Experimental Results of a Plasma Wakefield Accelerator using Multiple Electron Bunches

by

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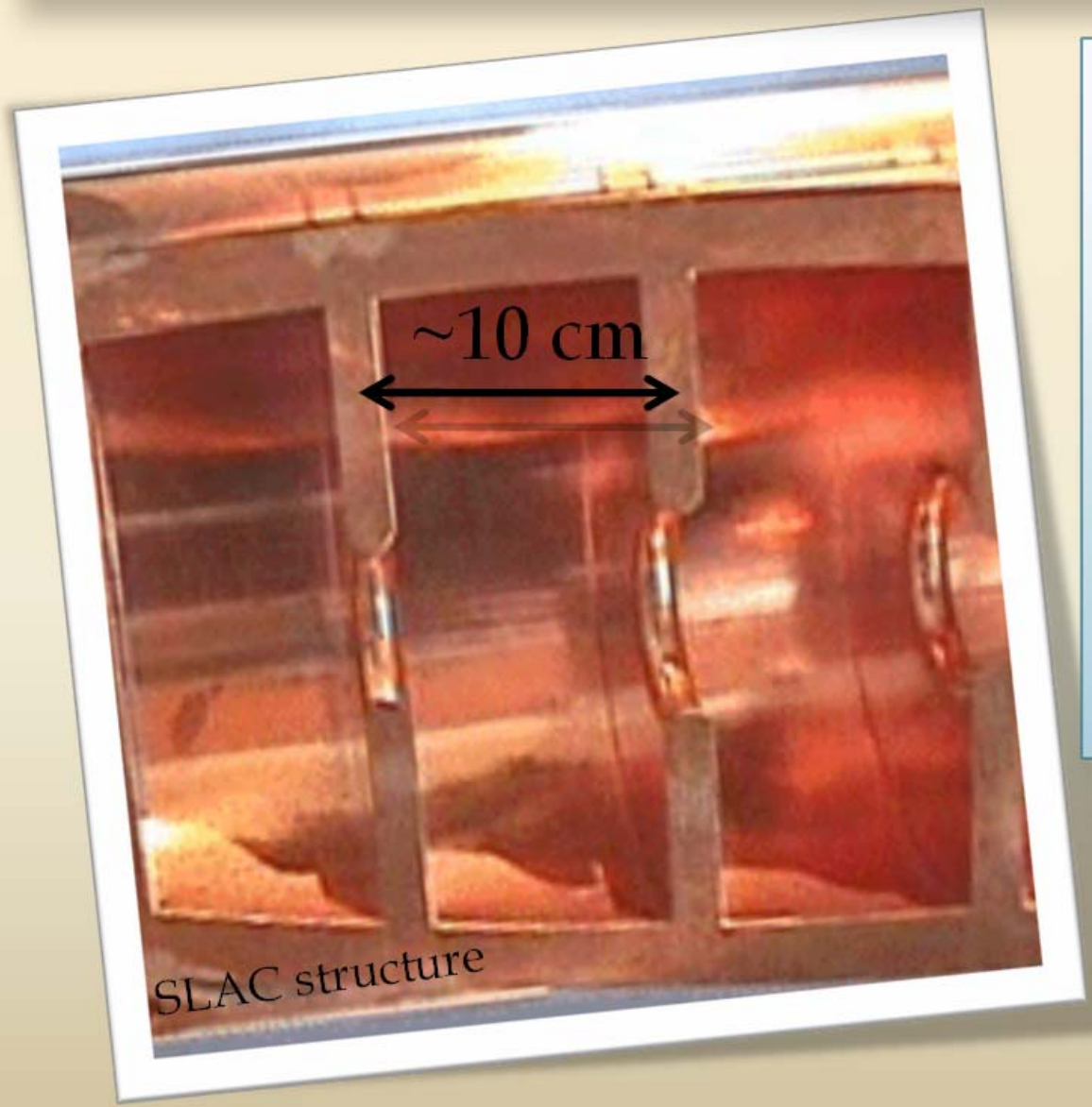
Today's Menu

- **Antipasti**
  Introduction to plasma accelerators
- **Prima Piatti**
  Experiments with multiple electron drivers
- **Secondi Piatti**
  Simulations towards an energy multiplier

Limits of Accelerators



- Gradient of
35 MeV/m (ILC)
150MeV/m (CLIC)

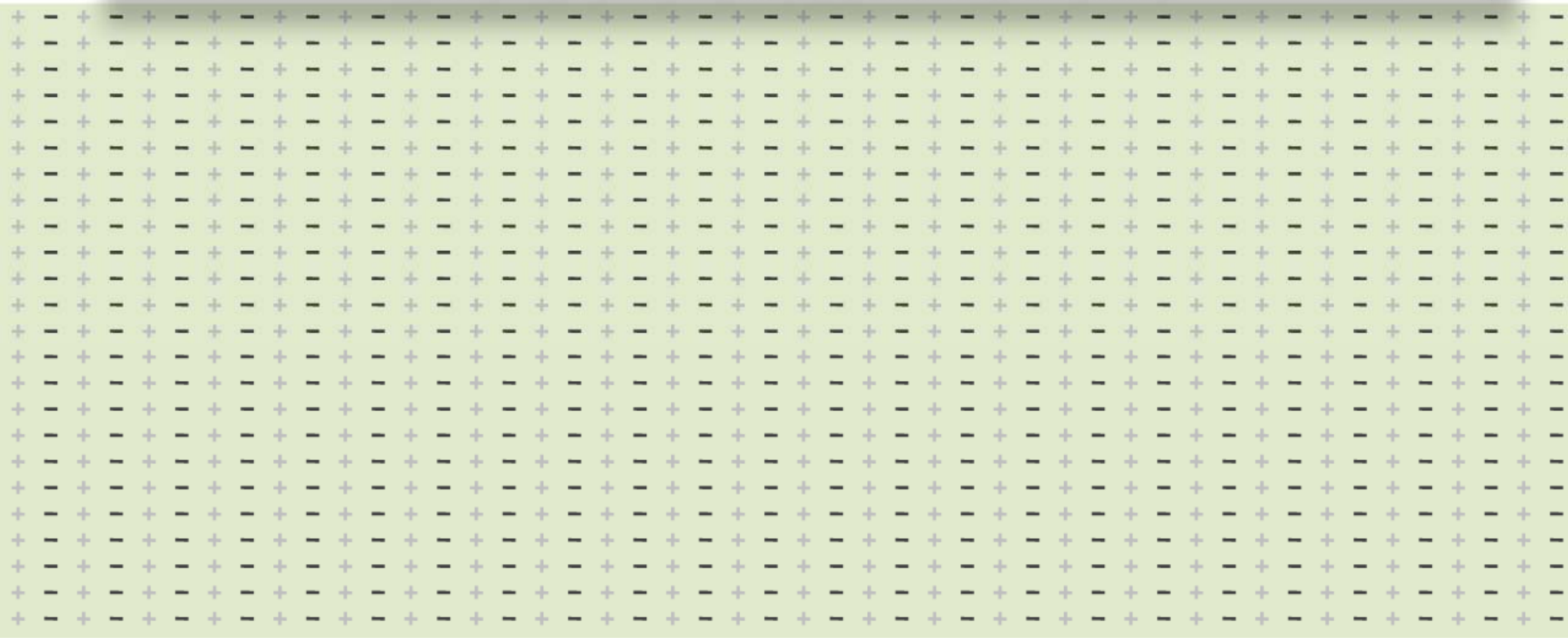
- Limited e.g. by
wall breakdown*

- Plasmas support
10 – 100 GeV/m

*Braun et al., Phys. Rev. Lett. 2003

Plasma Wakefield Accelerator

Basic Principles (Linear Regime)



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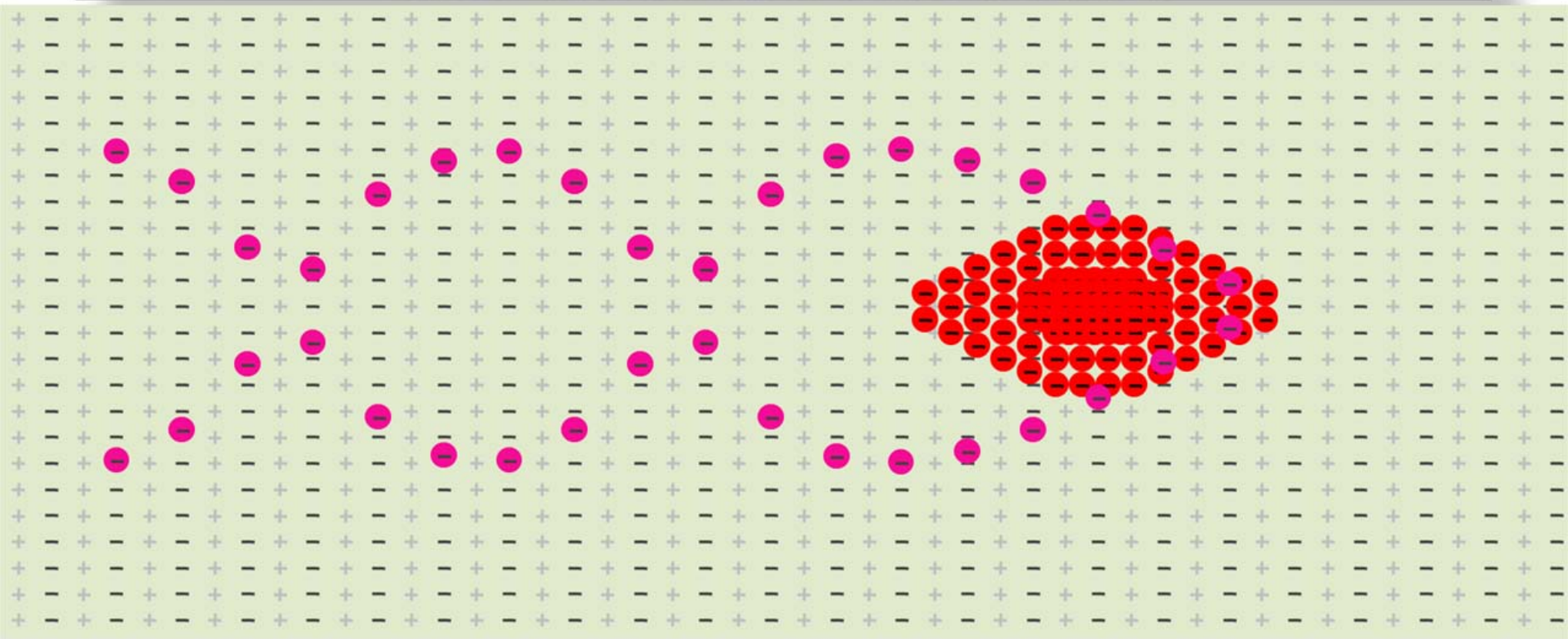

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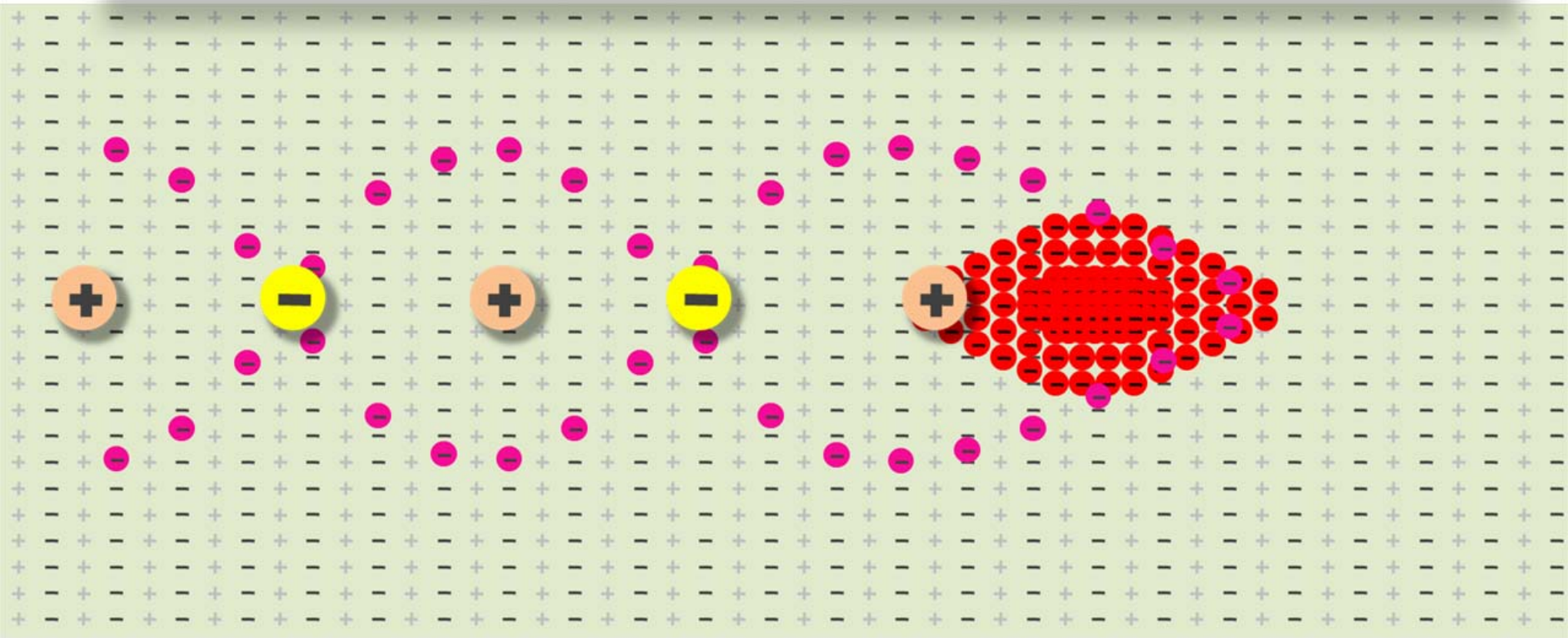

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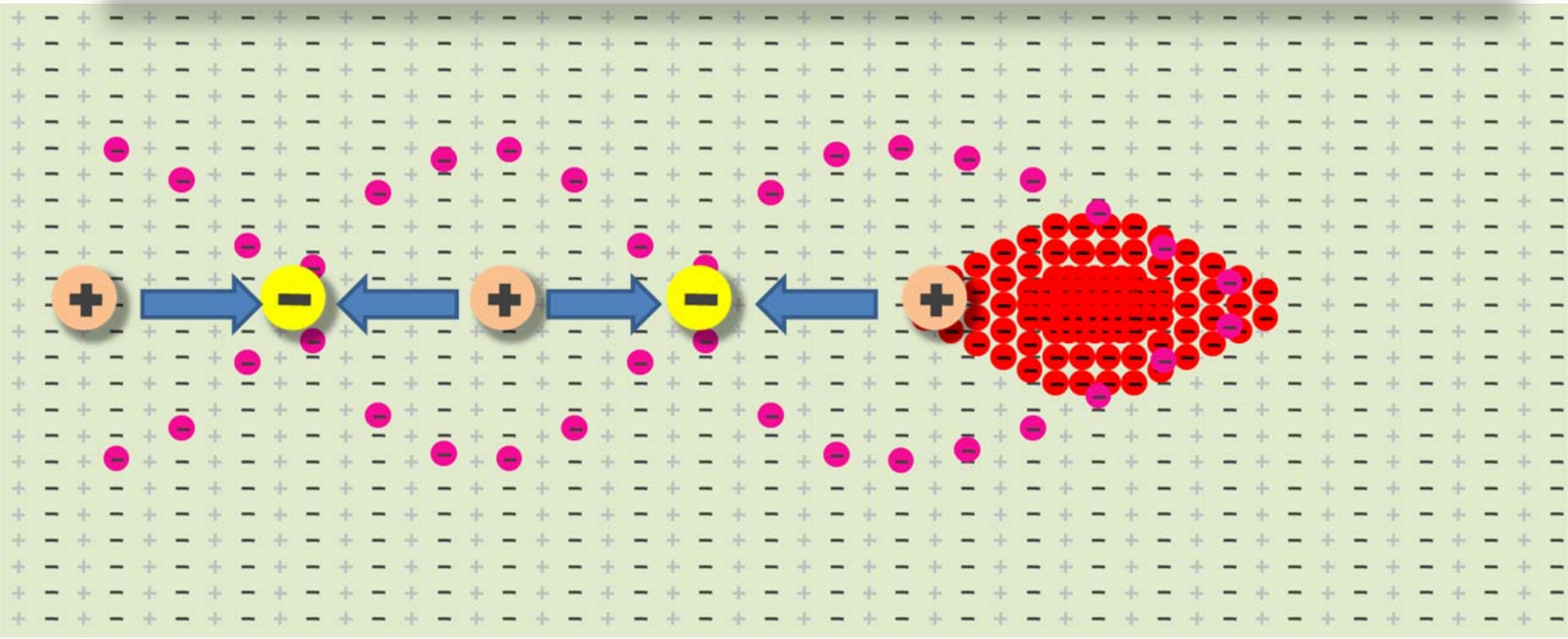

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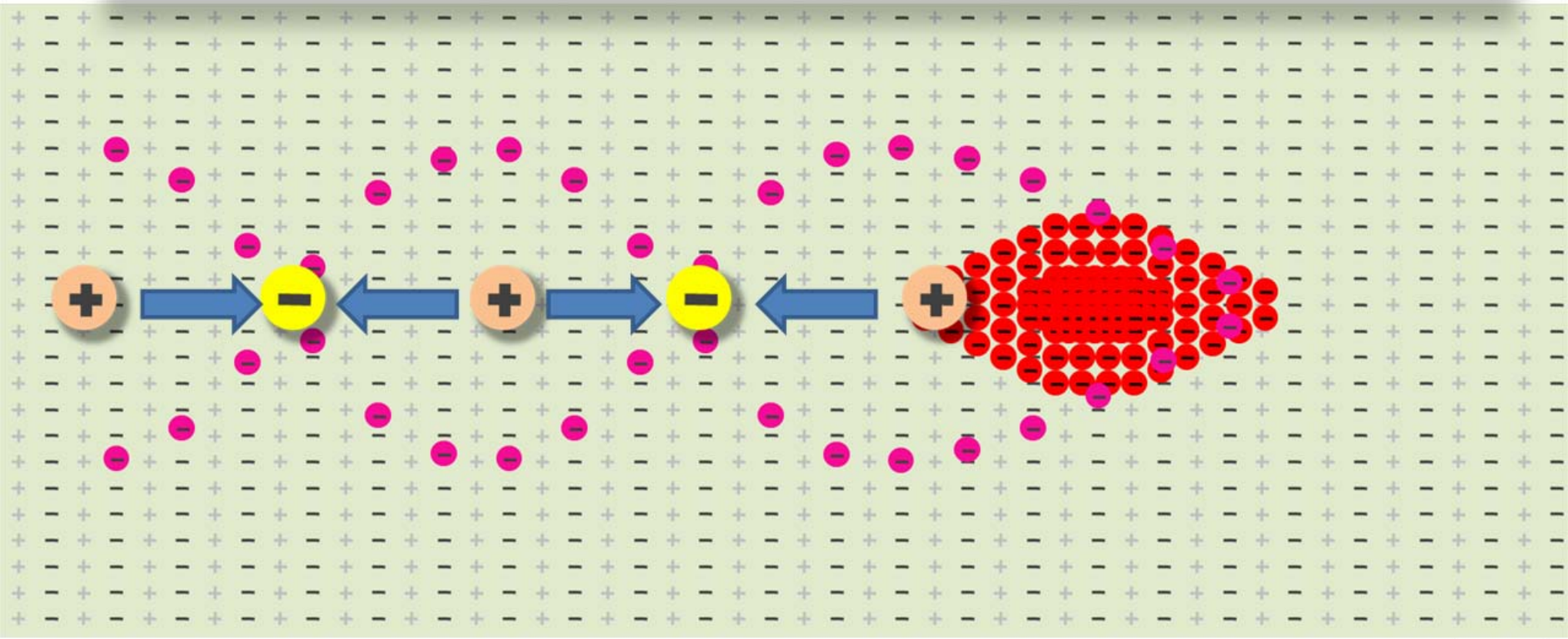
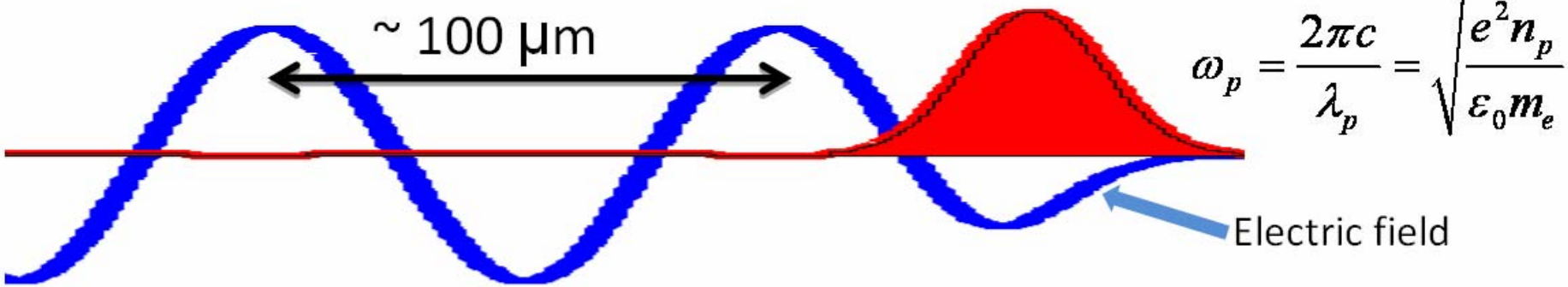
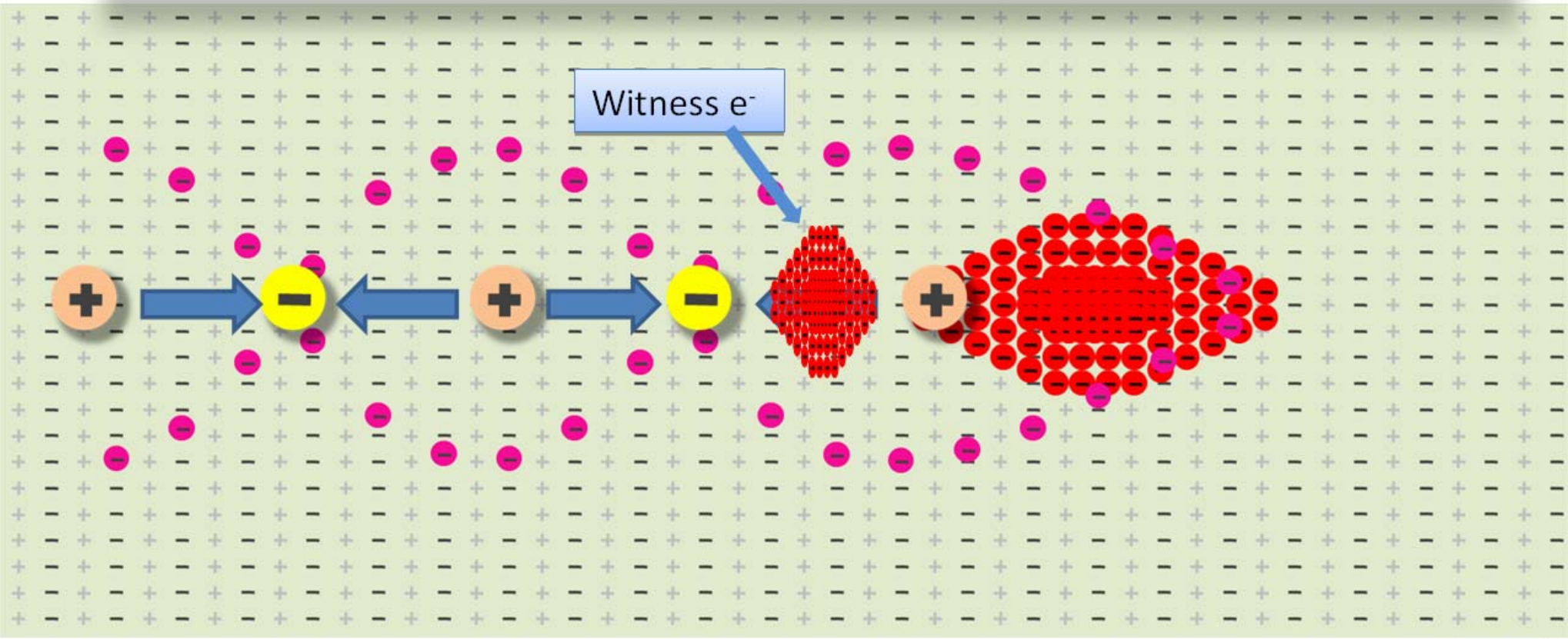


