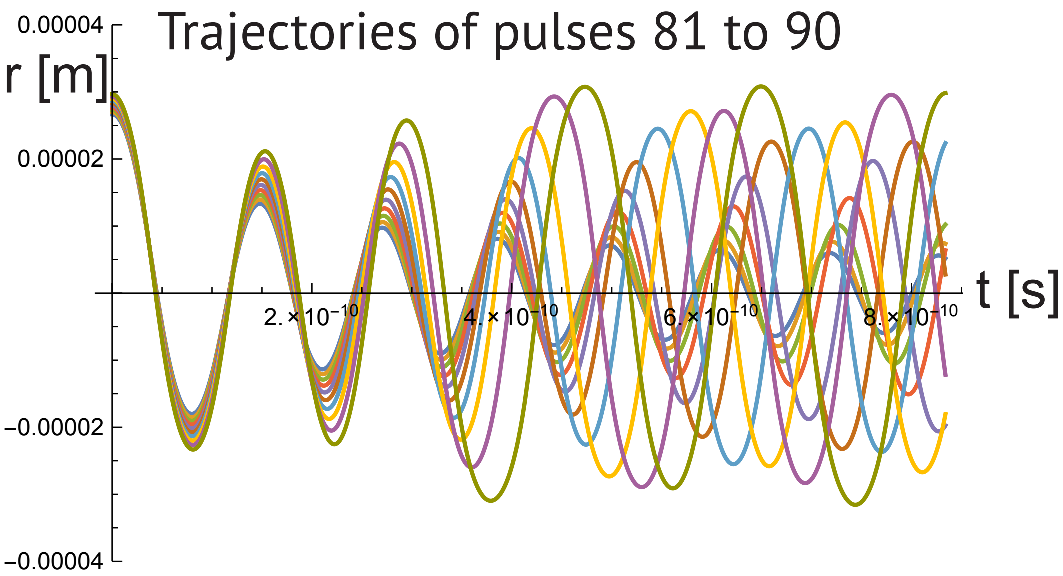
at the moment when the pulse 10 is at z = 0