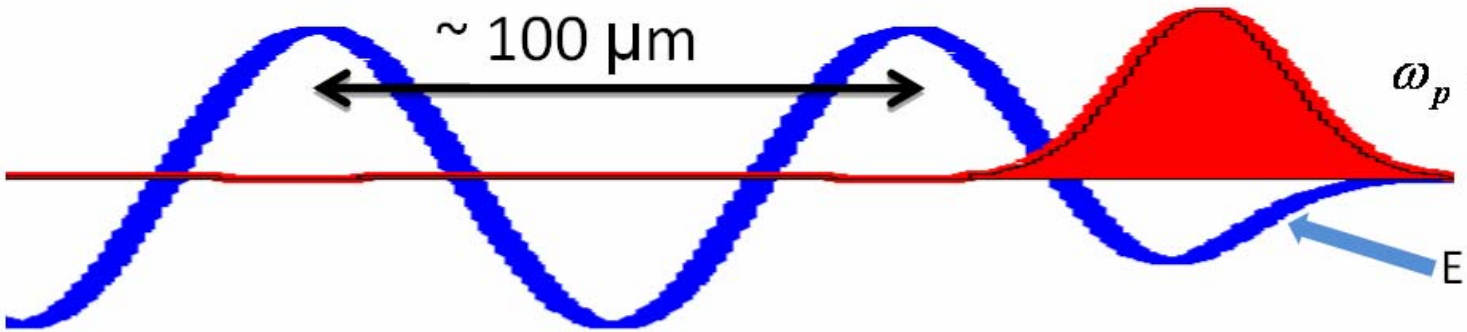


$$\omega_p = \frac{2\pi c}{\lambda_p} = \sqrt{\frac{e^2 n_p}{\varepsilon_0 m_e}}$$

Plasma Wakefield Accelerator

Basic Principles (Linear Regime)





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Plasma Wakefield Accelerator

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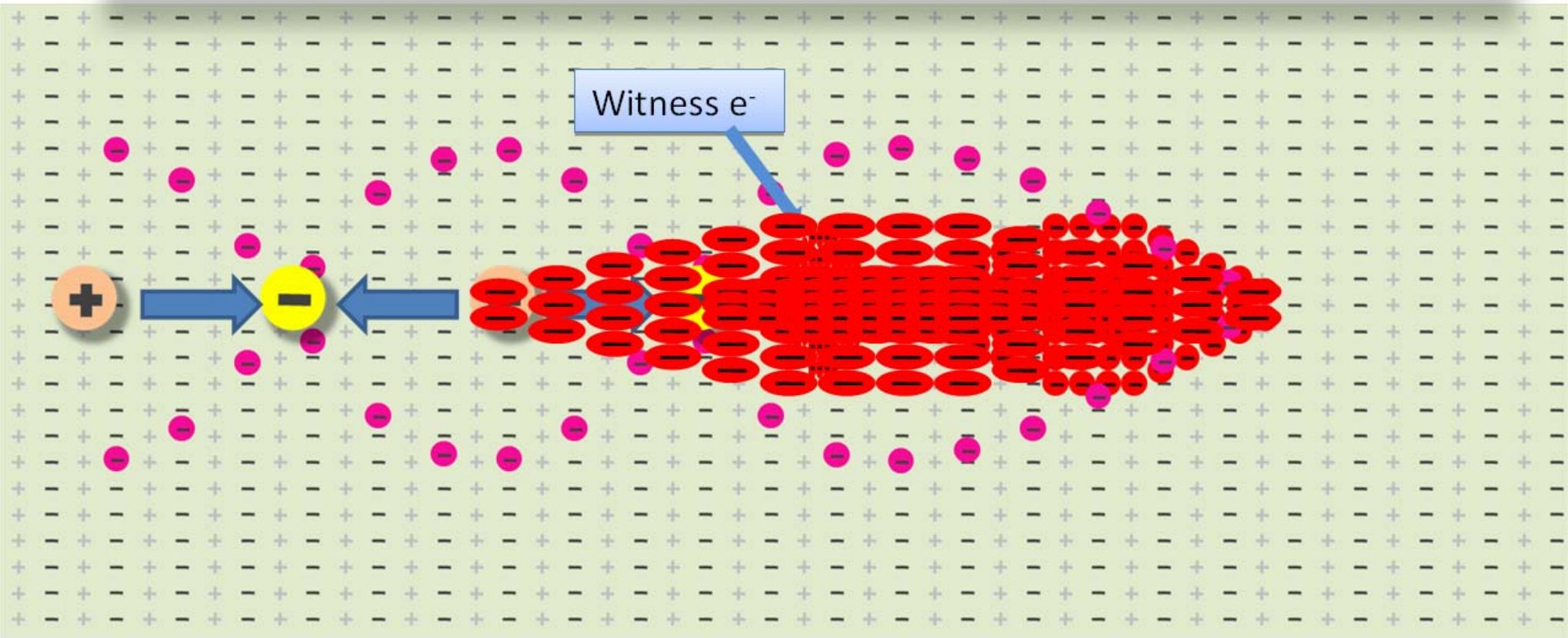
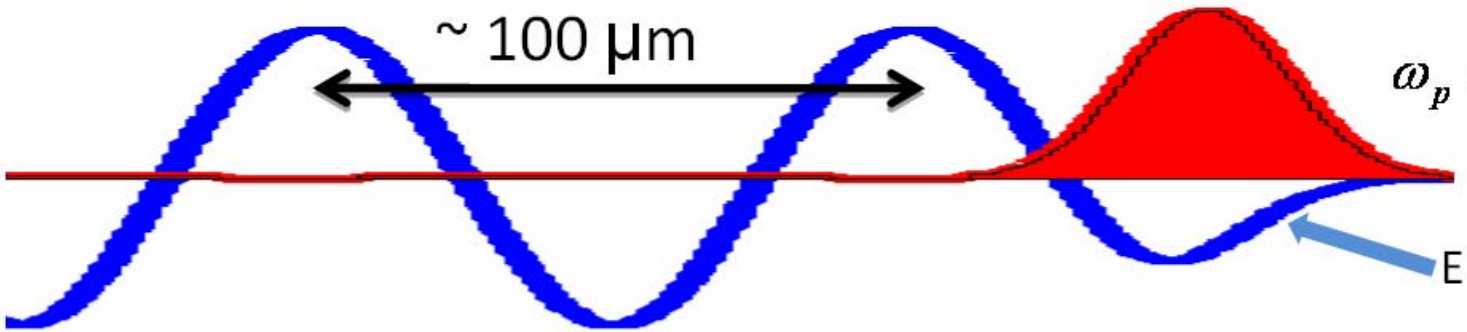
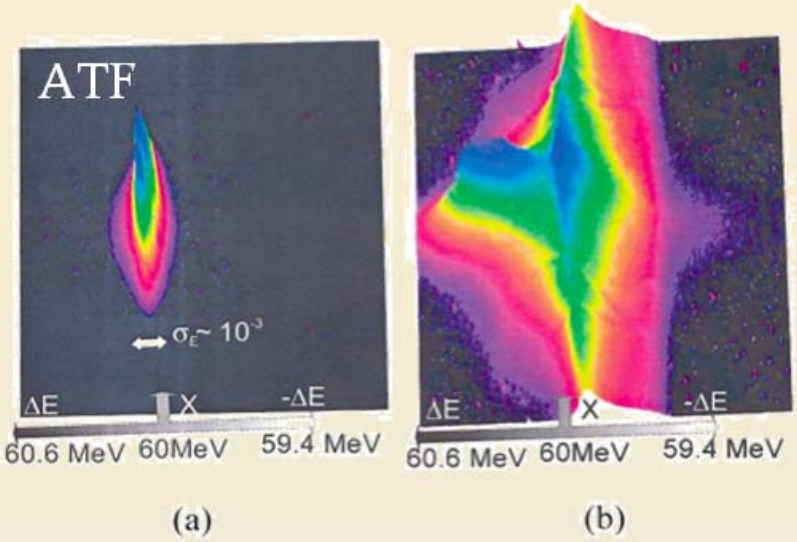




$$\omega_p = \frac{2\pi c}{\lambda_p} = \sqrt{\frac{e^2 n_p}{\varepsilon_0 m_e}}$$

Some Experimental Results
Using electron bunches



(a) (b)

- 35 MeV/m over 1.7cm of plasma

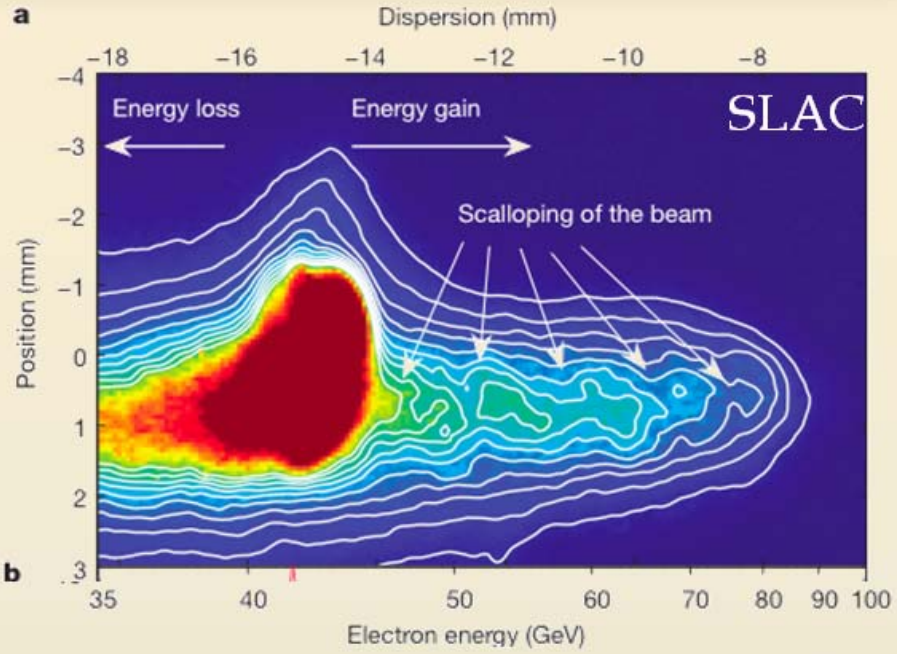


Figure 2 | Energy spectrum of the electrons. **a**, Energy spectrum of the electrons in the 35–100 GeV range as observed in plane 2. The dispersion

Can we multiply the energy?

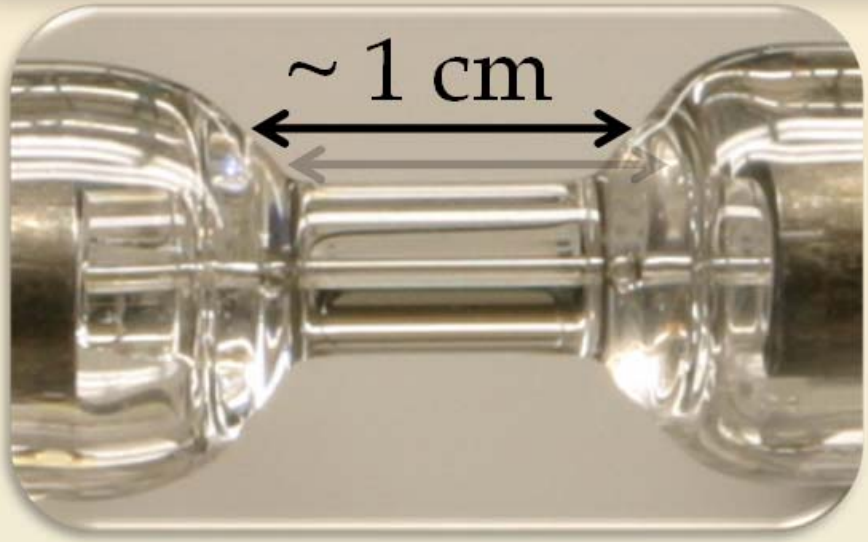
(thus reducing the length and cost)

- 50 GeV/m over 85cm of plasma
- Energy doubling! (42 GeV→84 GeV)

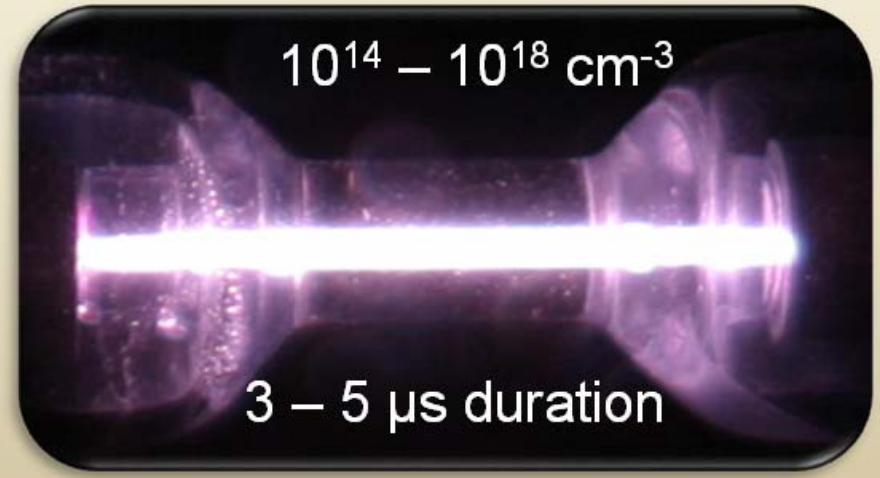
Yakimenko et al., Phys. Rev. Lett. 2003

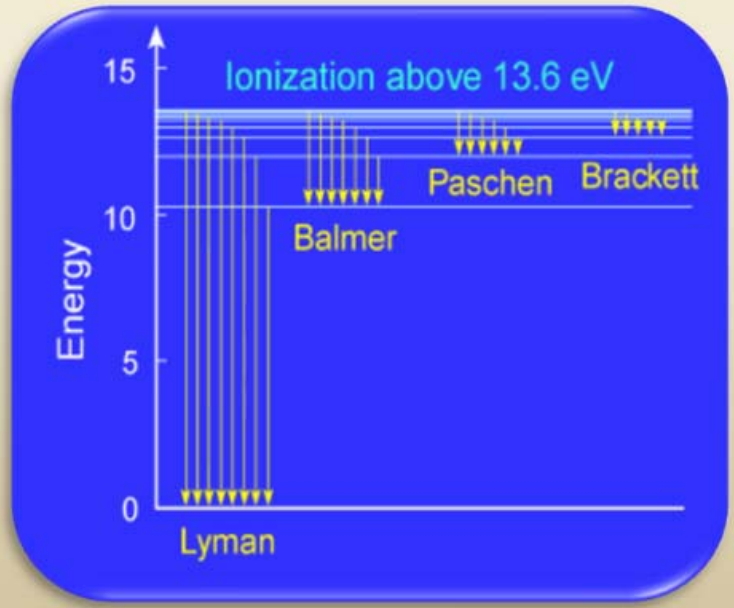
Blumenfeld et al., Nature 2007

Plasma Source
An example of capillary discharge



- 0.1 – 1 atm H_2
- 20 kV charging voltage
- Collect light to measure plasma density (Stark Broadening)

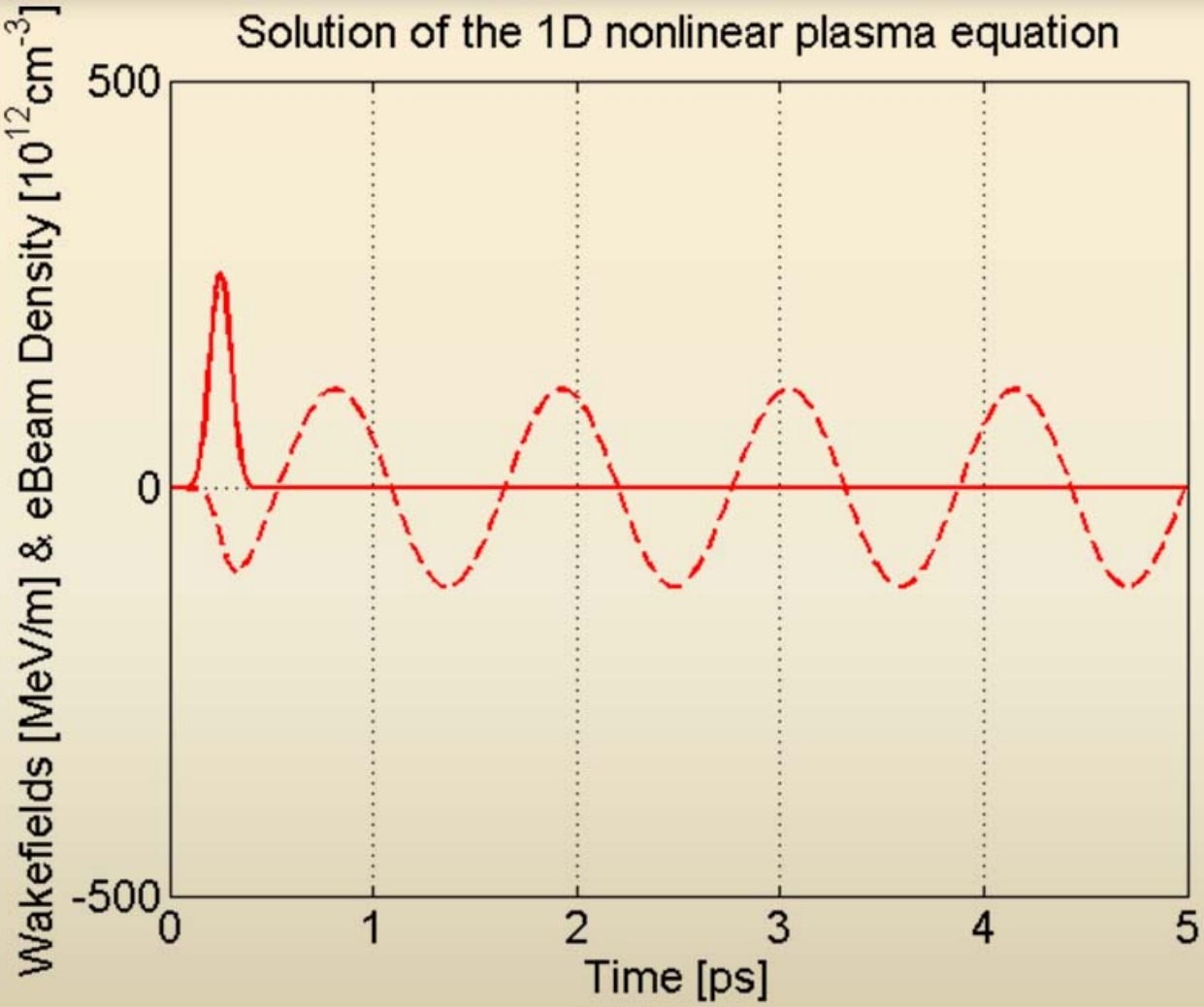




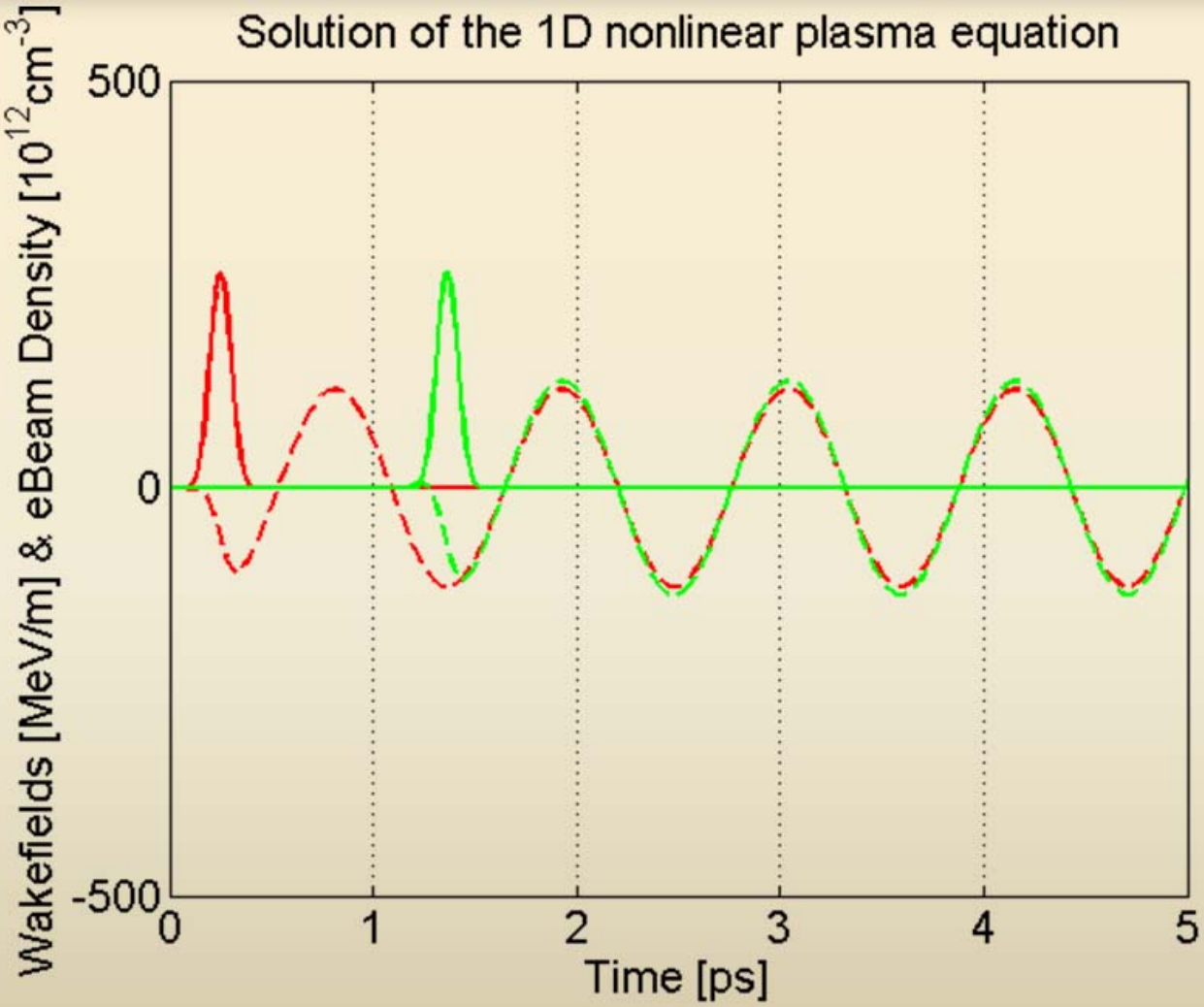
Prima Piatti

Multiple Drive Bunches

Multiple Bunches



Multiple Bunches



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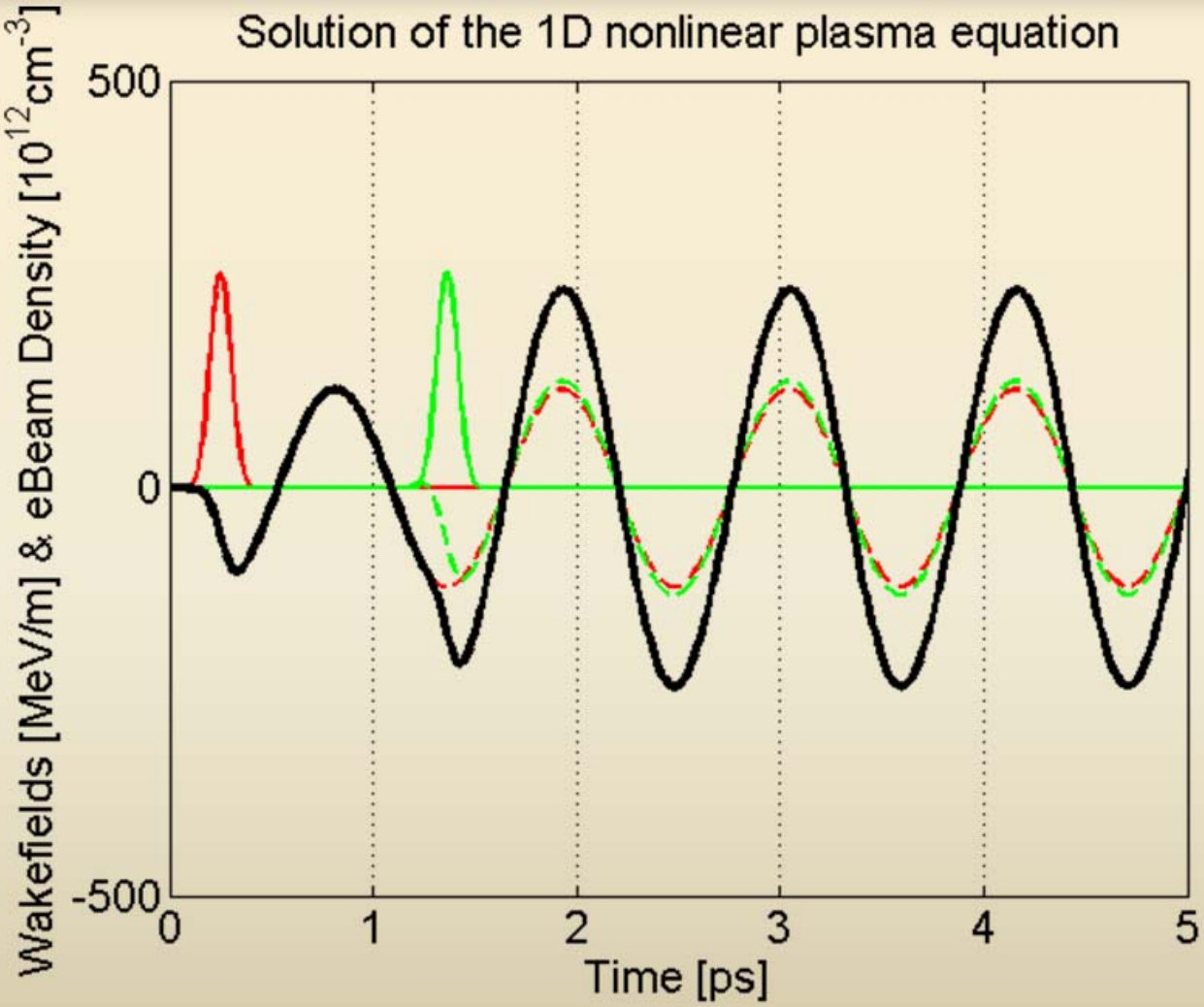

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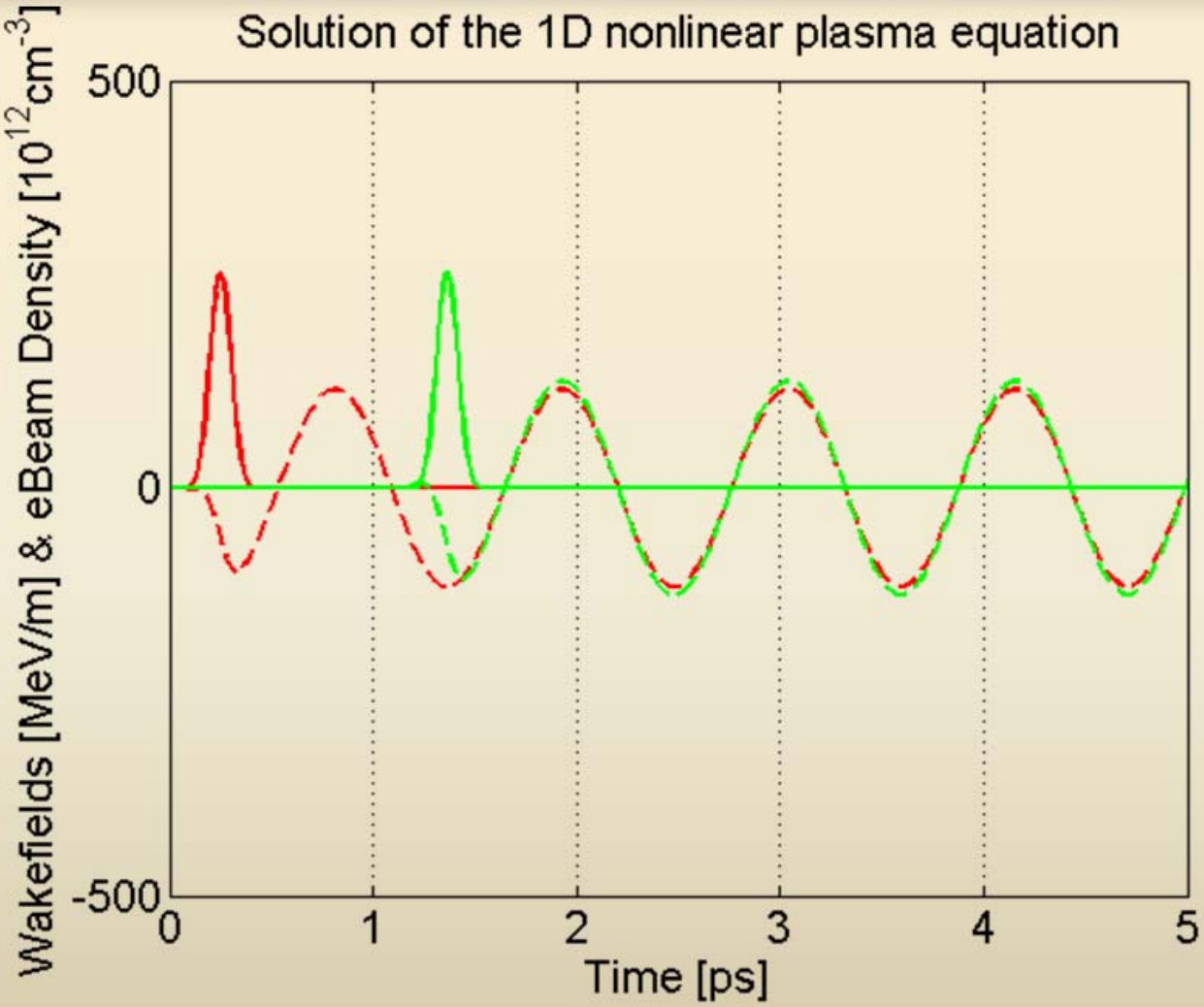

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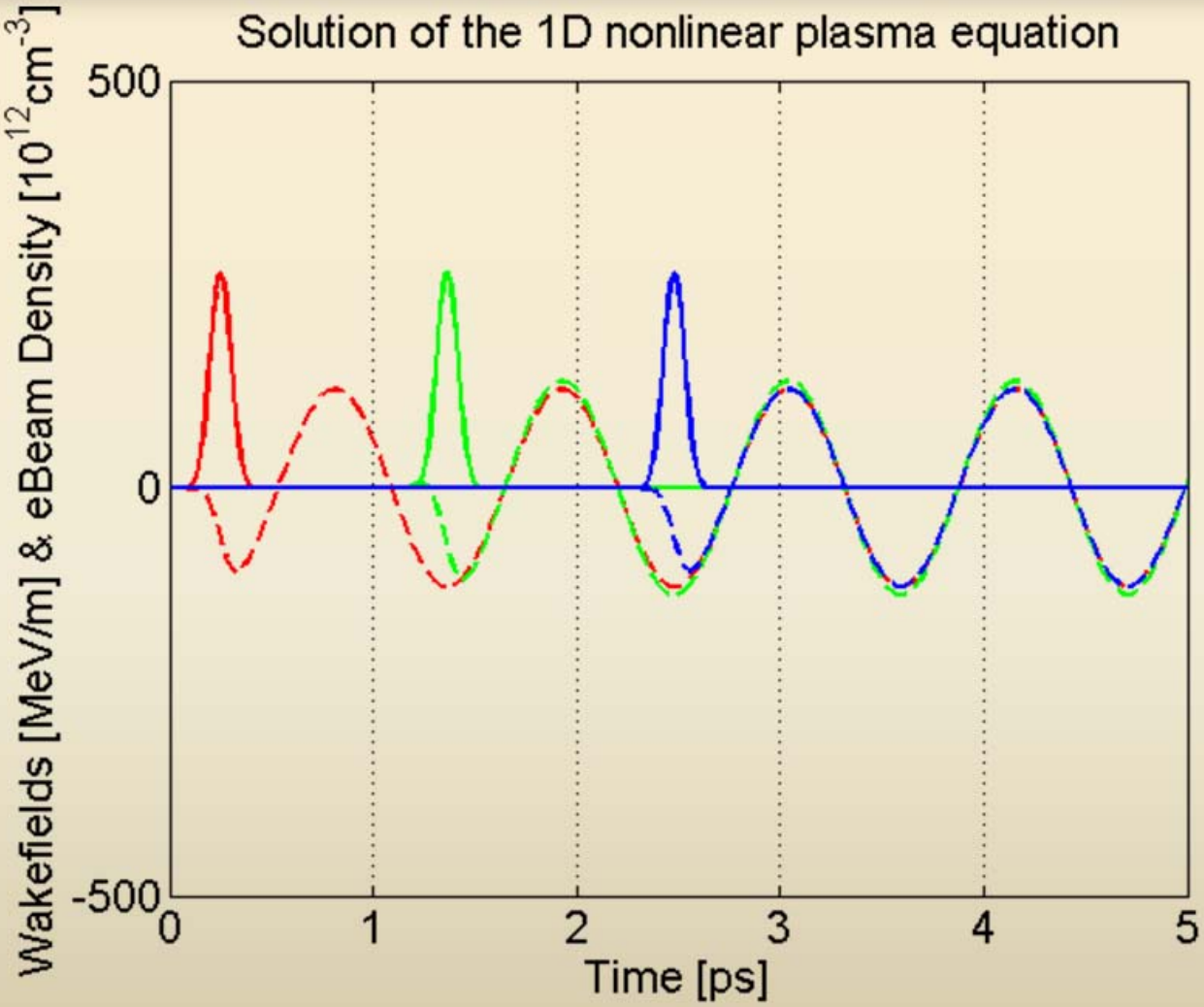

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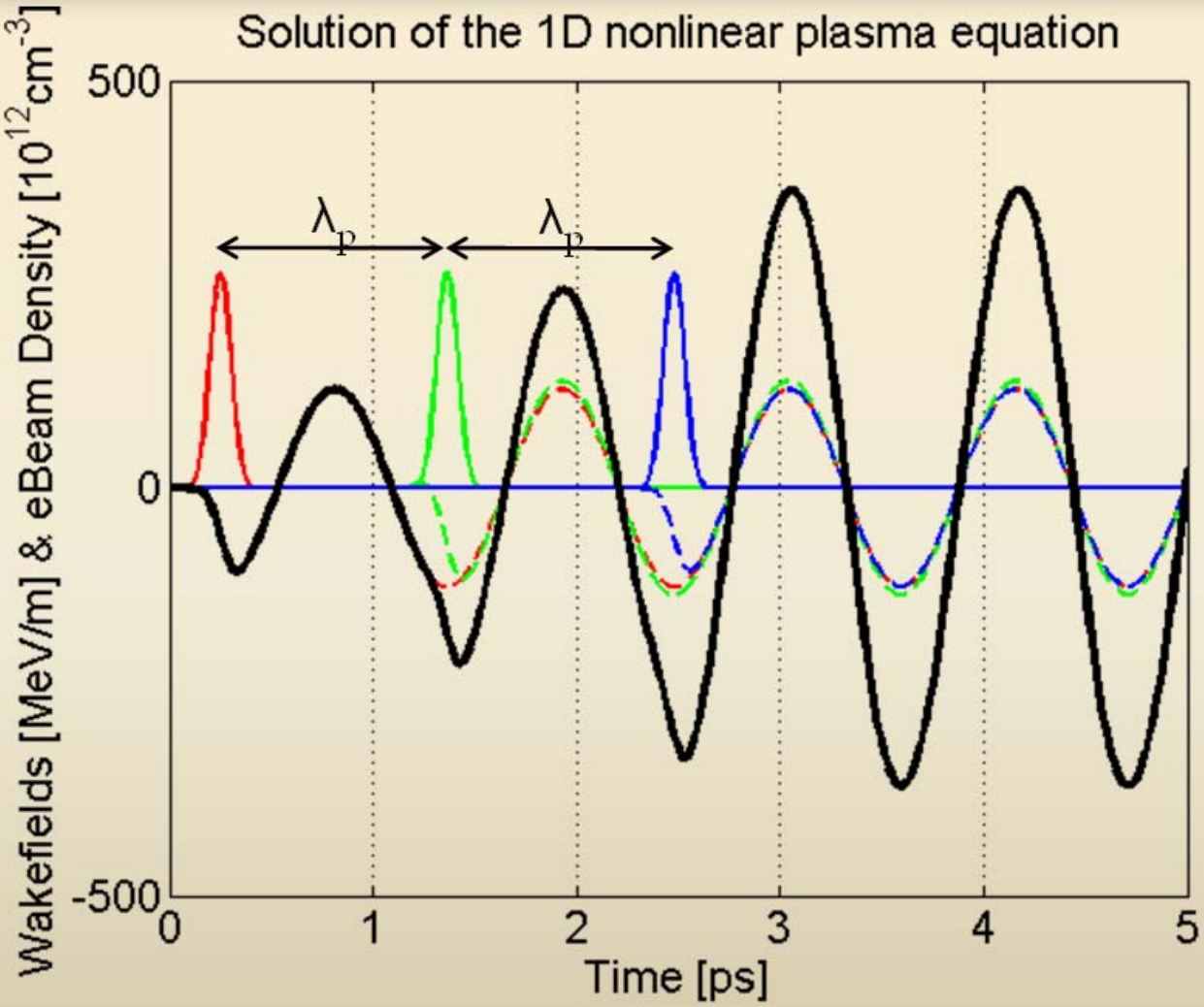

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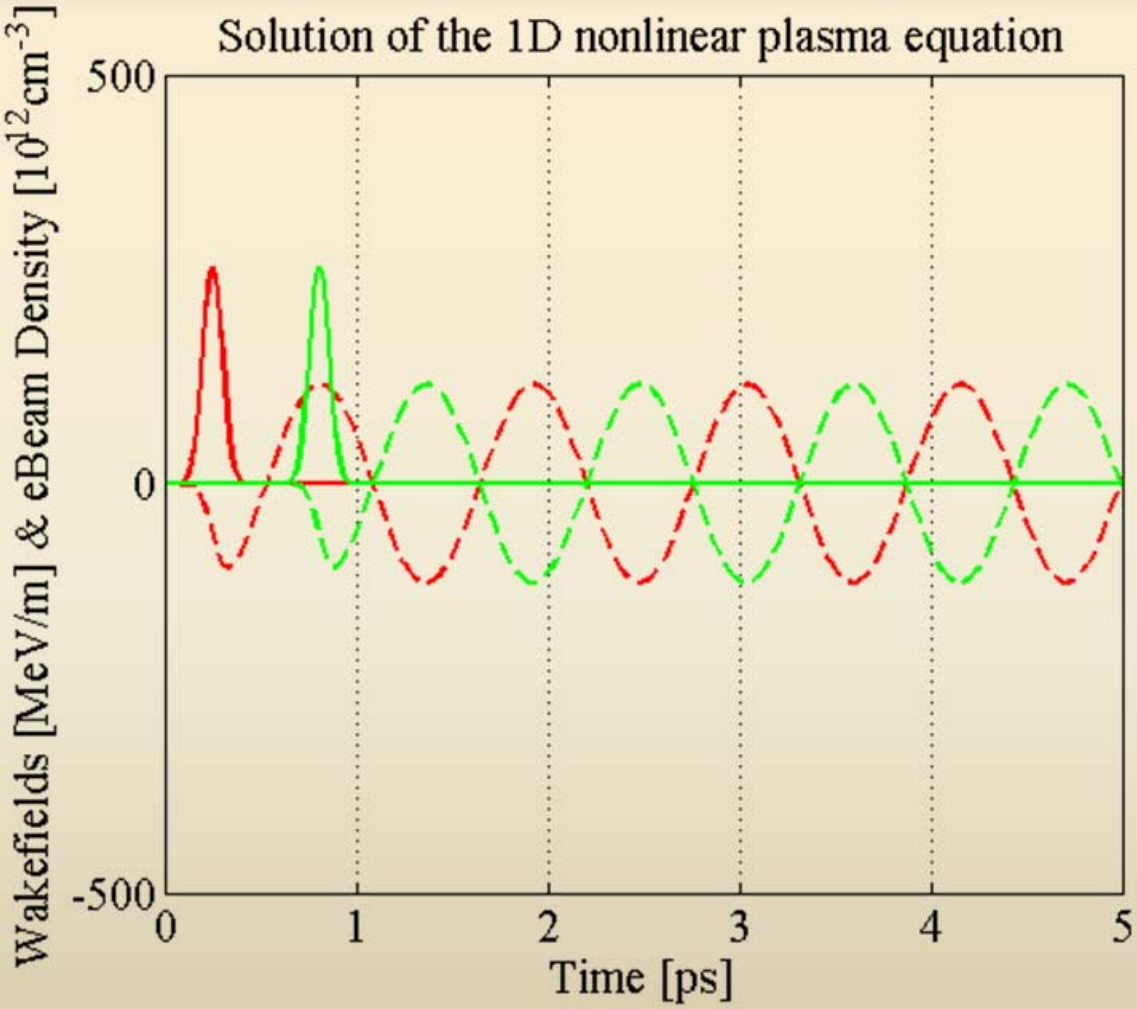

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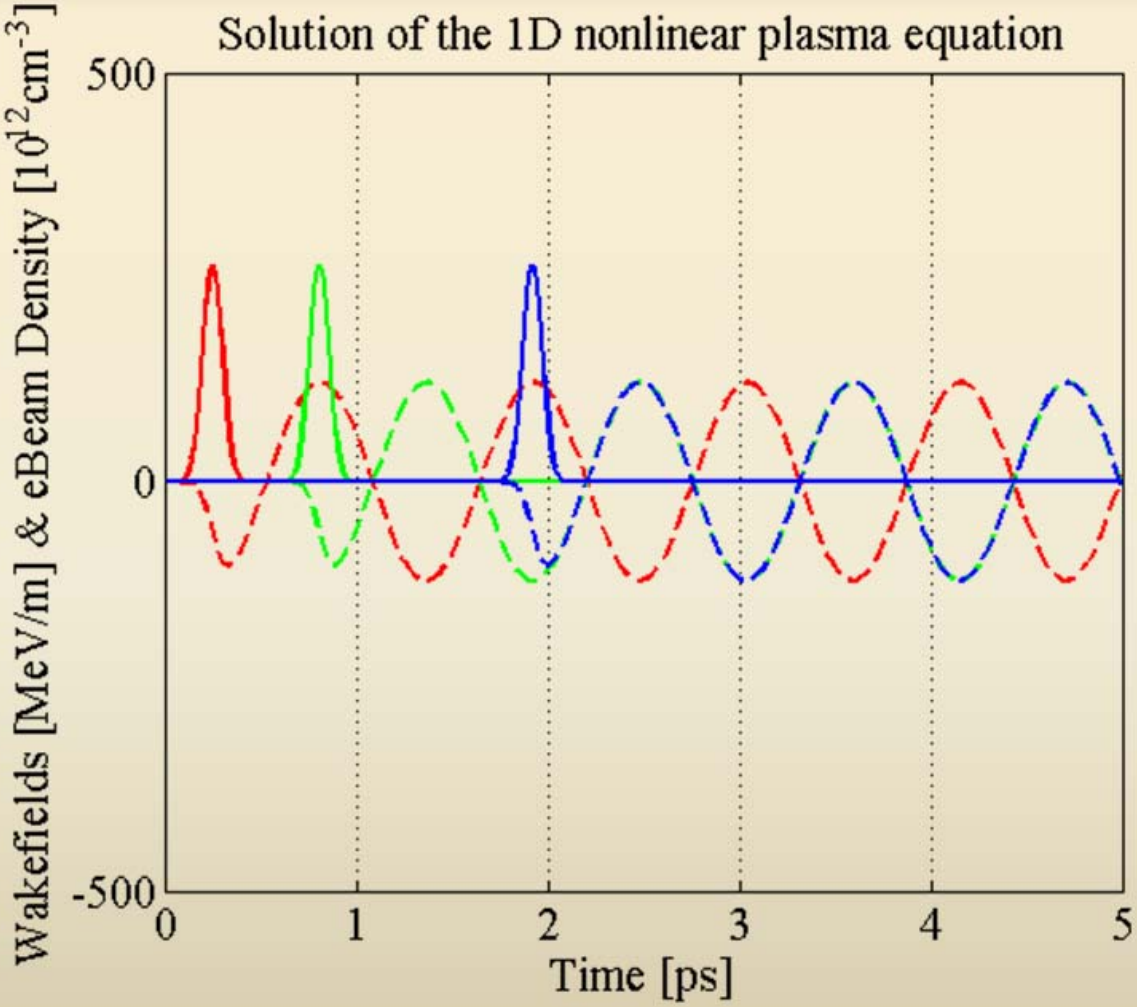