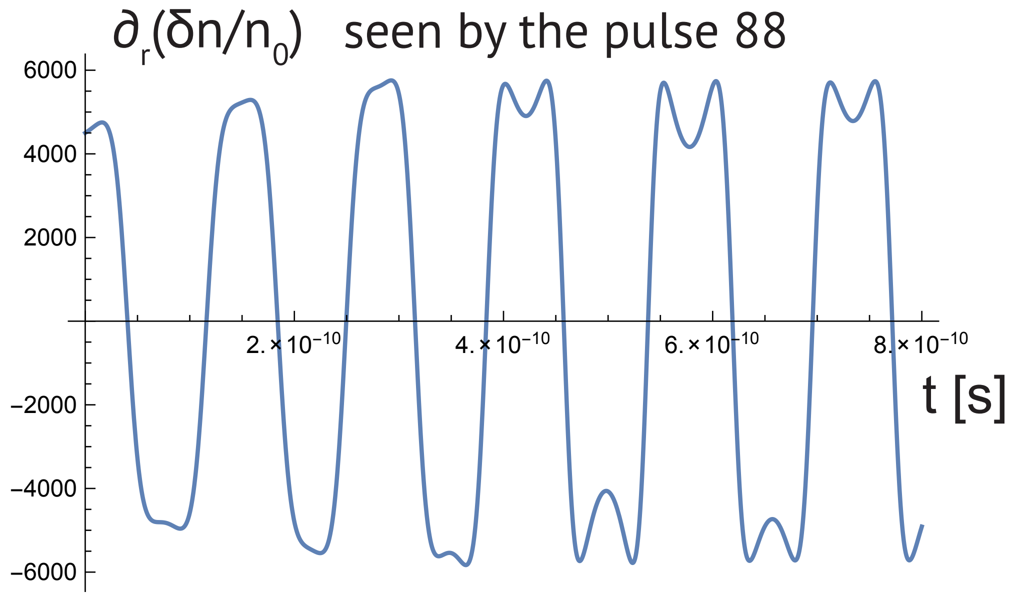
f is not more than about 0.2

120 pulses and transverse limit; α = 0.002









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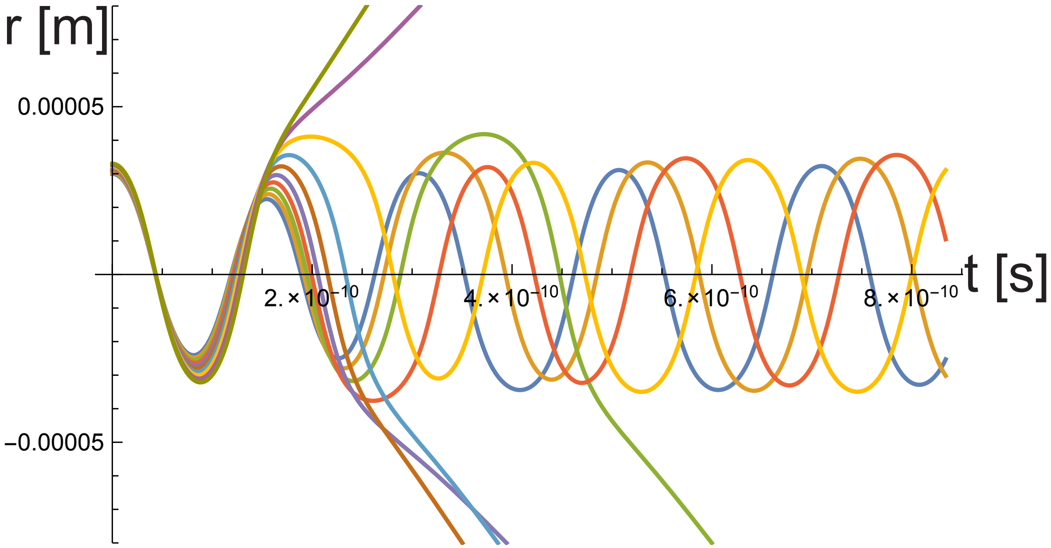
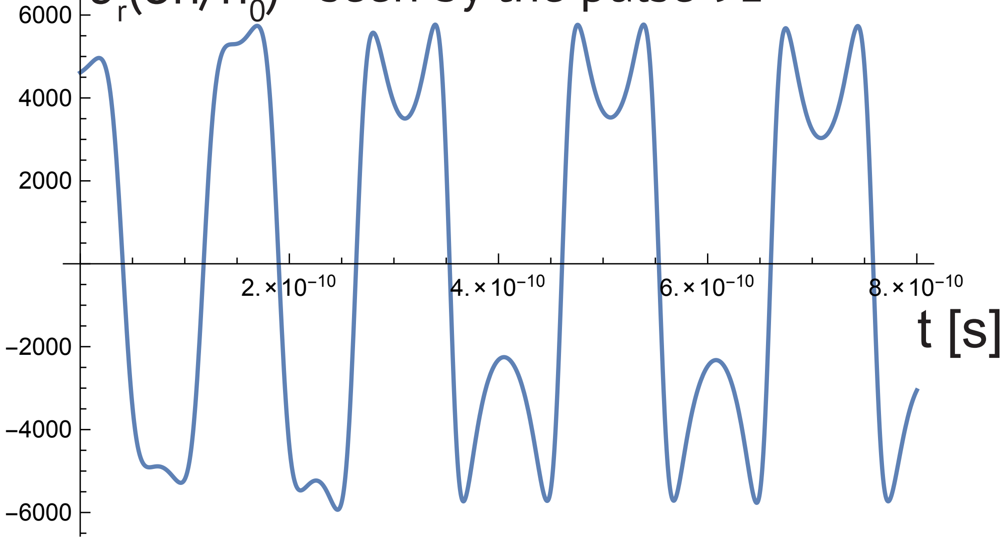
120 pulses and transverse limit; α = 0.002

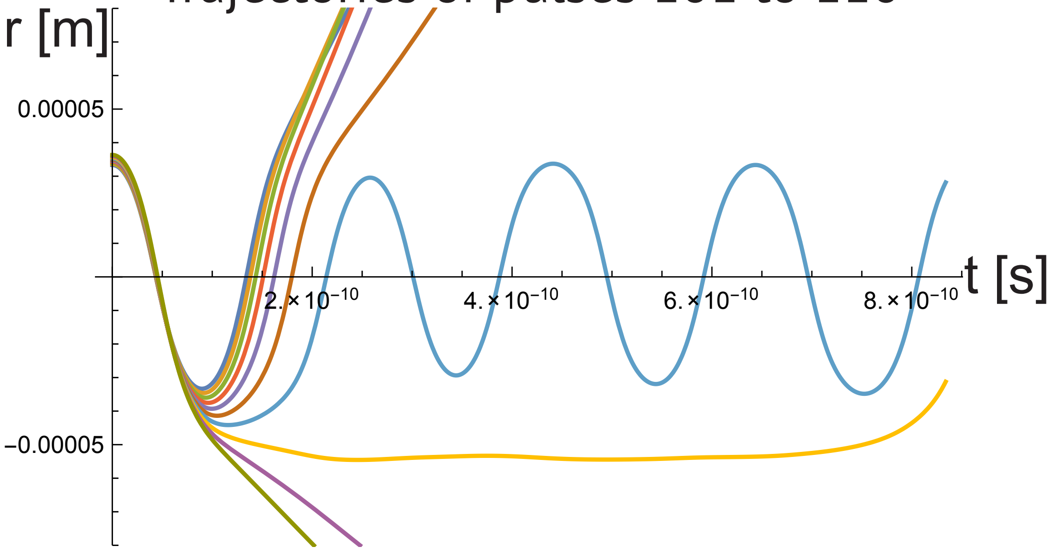
Trajectories of pulses 91 to 100



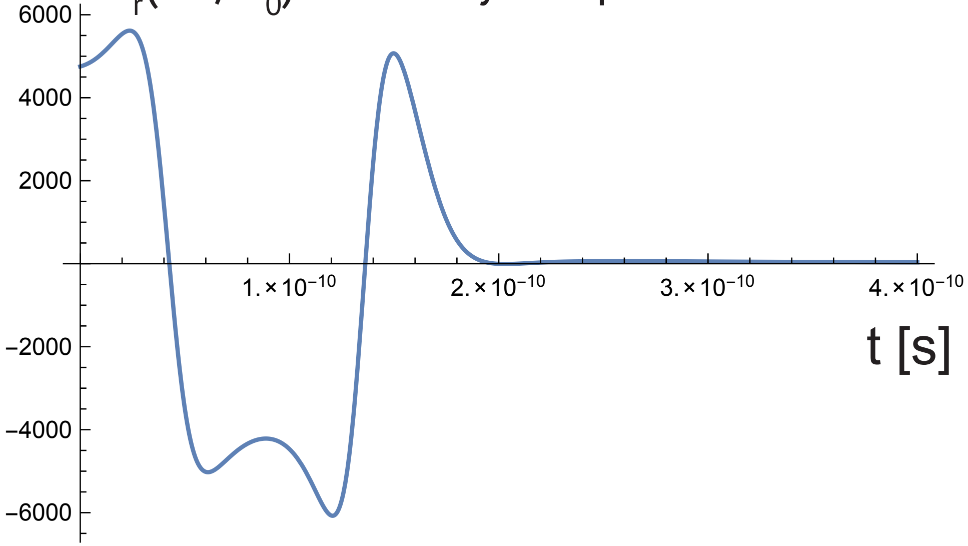
$\partial_r(\delta n/n_0)$ seen by the pulse 91