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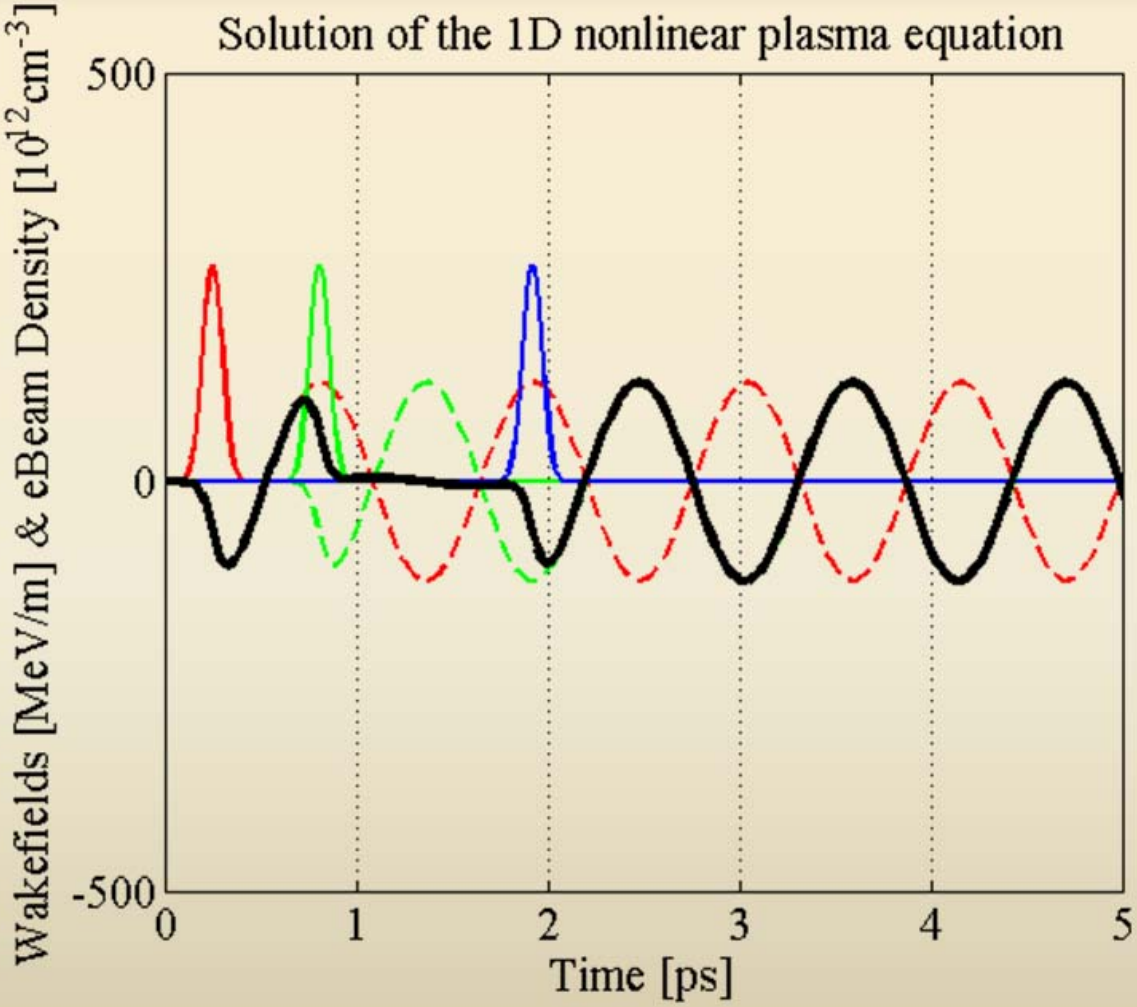
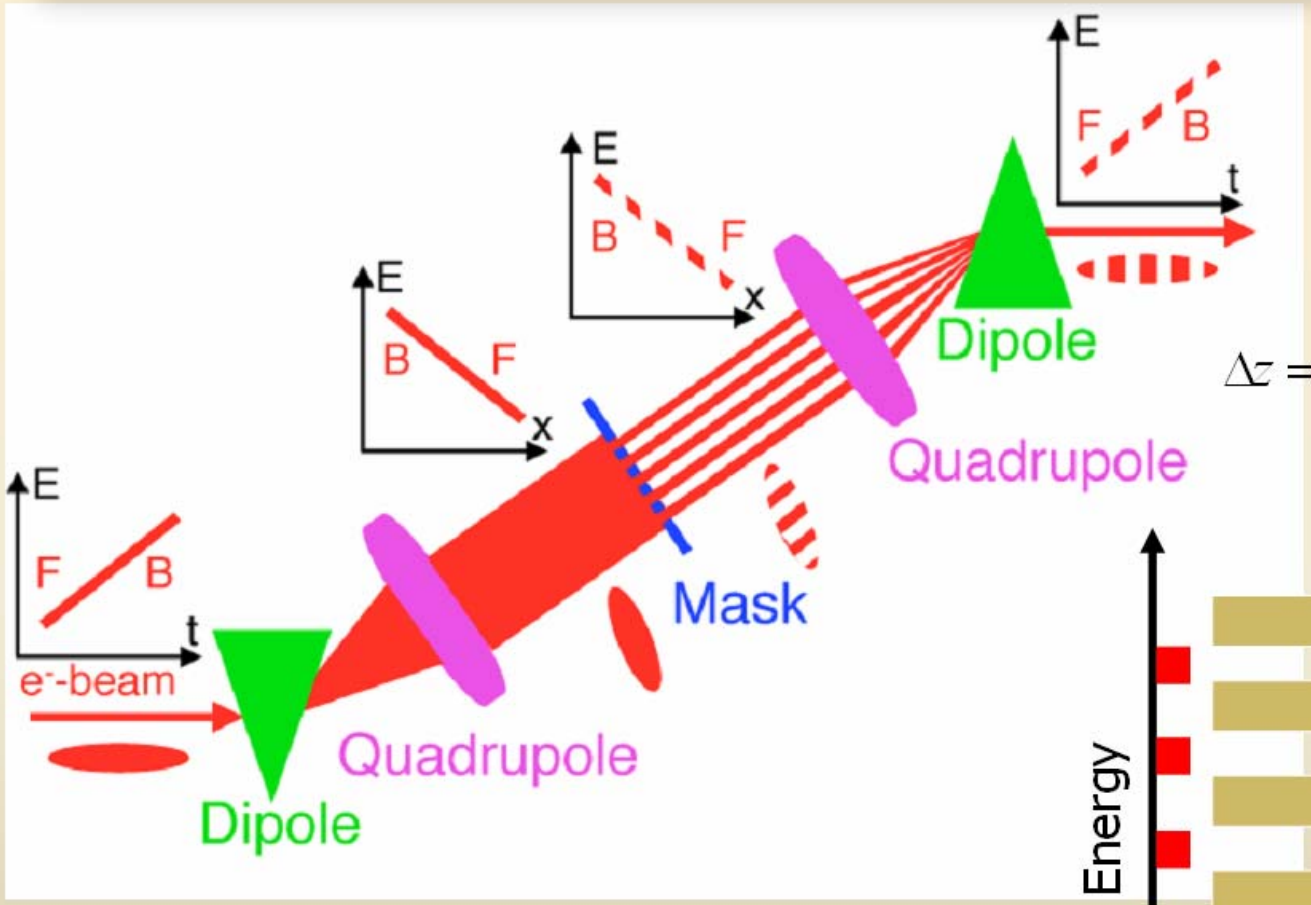
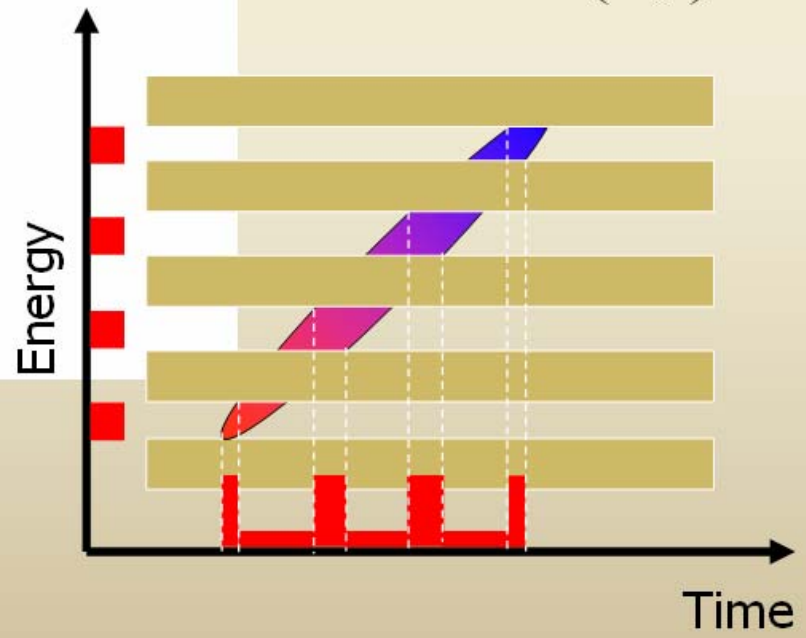


Generating Microbunches
by dispersing the energy

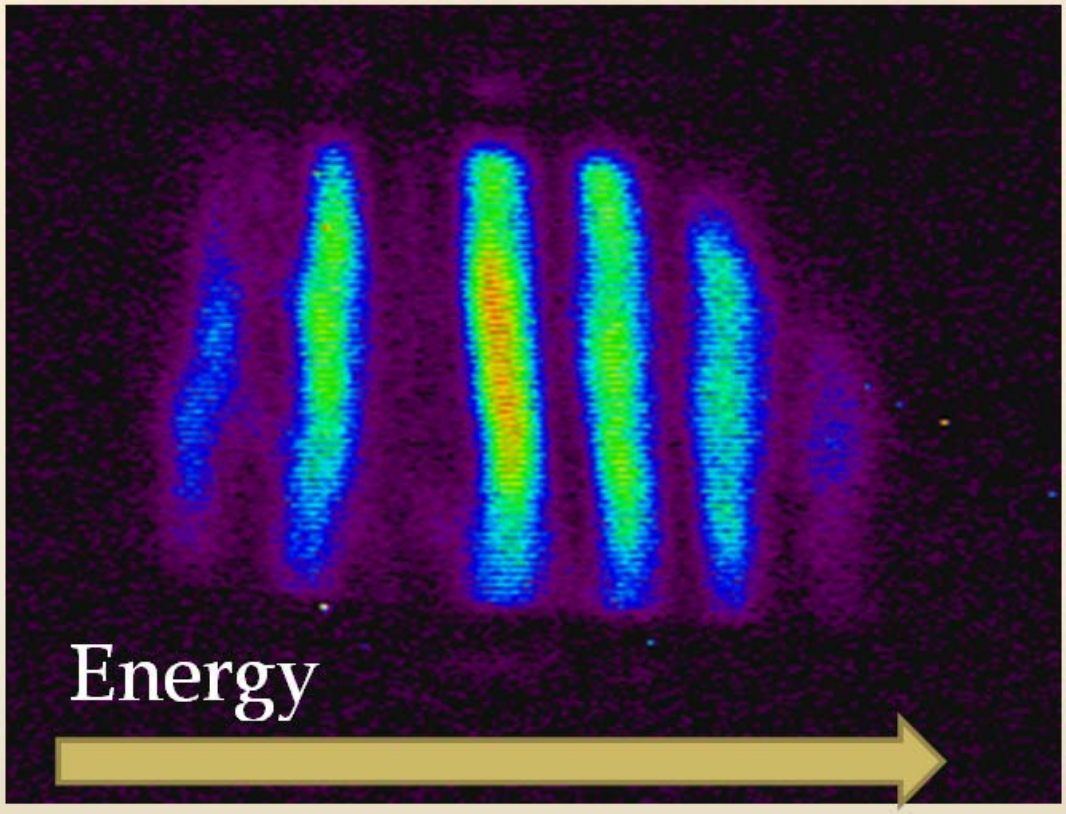


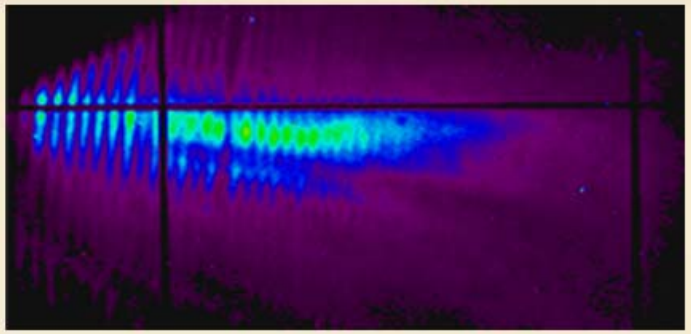
$$\Delta z = \frac{\sigma_z'}{N_b} = D\frac{\sigma_z \pm R_{56}\left(\frac{\Delta E}{E_0}\right)}{\eta_{x,mask}\left(\frac{\Delta E}{E_0}\right)}$$

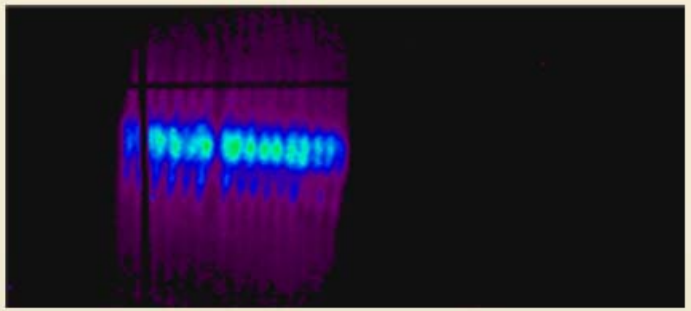


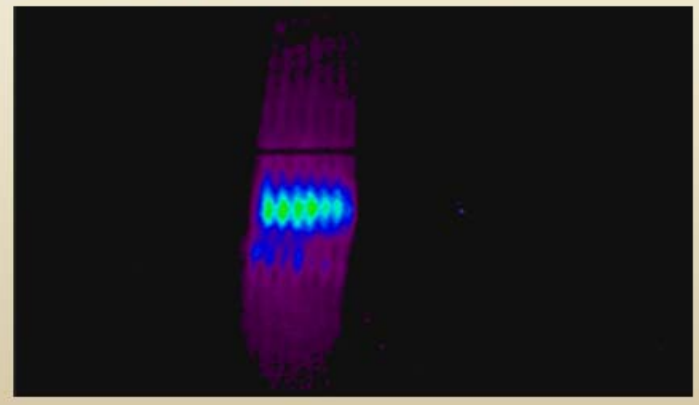
P. Muggli et al., Phys. Rev. Lett. 2008

Examples of microbunches



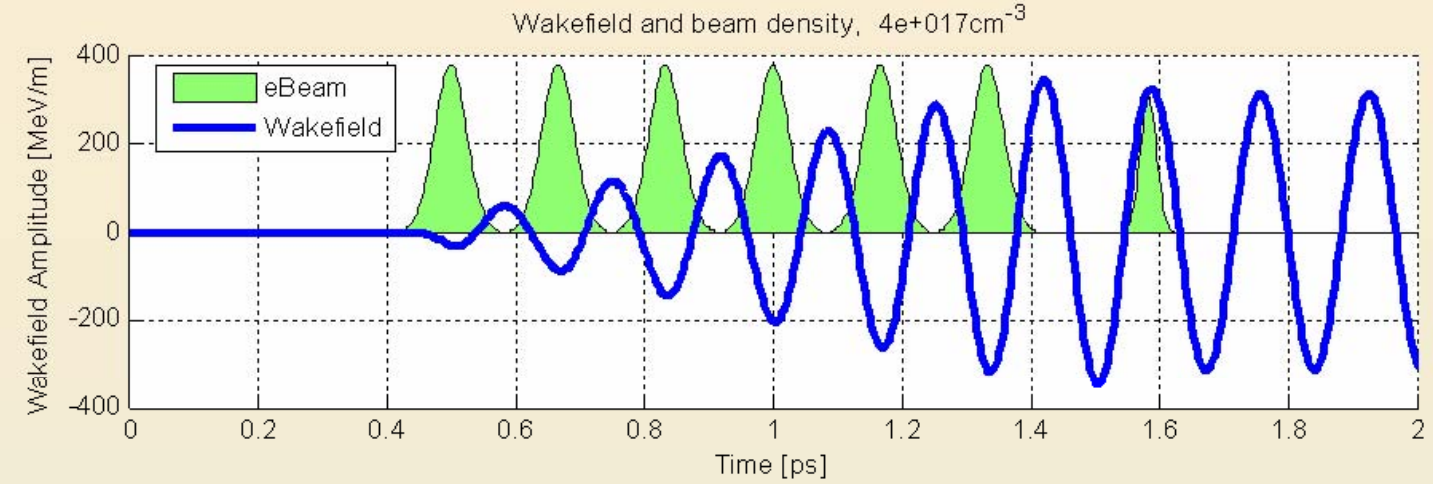


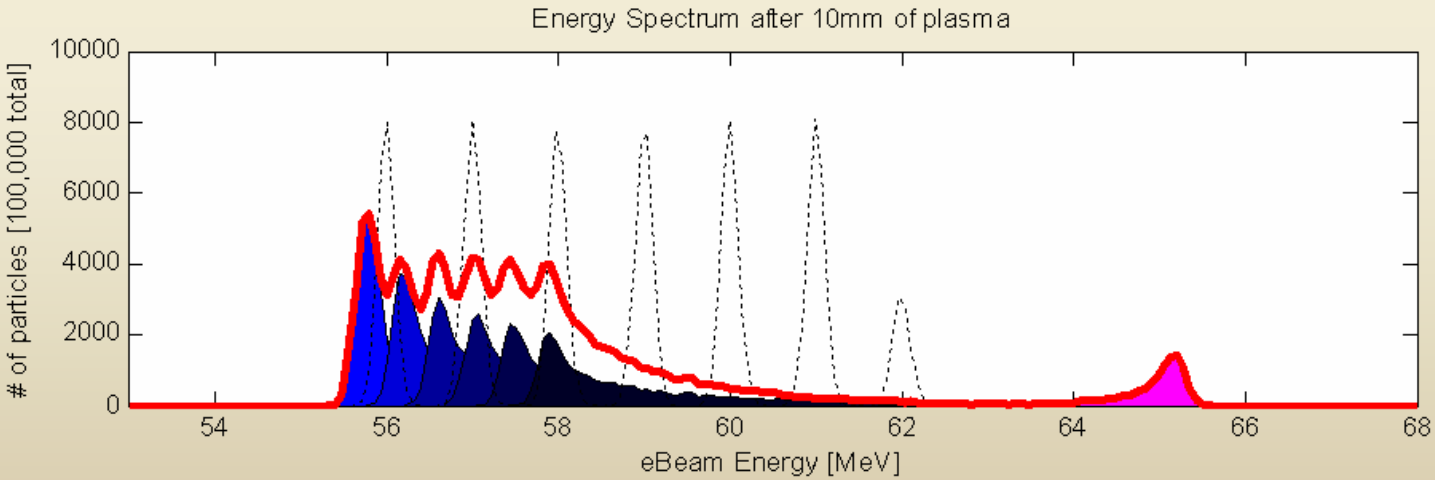




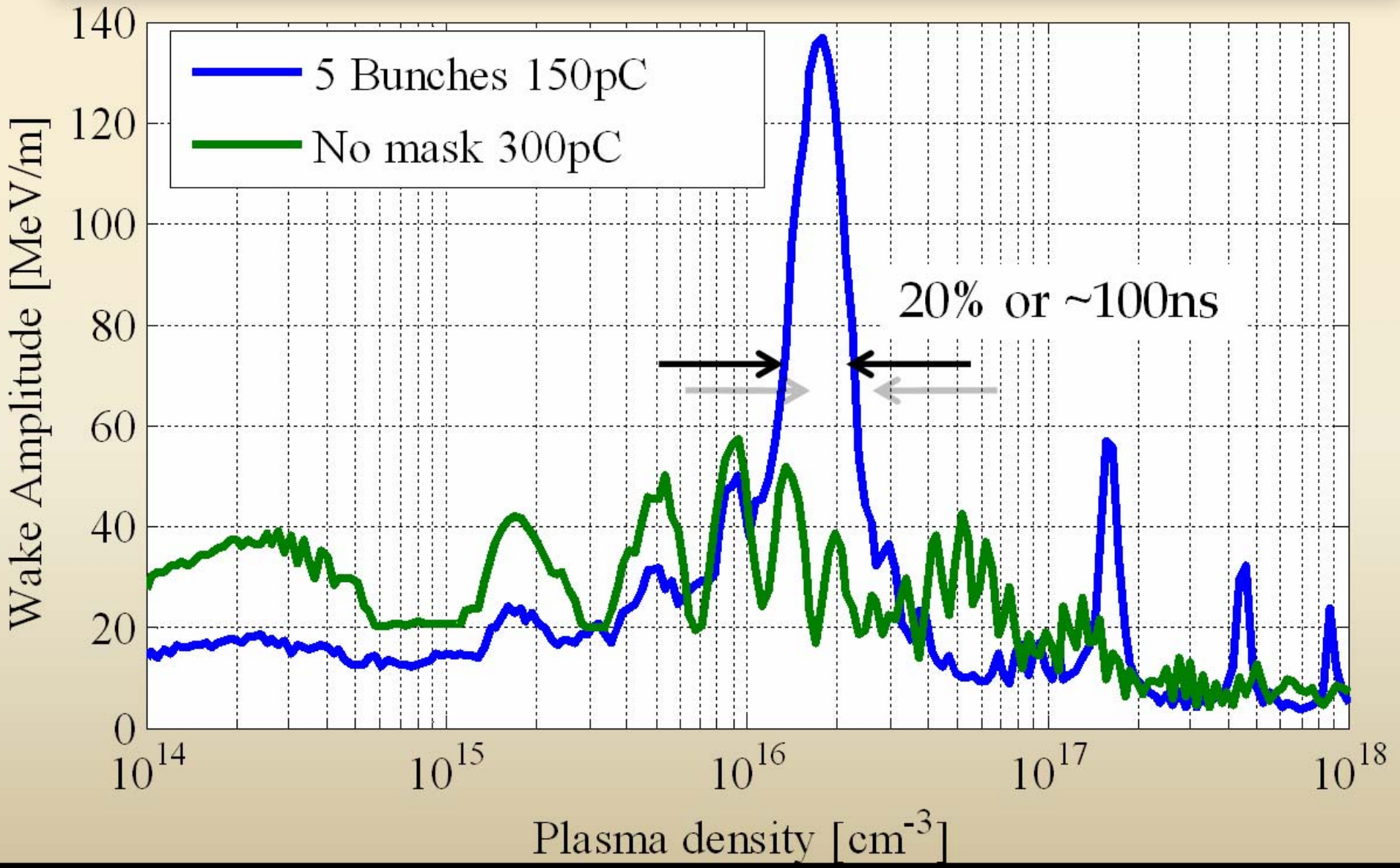
- 150-200 pC after the mask
- 100 – 300 μm period
- Resonant at 10^{16} – 10^{17} cm^{-3}

7 Bunches
Resonant Plasma Density





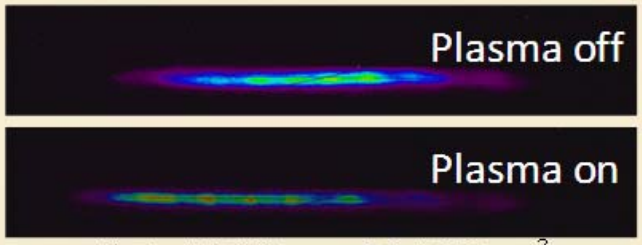
Wakefield Amplitude
Predicted, Mask vs. No Mask

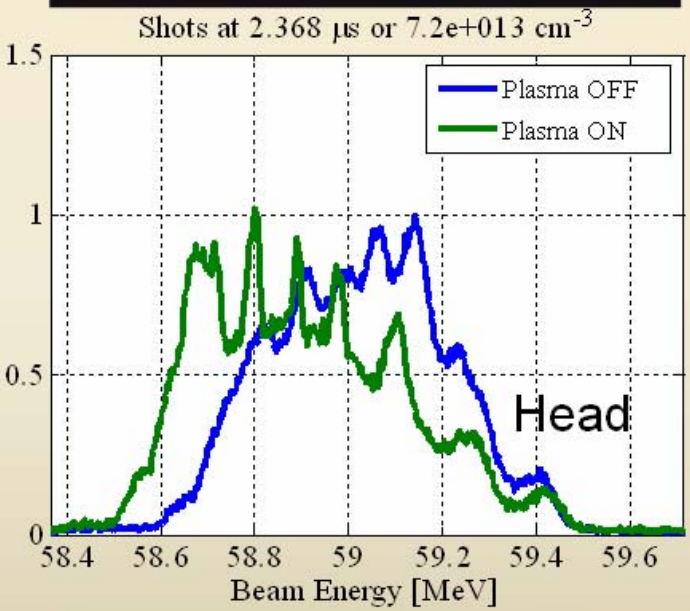


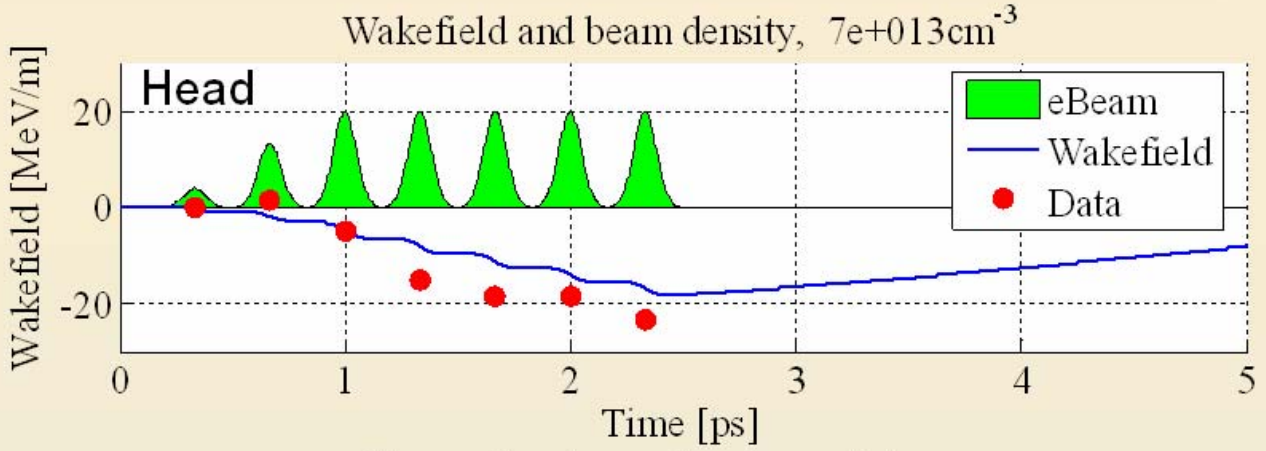
Results at low plasma density

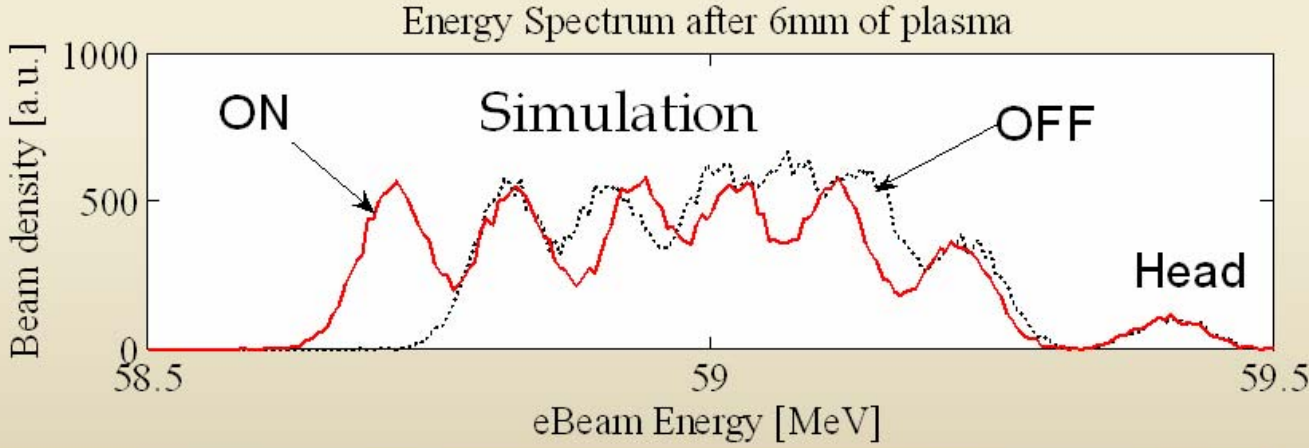
59 MeV, 400 pC beam

Experiment







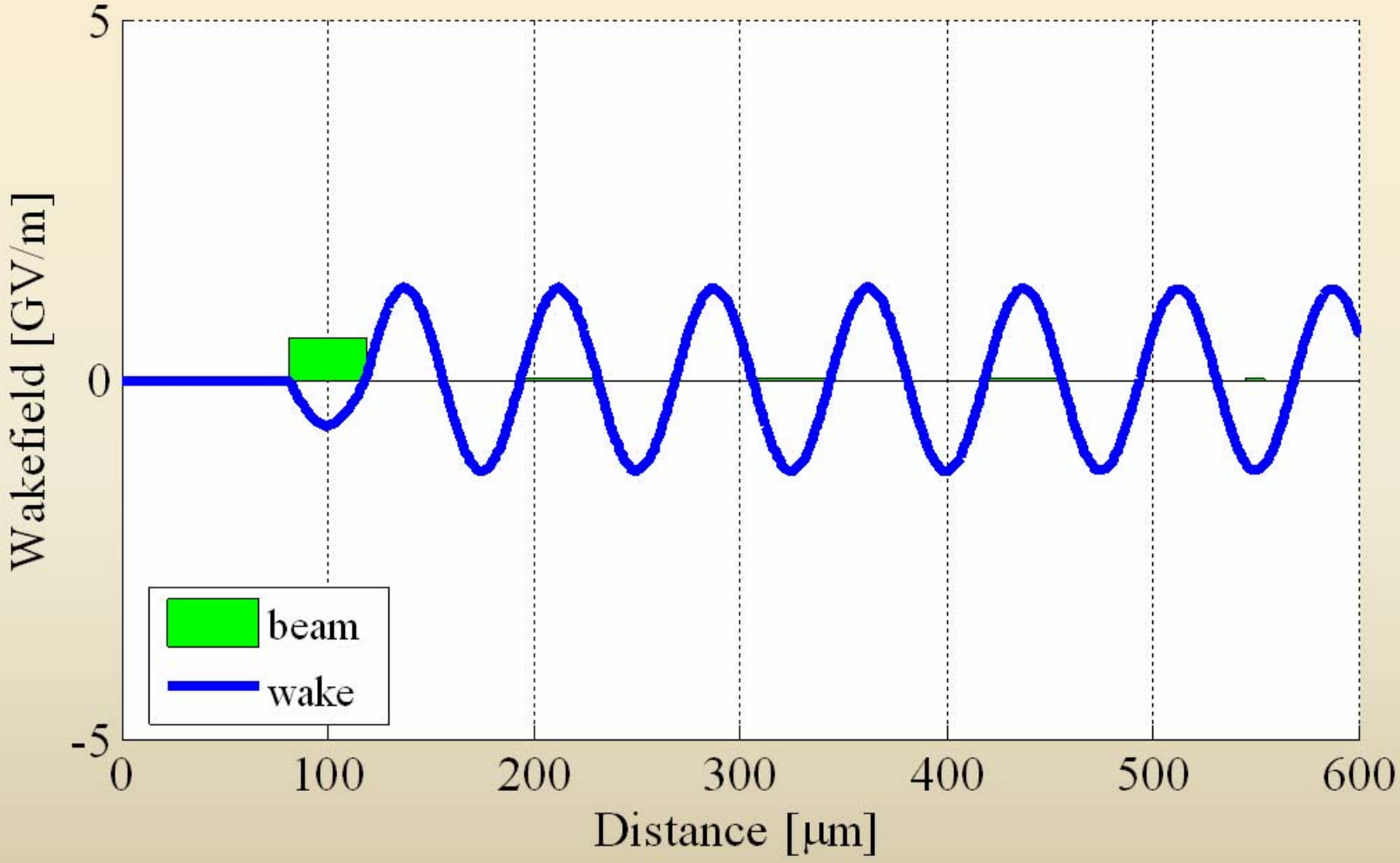


- whole bunch: 35MeV/m
- microbunches: 22MeV/m after 6mm of plasma @ 7×10^{13} cm^{-3}

Secondi Piatti

Ideas for an Energy Multiplier

Getting High Transfomer Ratio



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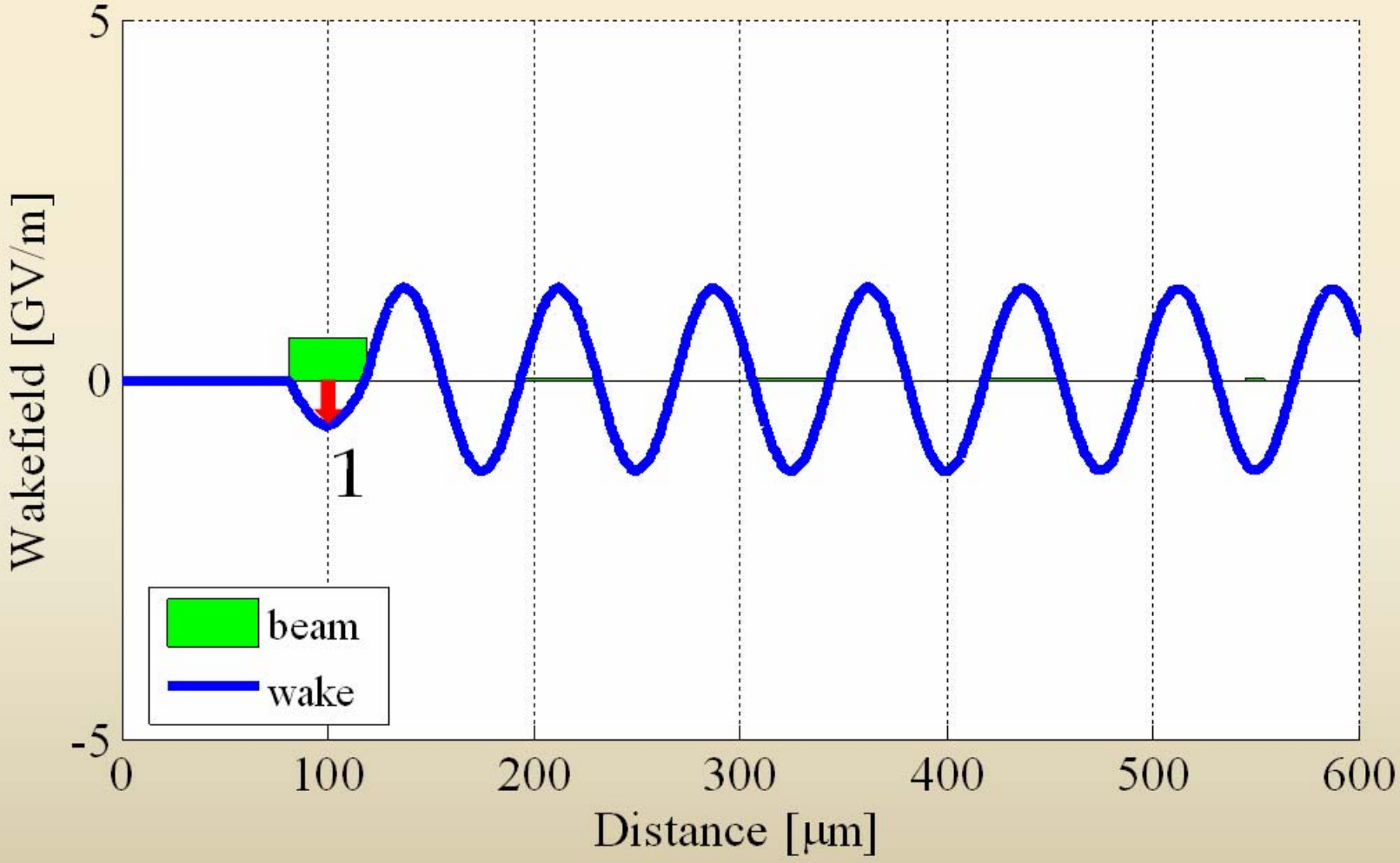

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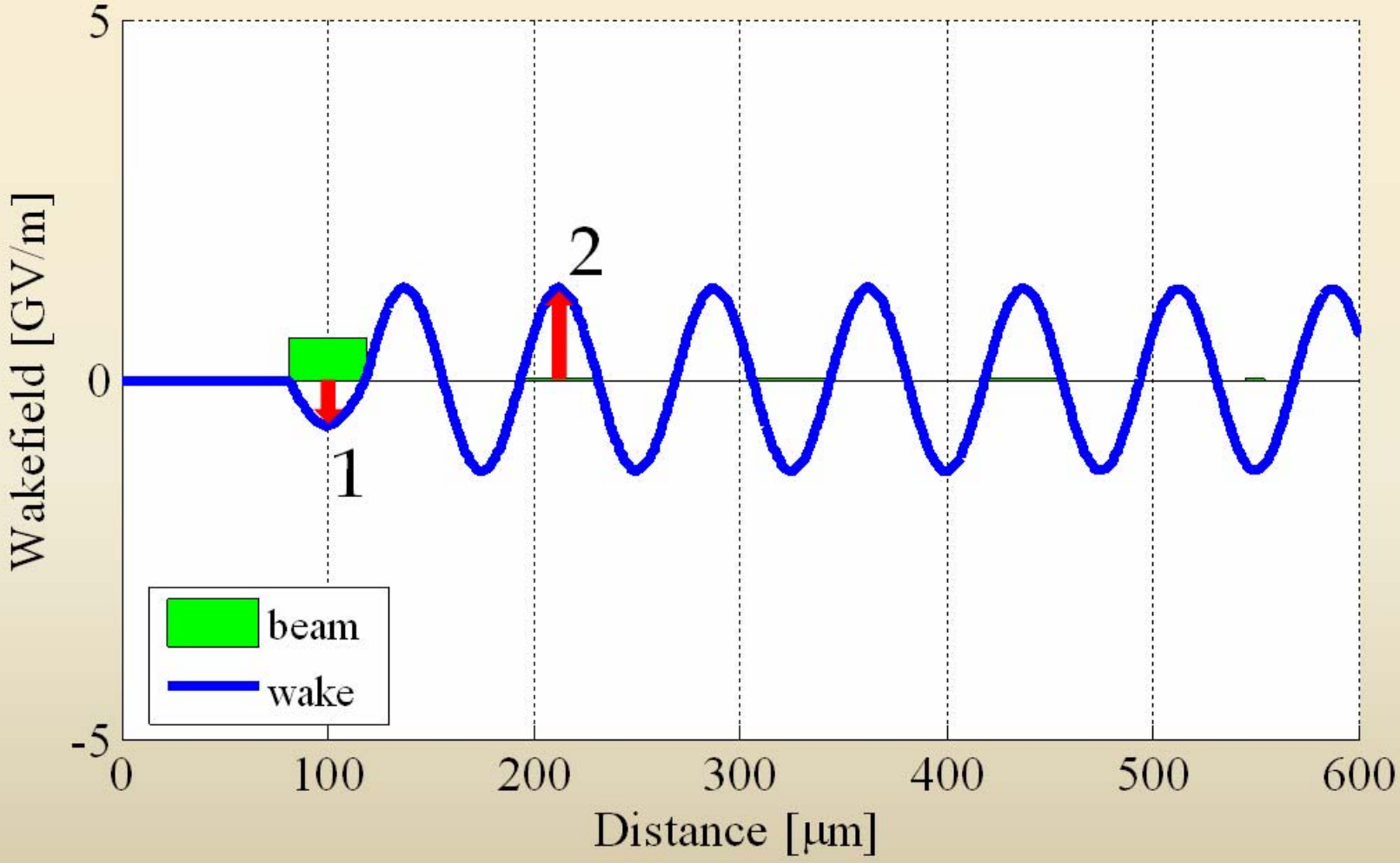

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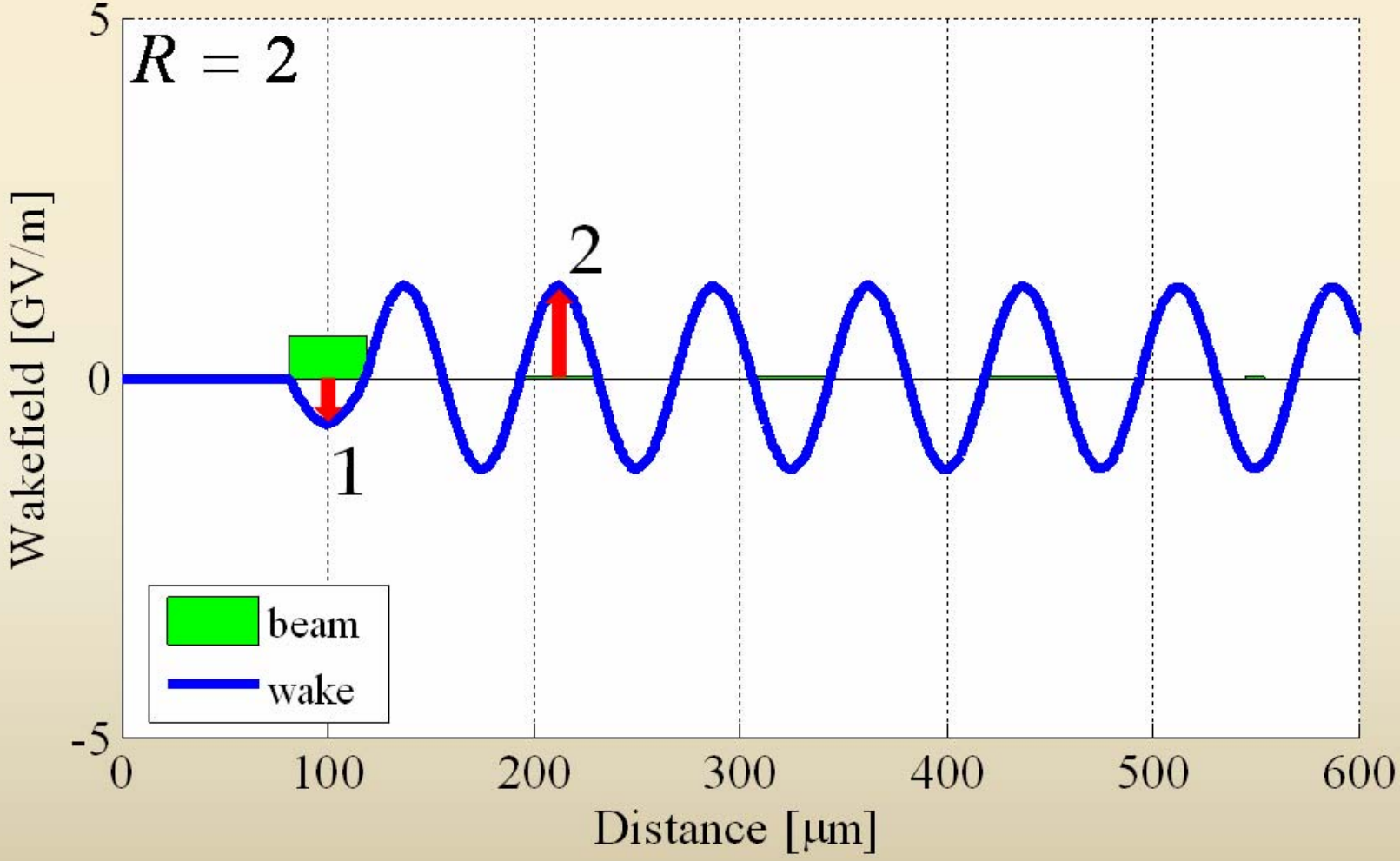

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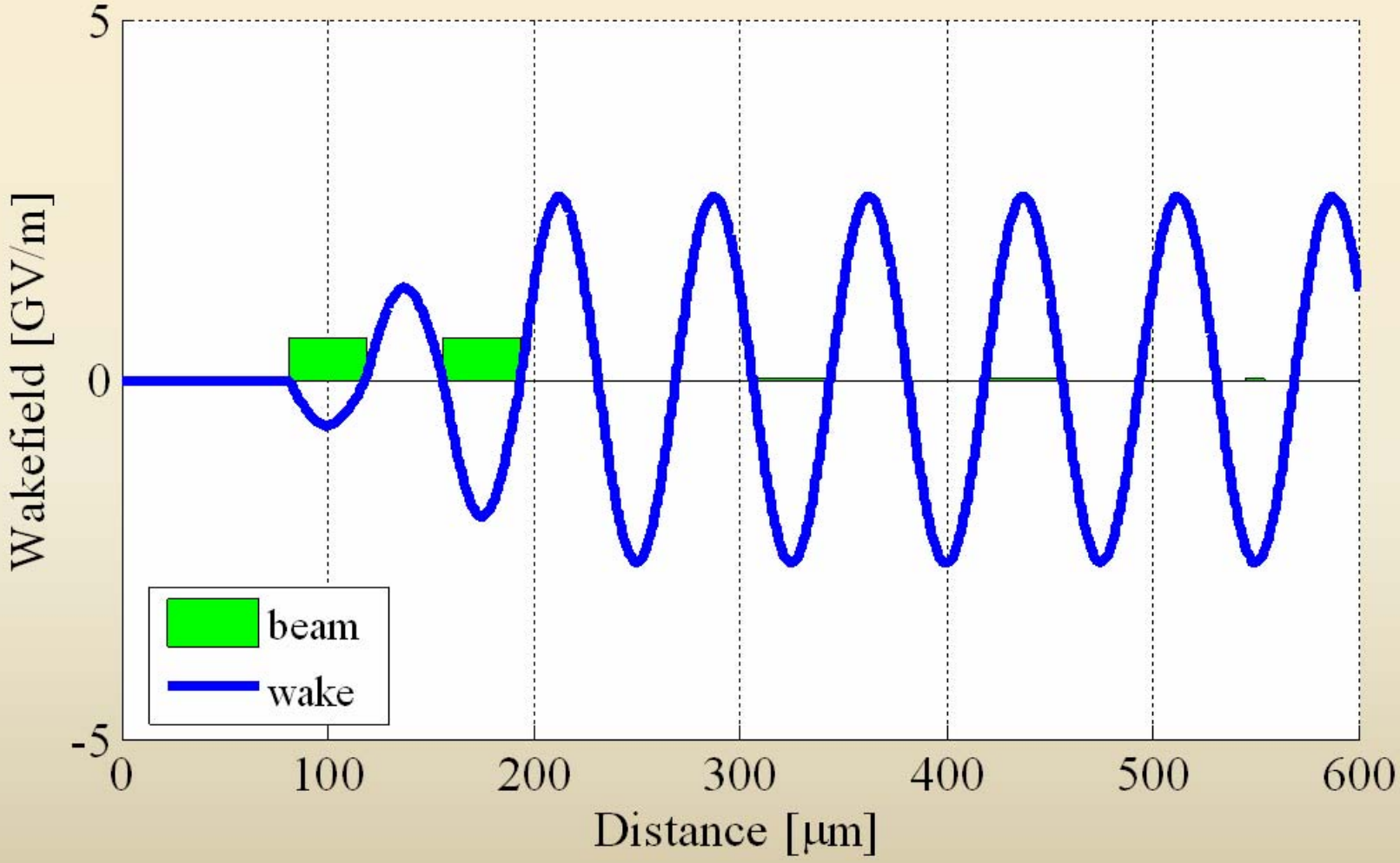

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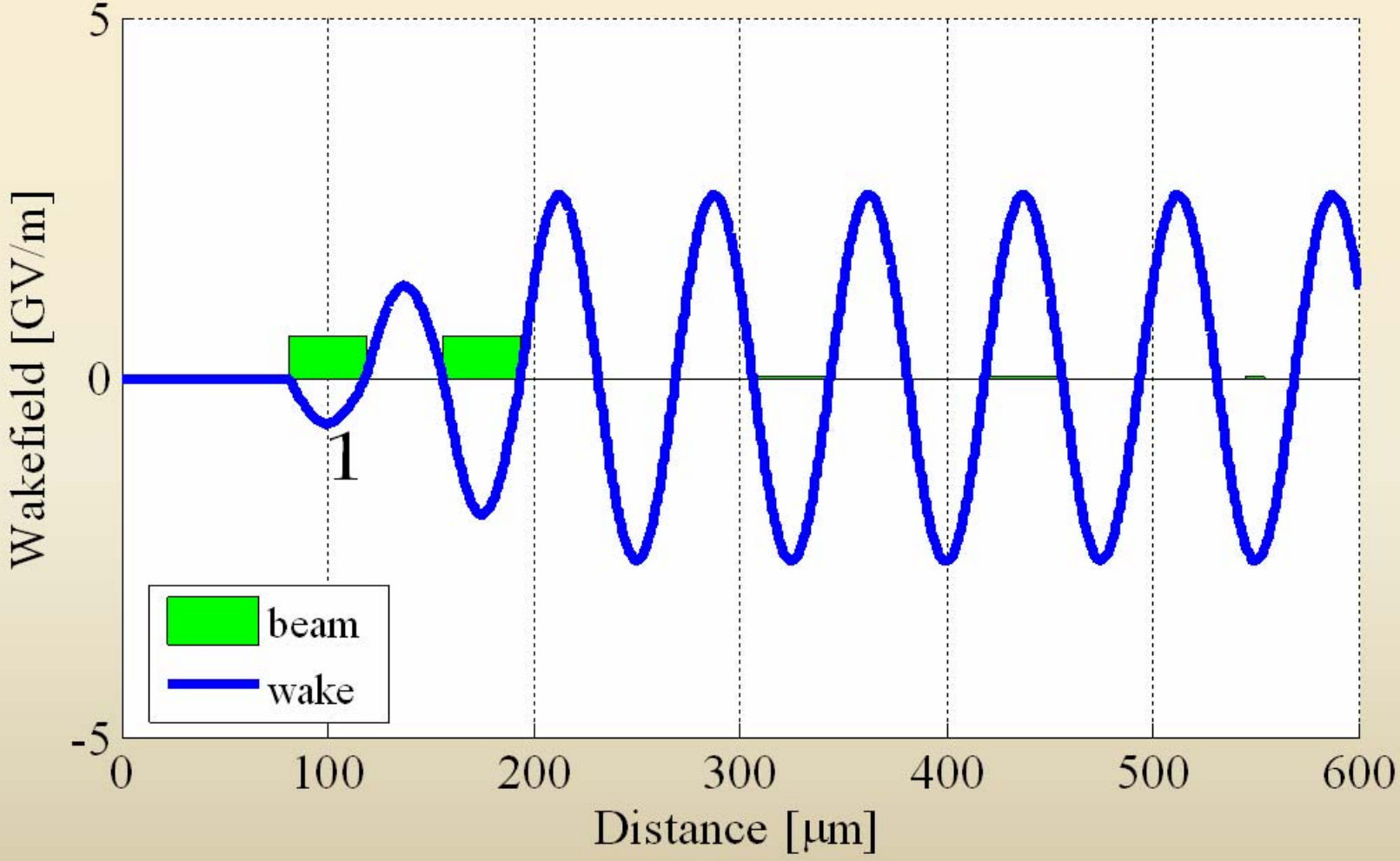