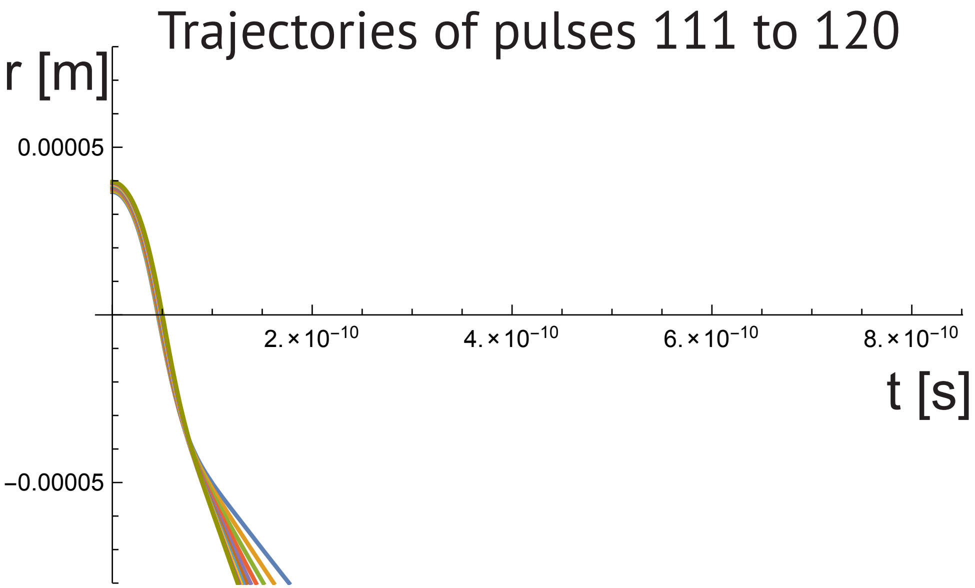
Trajectories of pulses 101 to 110

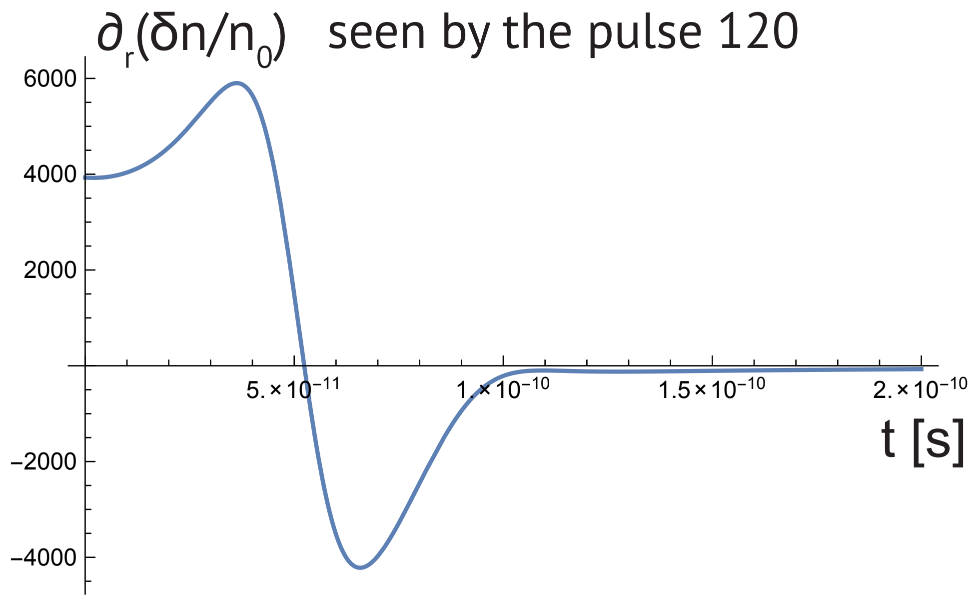


$\partial_r(\delta n/n_0)$ seen by the pulse 101



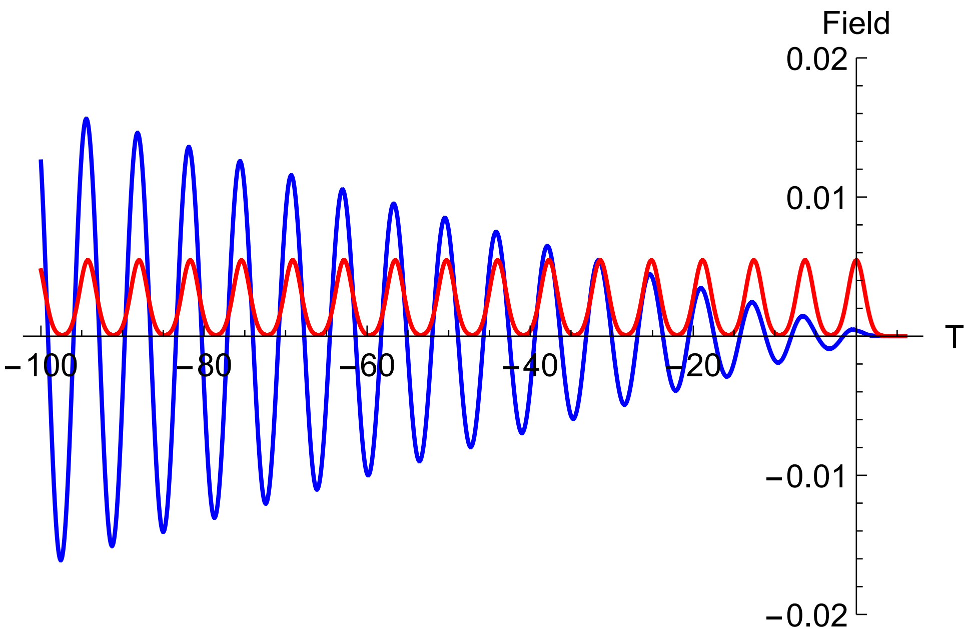