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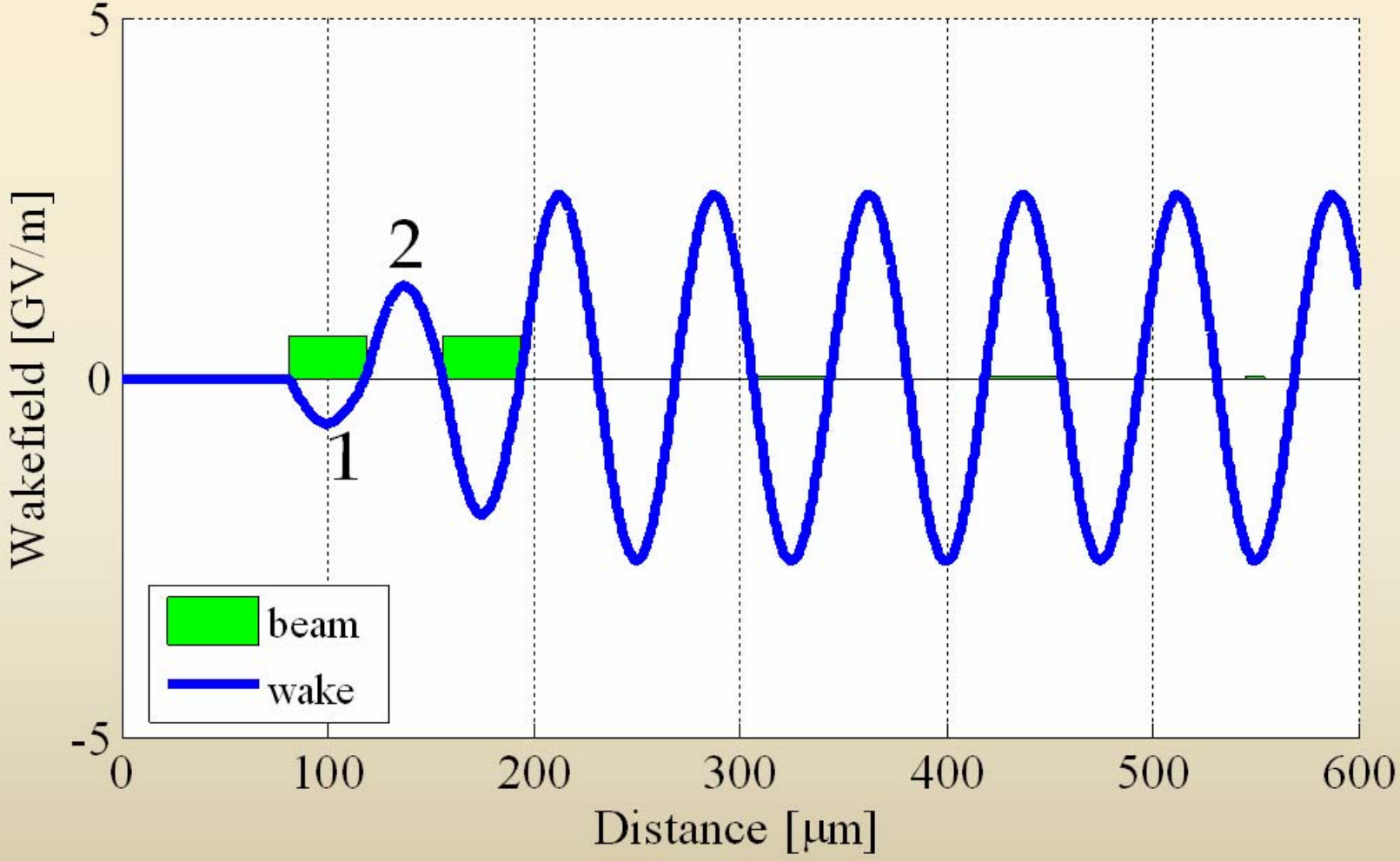

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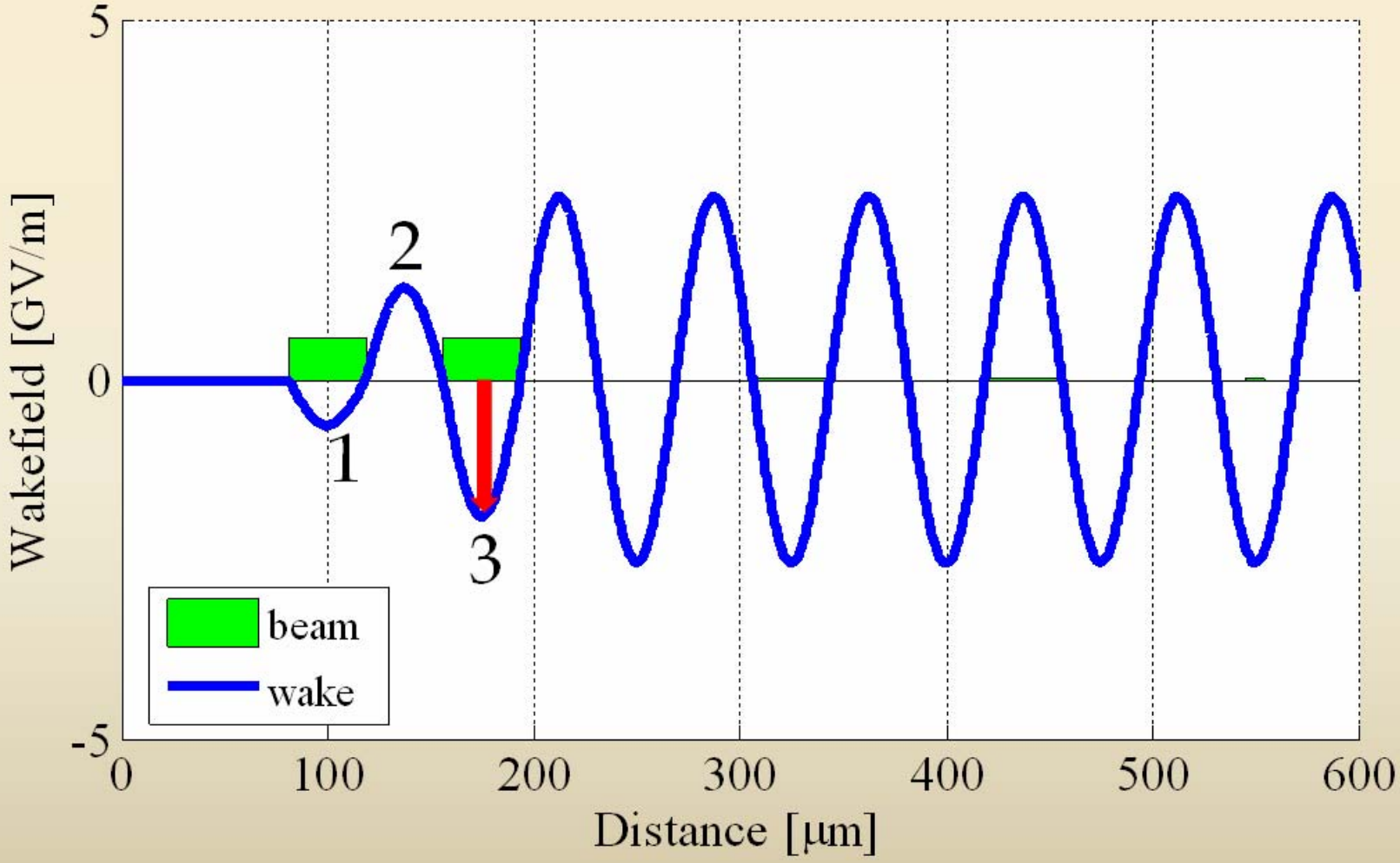

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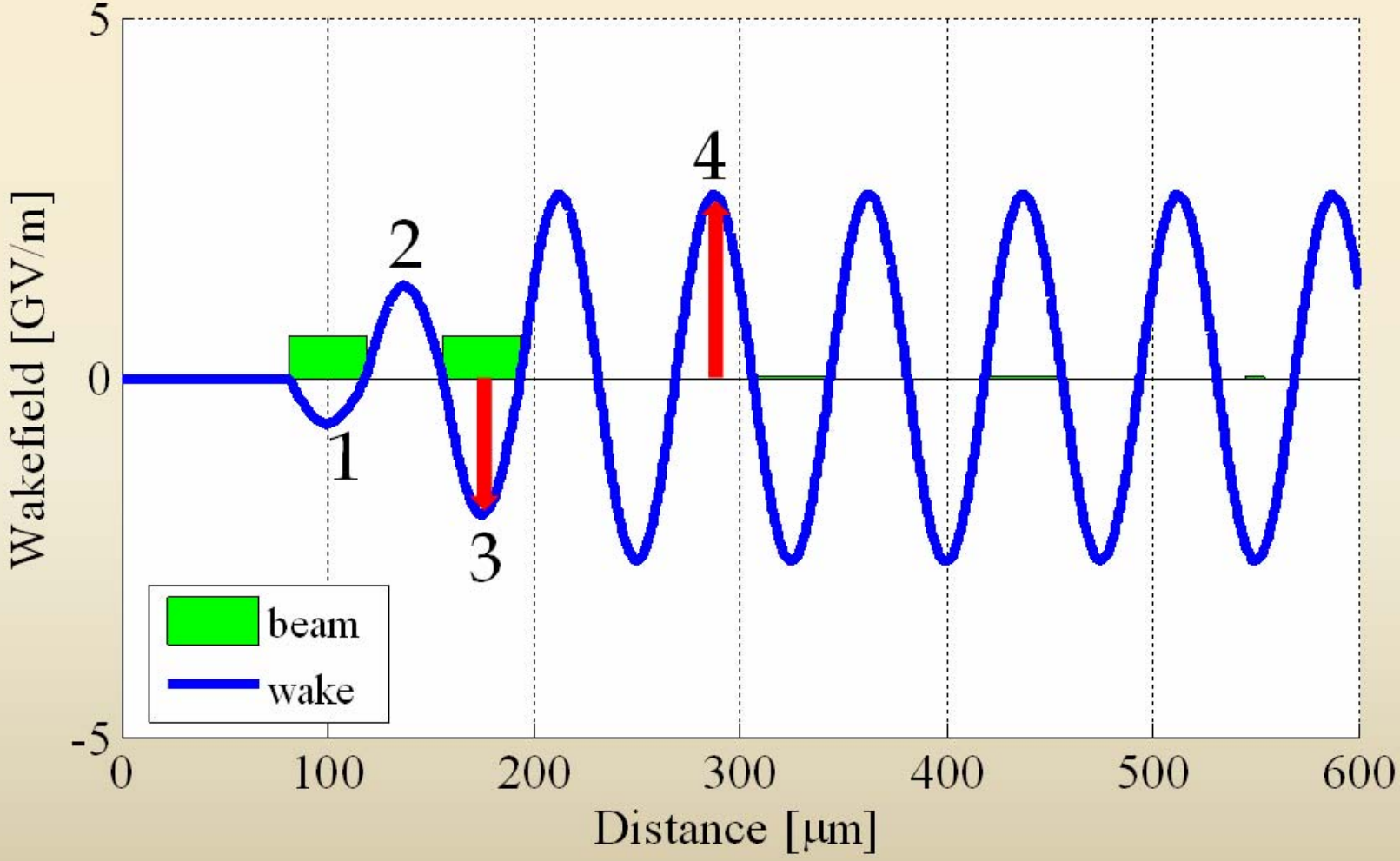

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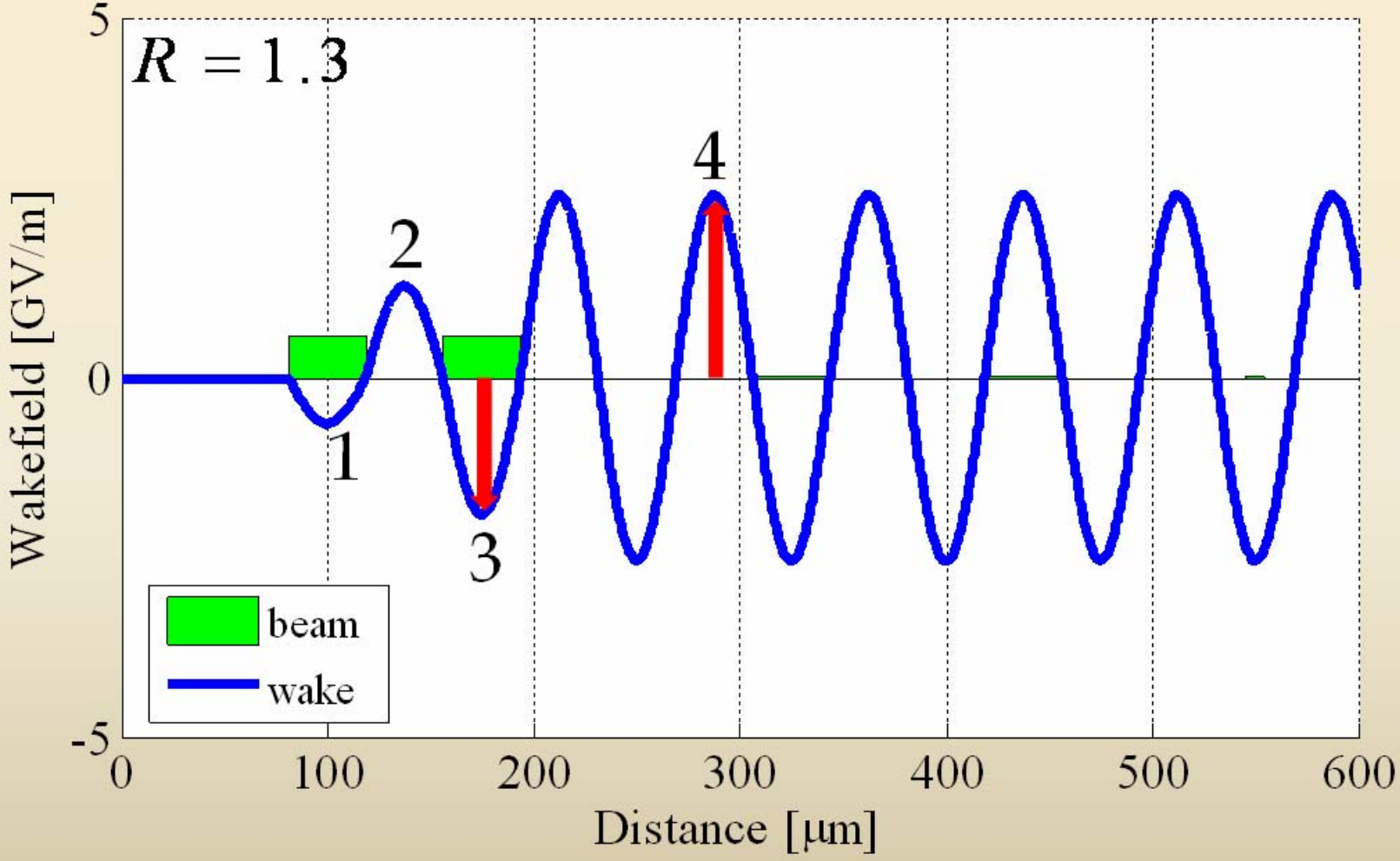

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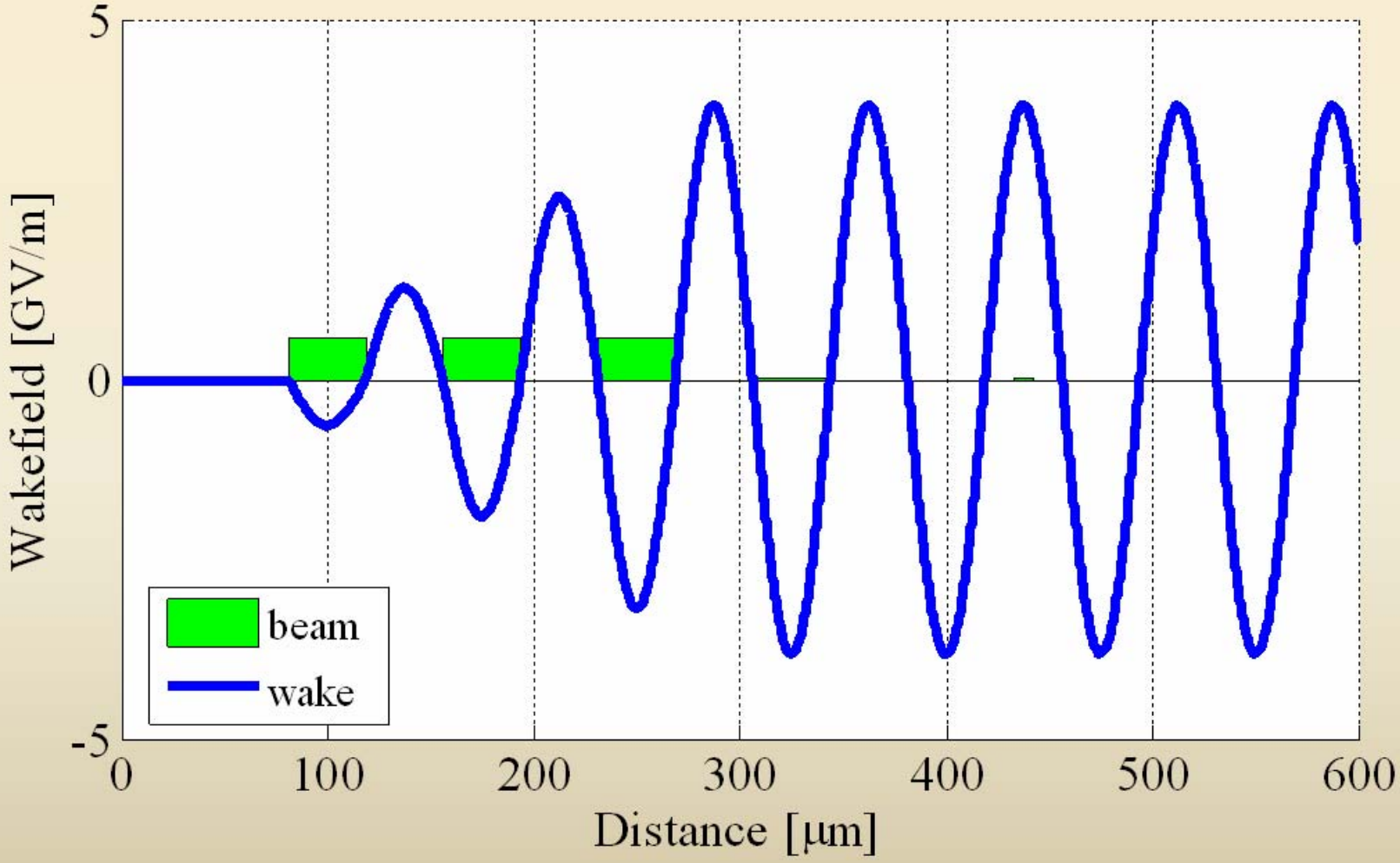

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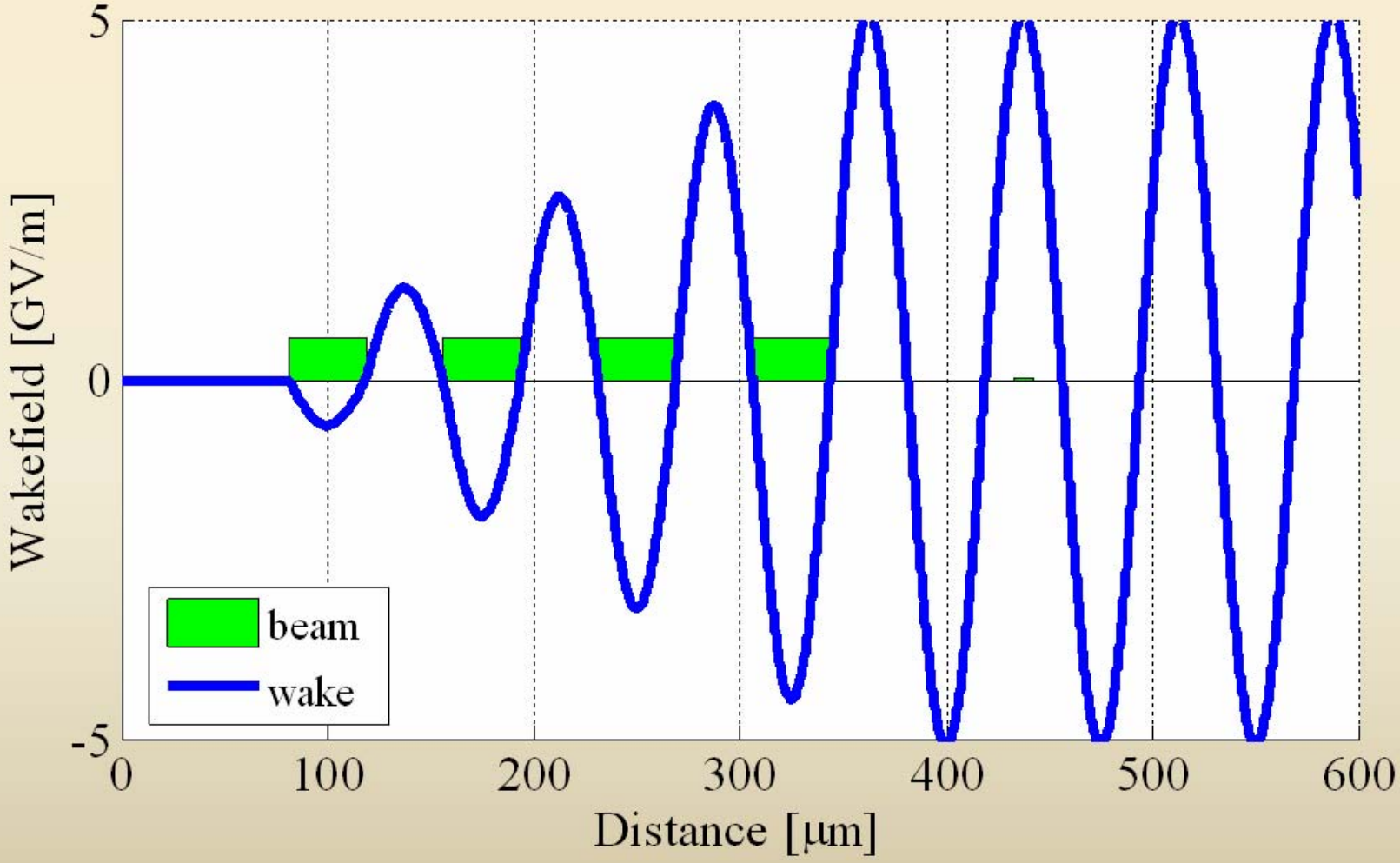

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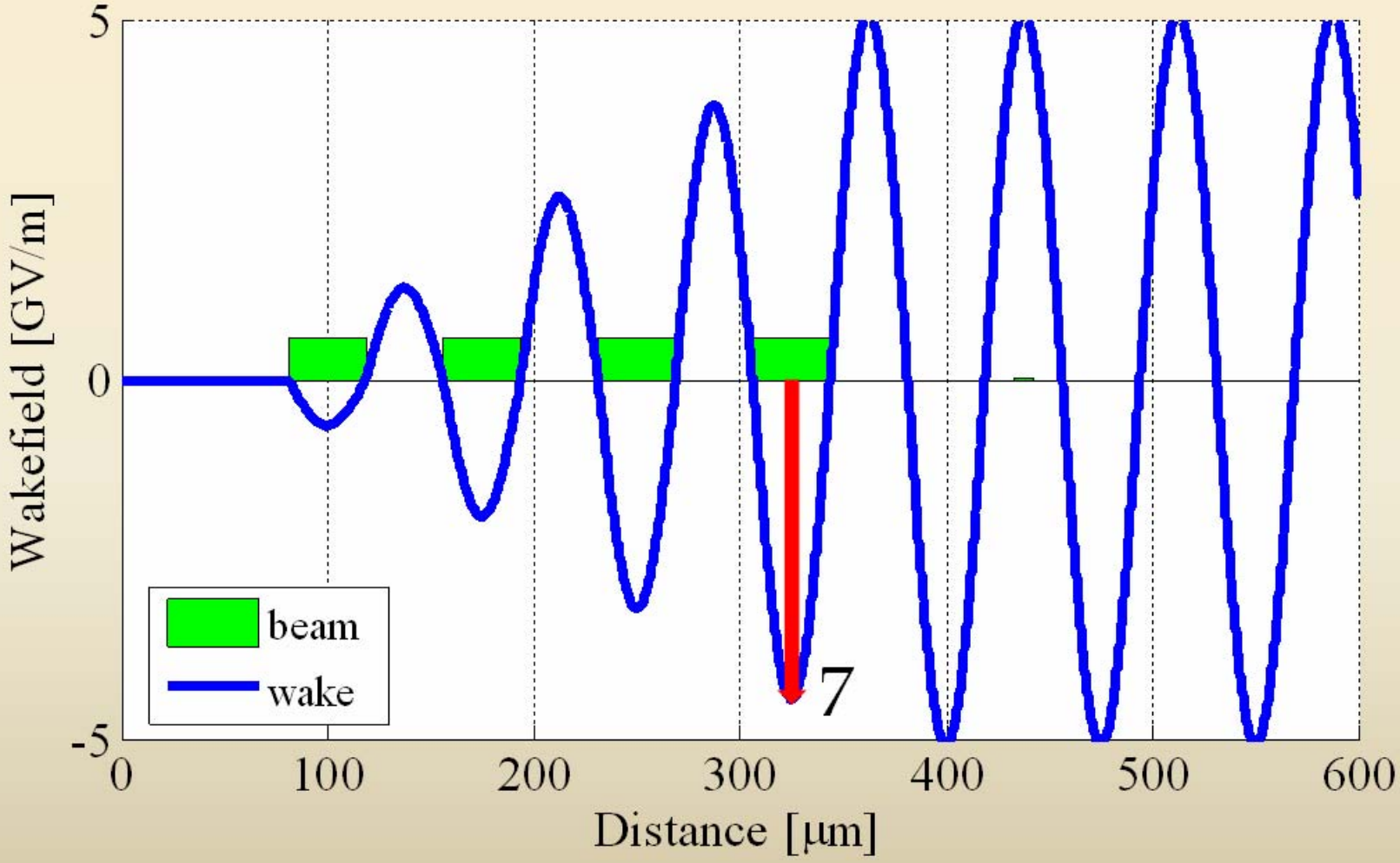