120 pulses and transverse limit; α = 0.002





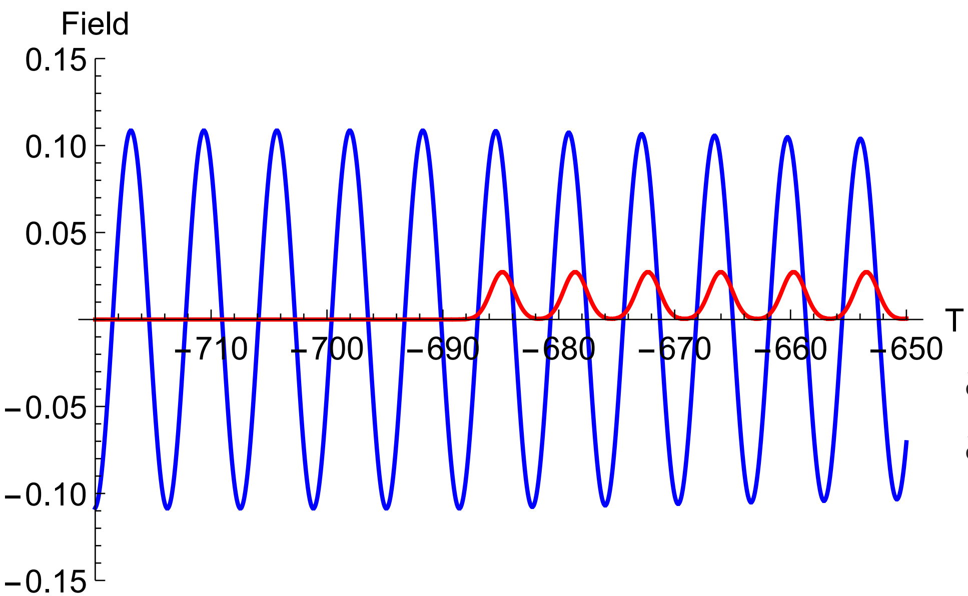
In the transverse plane, pulses need to be placed between the axis and the location of the maximum of the transverse component of the density gradient.