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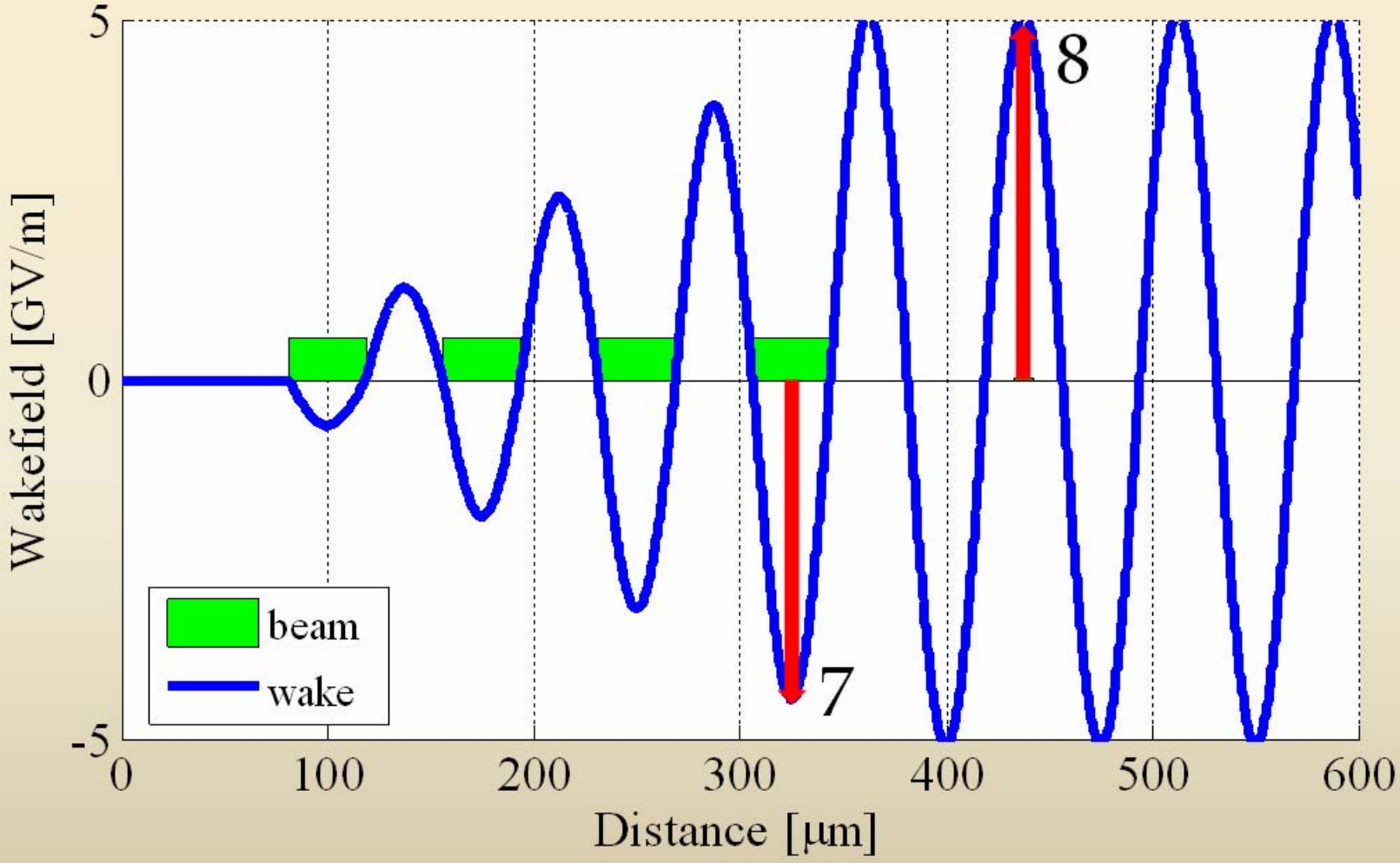

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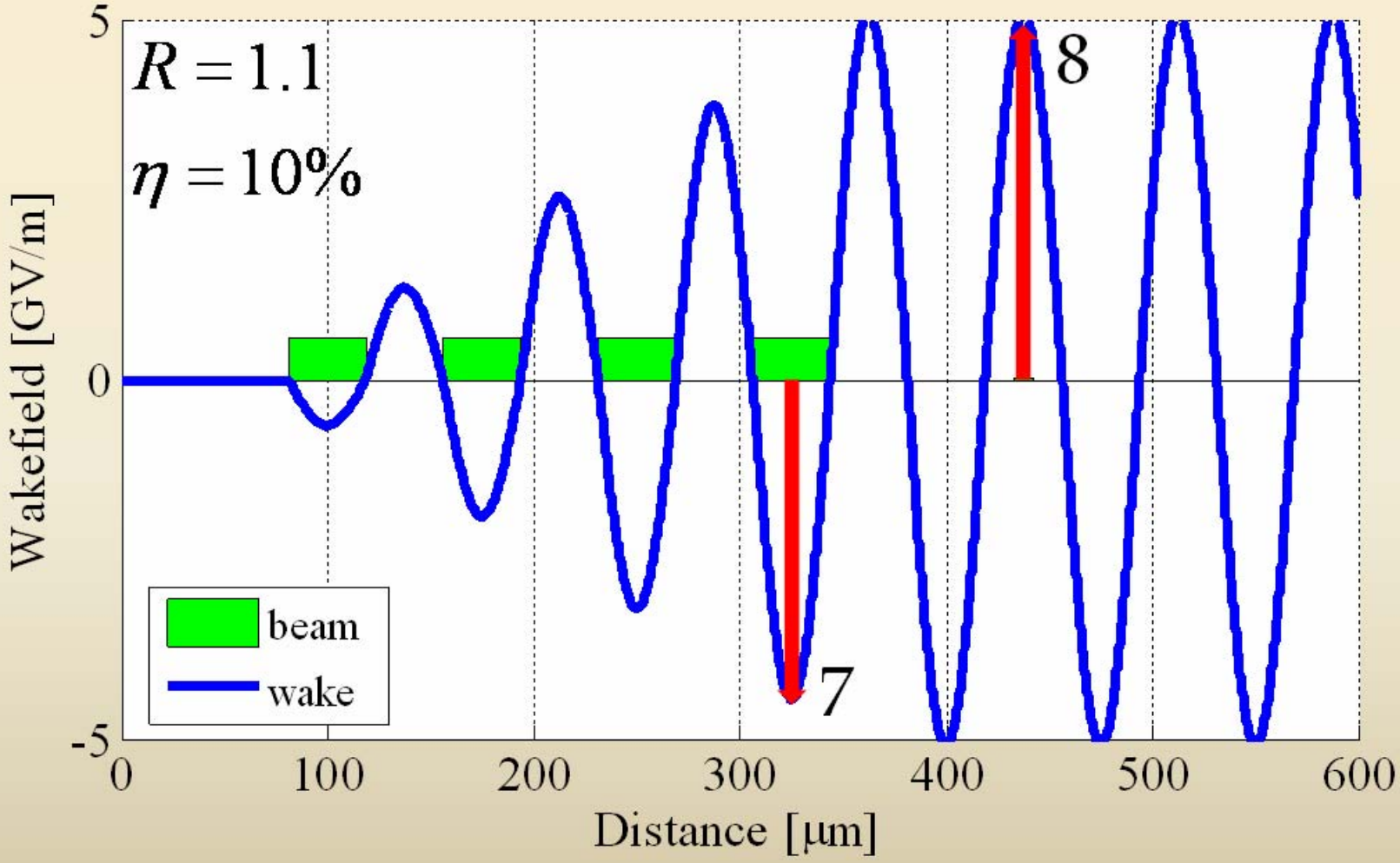

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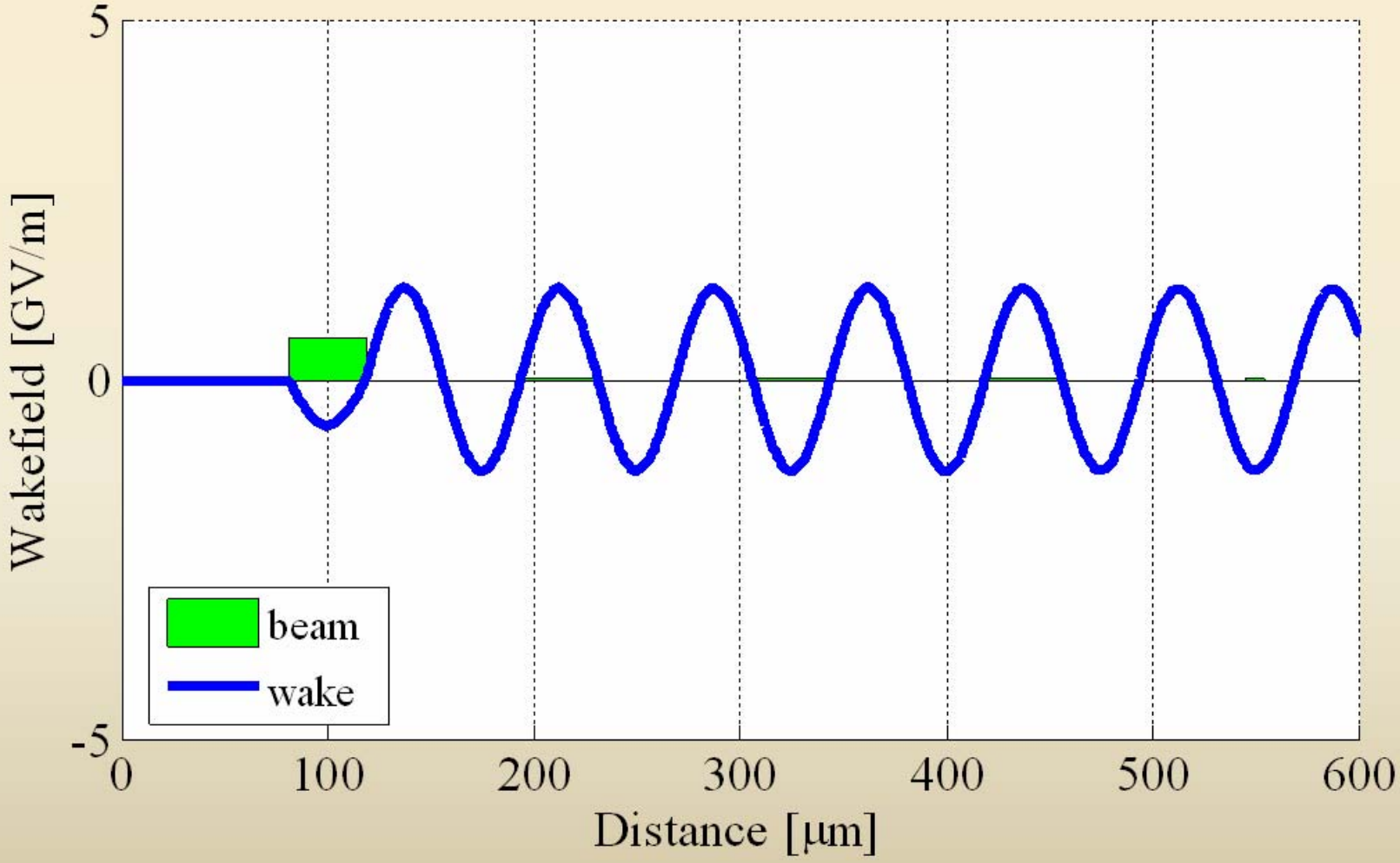

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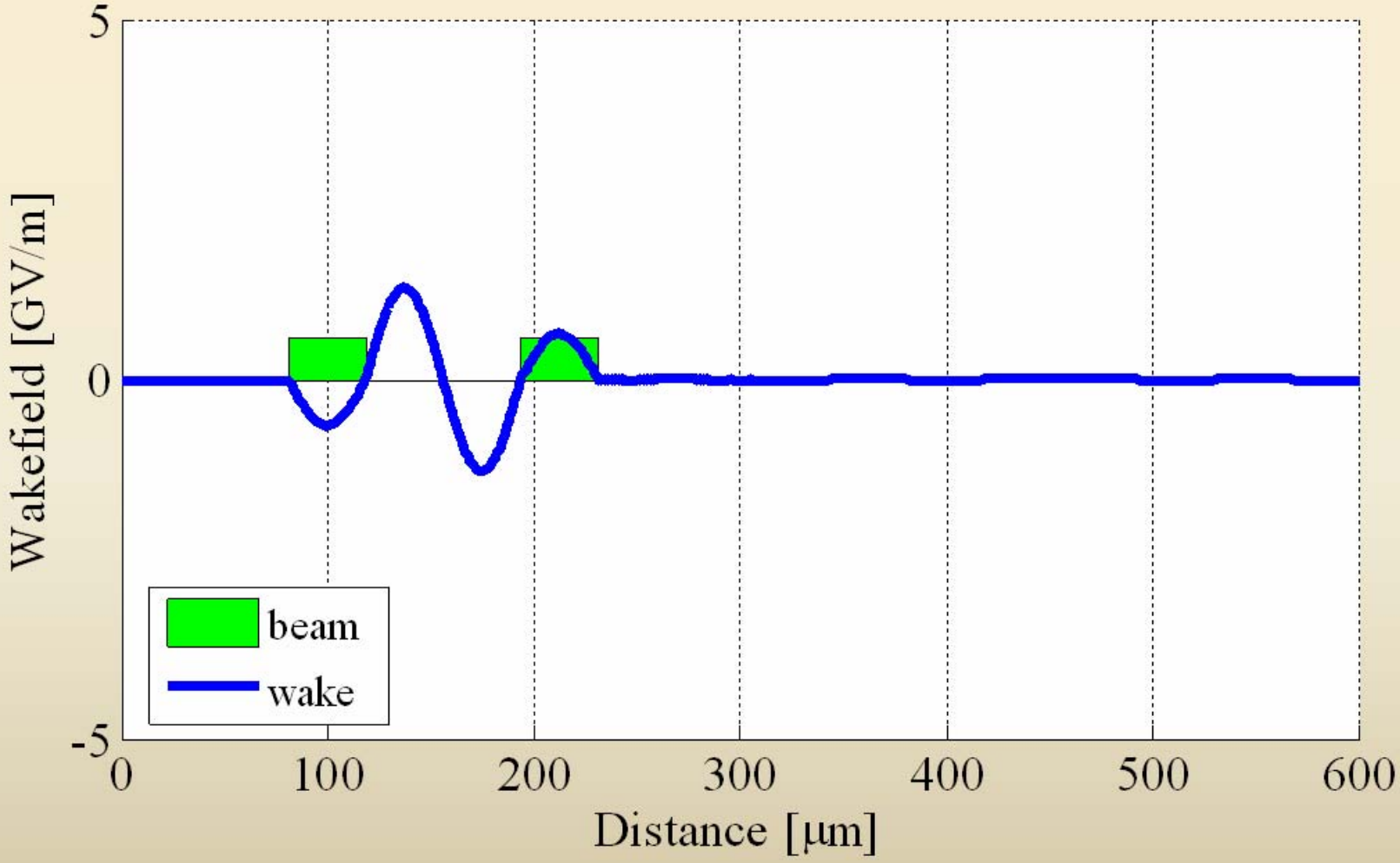
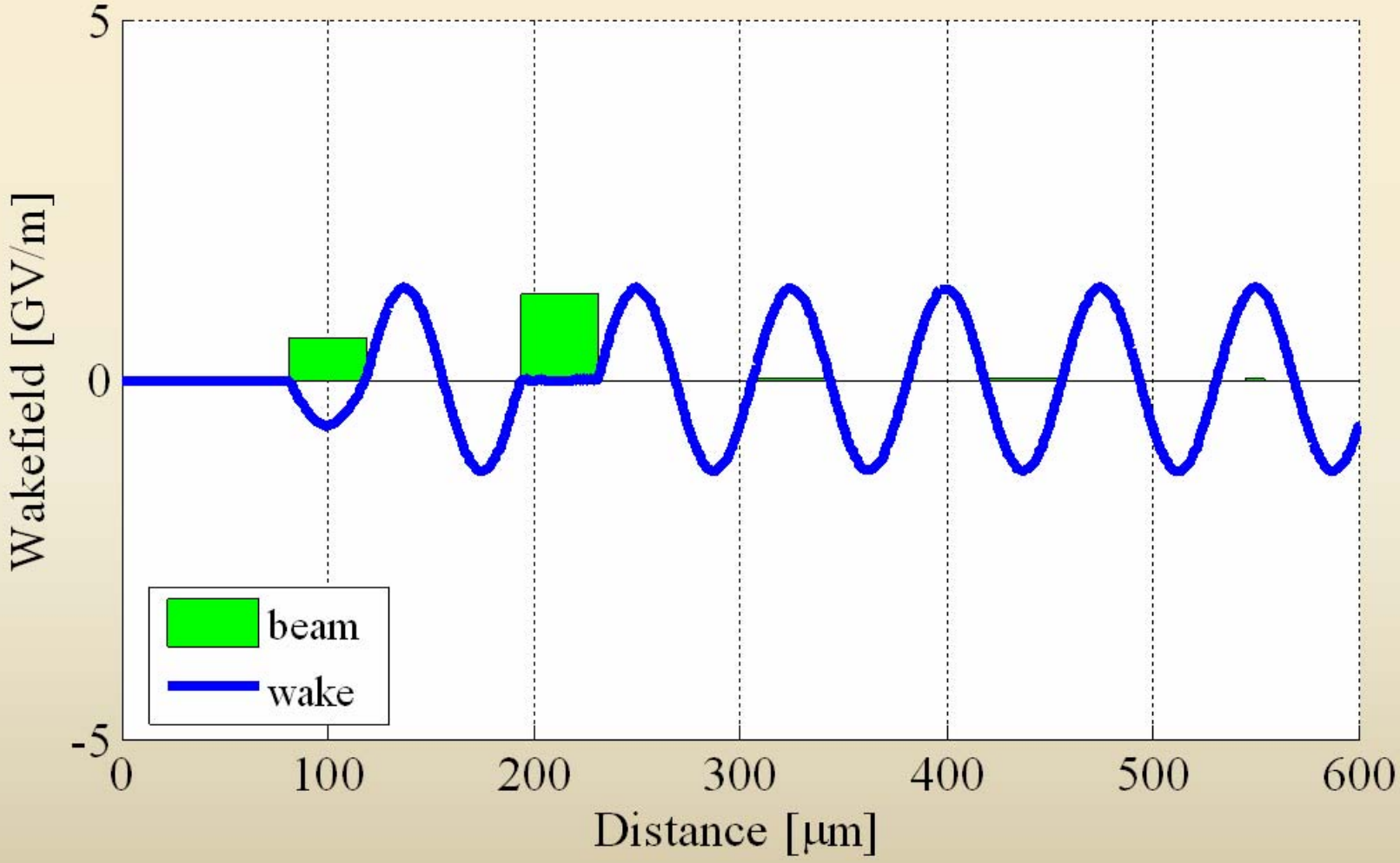
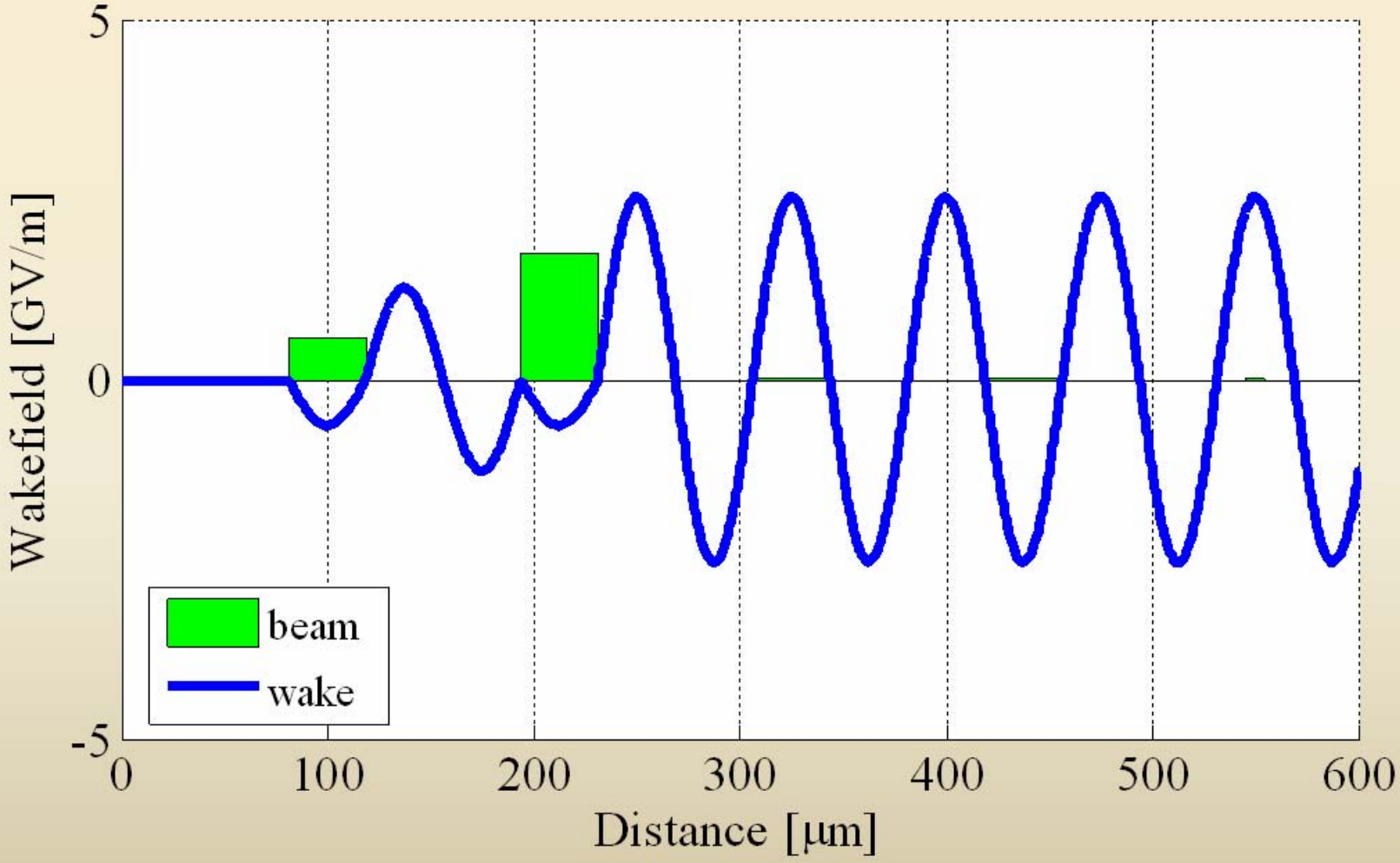