Relativistic plasma period growth



110 pulses on axis
nominal spacing: α = 0
weakly relativistic calculations

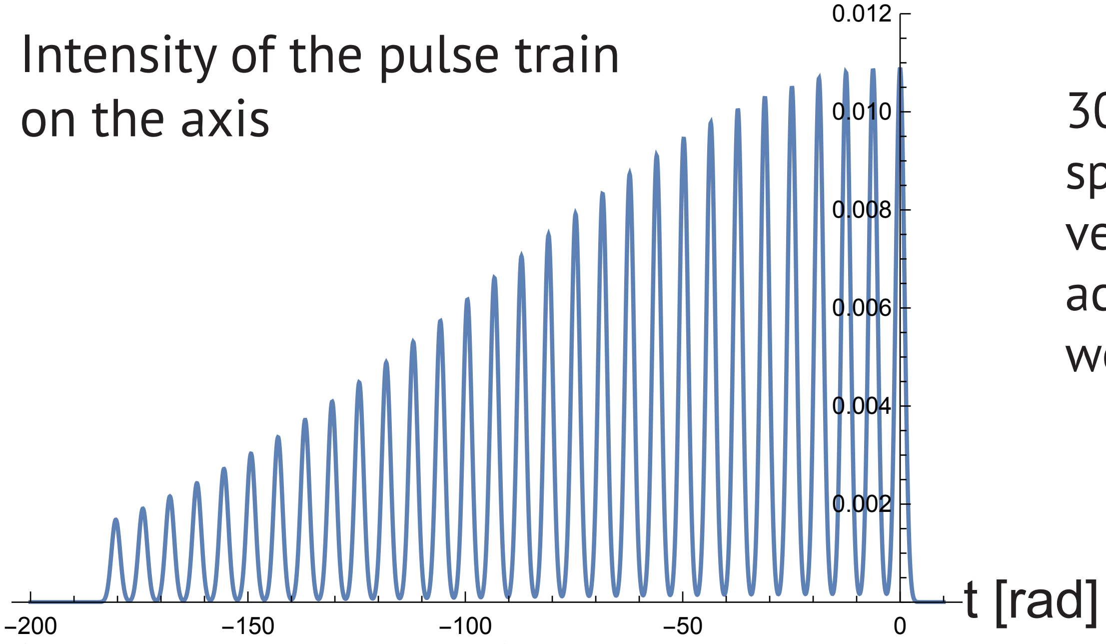
longitudinal electric field on axis and the intensity of the train of pulses.



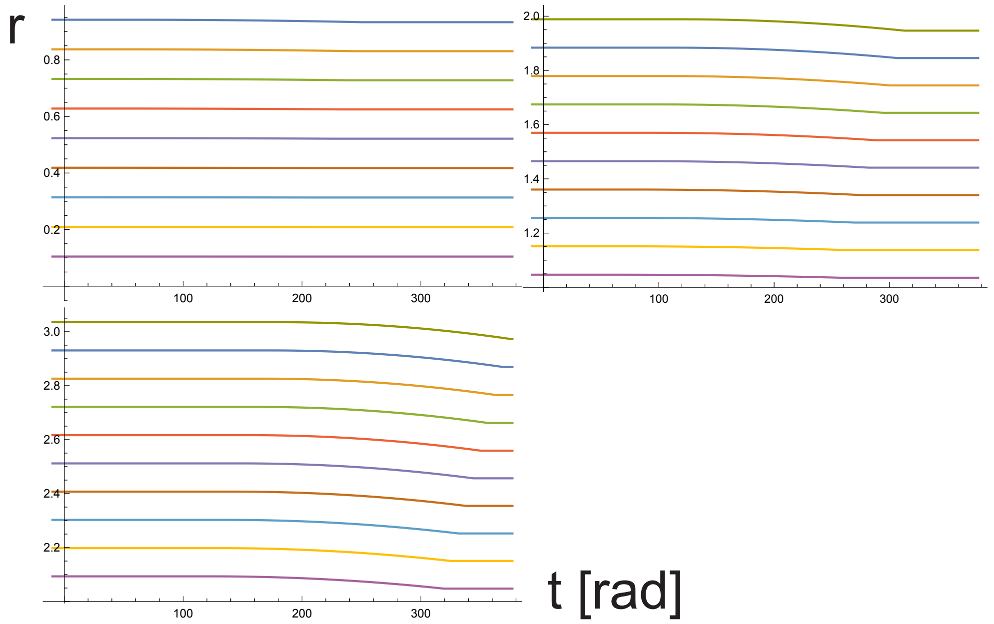
accumulated phase shift of about 0.6 rad; about 10% of $\lambda_{p.}$

The energy gradient

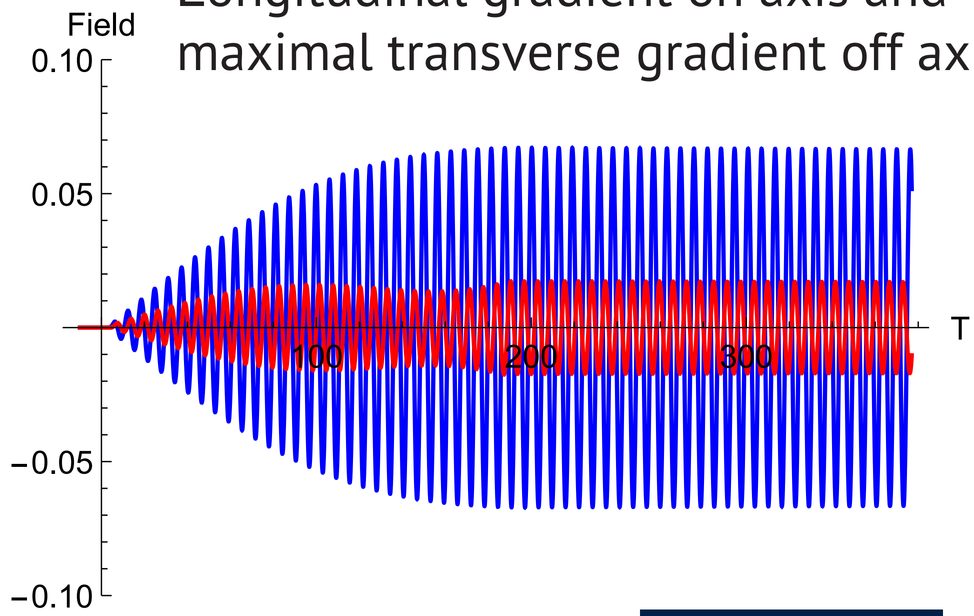
Intensity of the pulse train on the axis



30 pulses with increased a_0 by x2
spacing: α = 0.01
vertical spacing = $w_0/30$
accelerator length = 0.25 cm
weakly relativistic calculations



Longitudinal gradient on axis and maximal transverse gradient off axis



Summary

► Longitudinal, focusing, amount of the phase available for adjustments/tolerance is f λ_p (or f 2 π), where f is about 0.2.

- What matters is the accumulated longitudinal phase, not individual spacing of the pulses; one should be able to control it.
- Relativistic effects affect the longitudinal accumulated phase at the level of 10%; it is a shift of 10% not a cut so only appropriate adjustment is needed; no problem in principle.

► Transversely, pulses need to be between the axis and the location of the maximum of the density gradient.

► Further work:

- Extend weakly relativistic calculations to the full accelerator length ≈ 25 cm.
- Consider a parabolic plasma channel.
- Inject electrons and accelerate them.