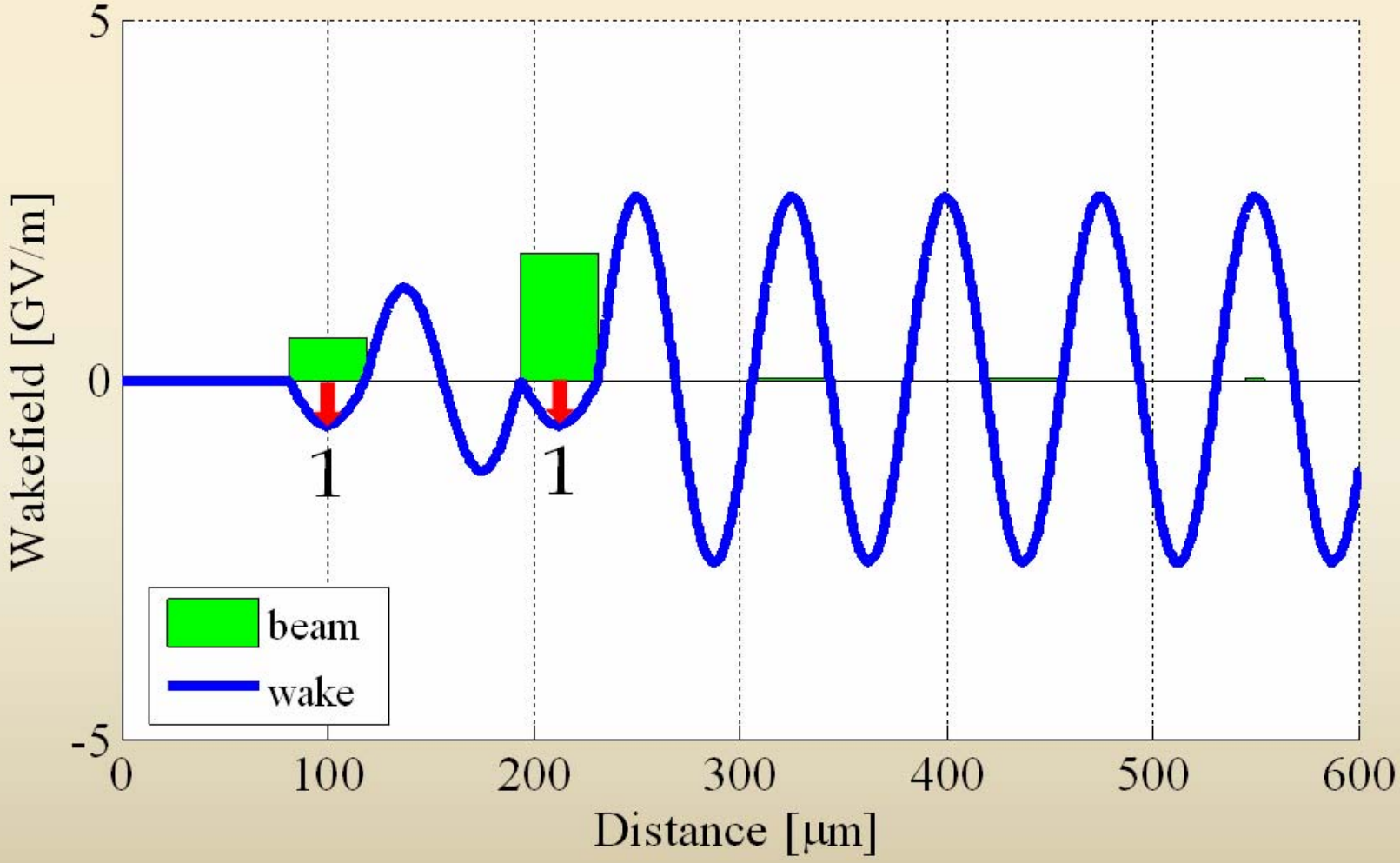
Getting High Transfomer Ratio



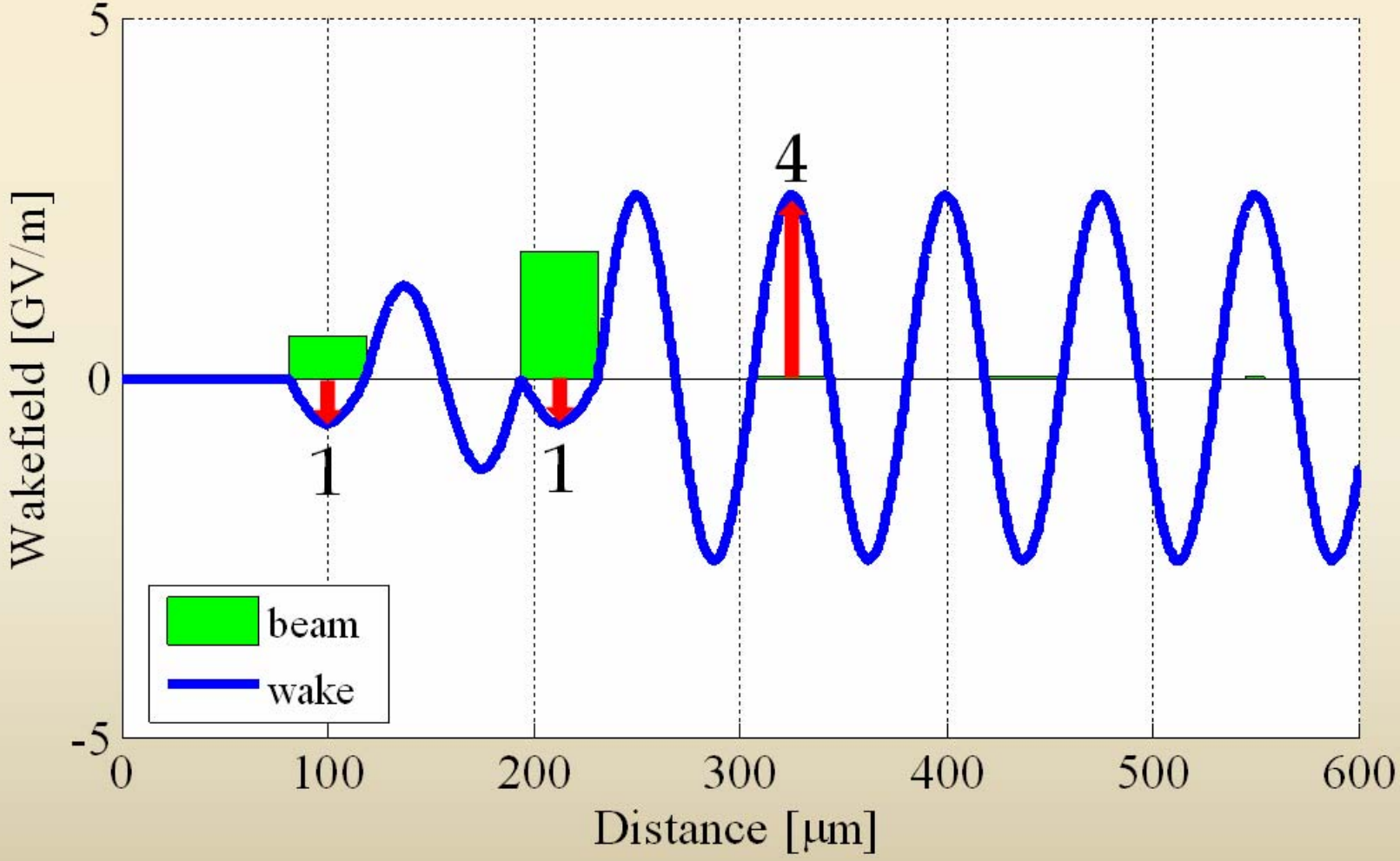
Getting High Transfomer Ratio



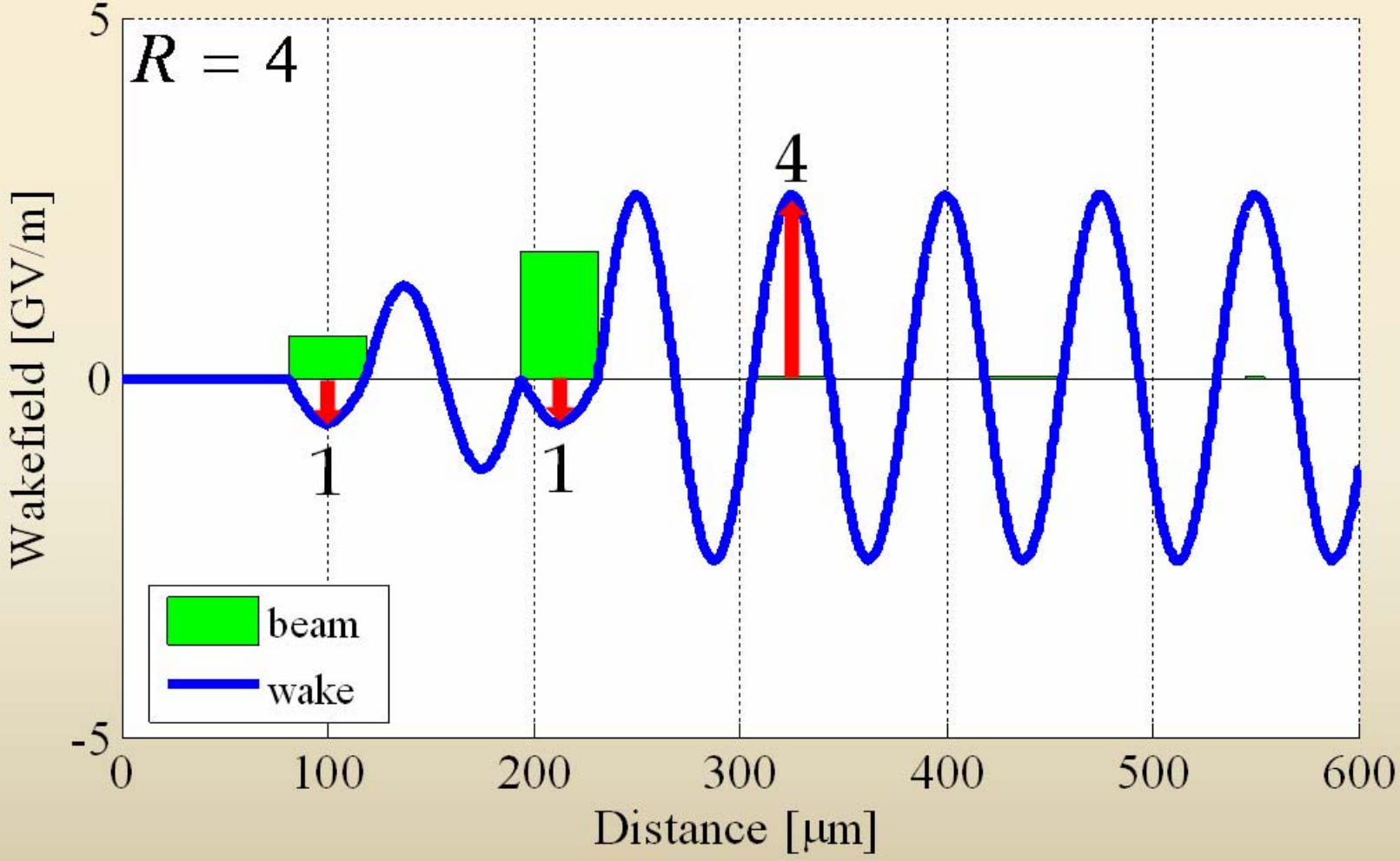
Getting High Transfomer Ratio



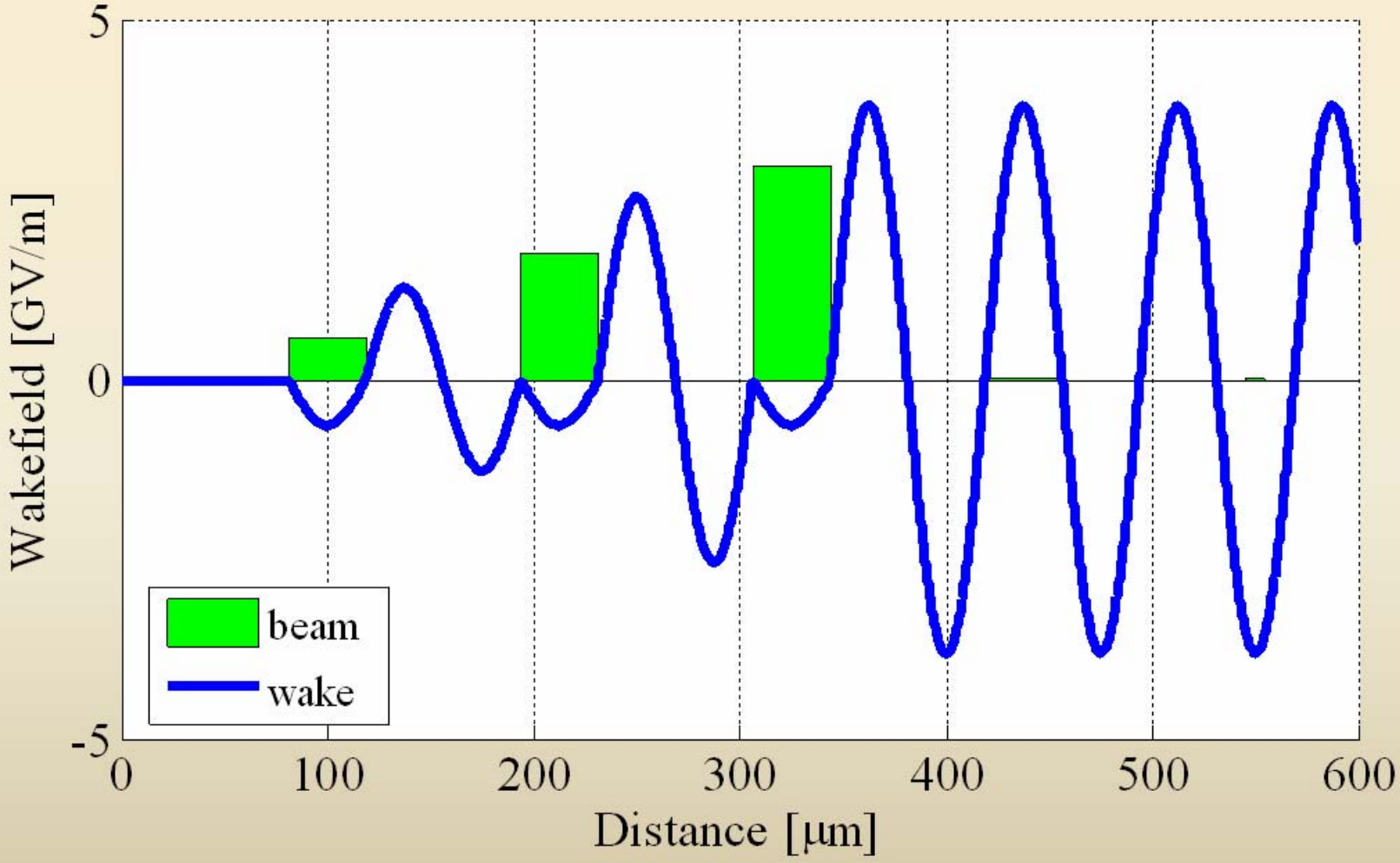
Getting High Transfomer Ratio



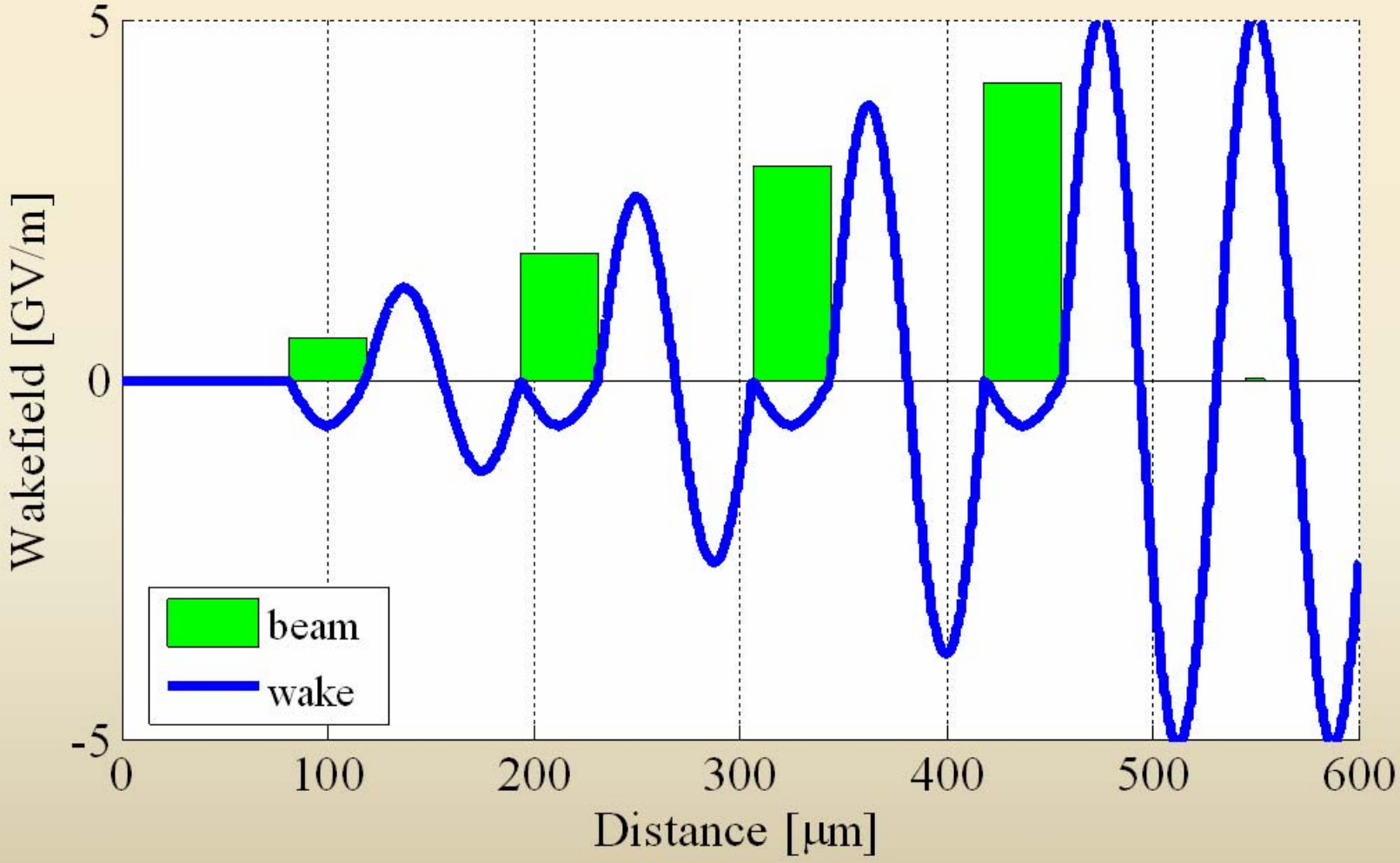
Getting High Transfomer Ratio



Getting High Transfomer Ratio



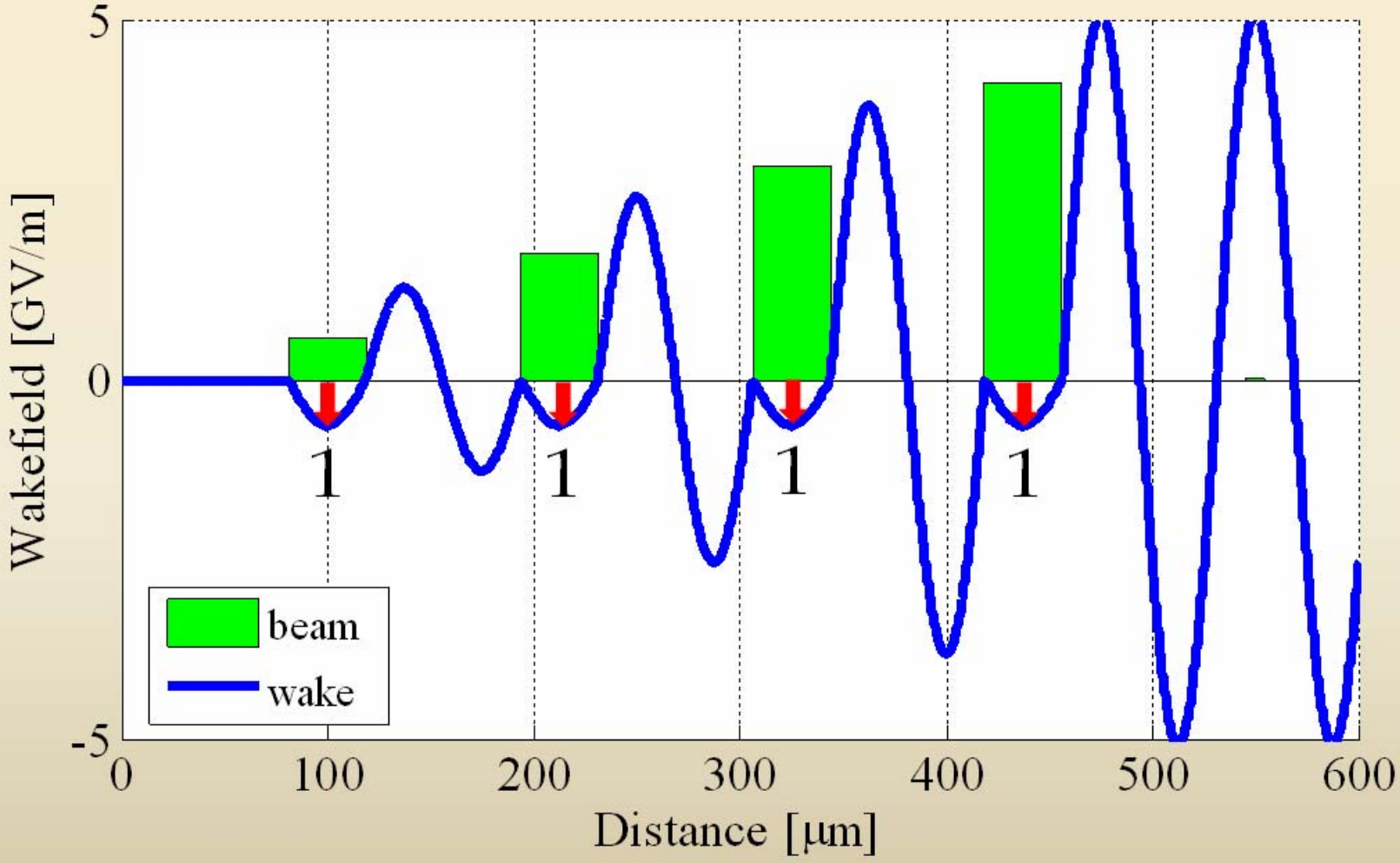
Getting High Transfomer Ratio



Laziev et al., EPAC 1988

Jing et al., Phys. Rev. Lett. 2007

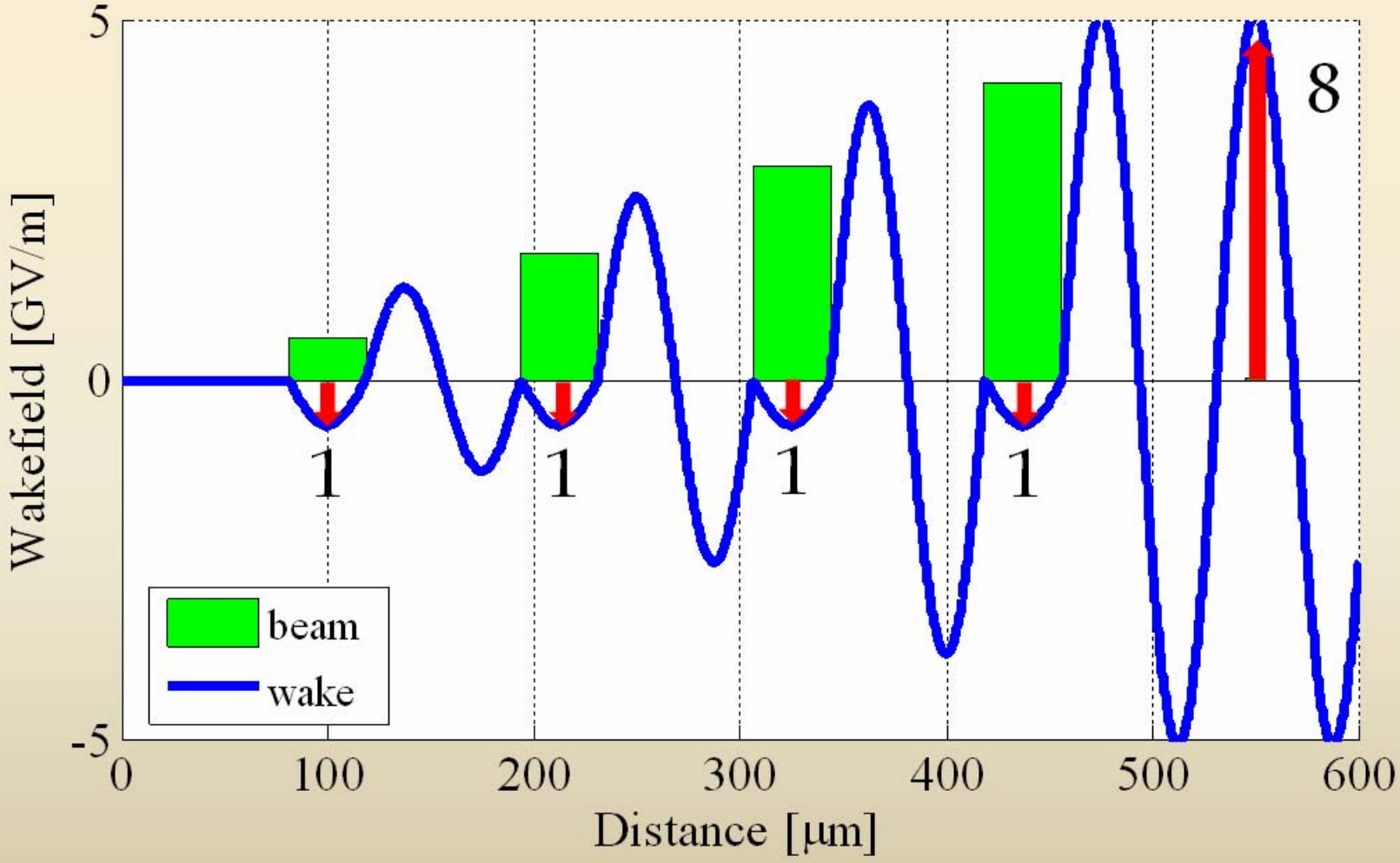
Getting High Transfomer Ratio



Laziev et al., EPAC 1988

Jing et al., Phys. Rev. Lett. 2007

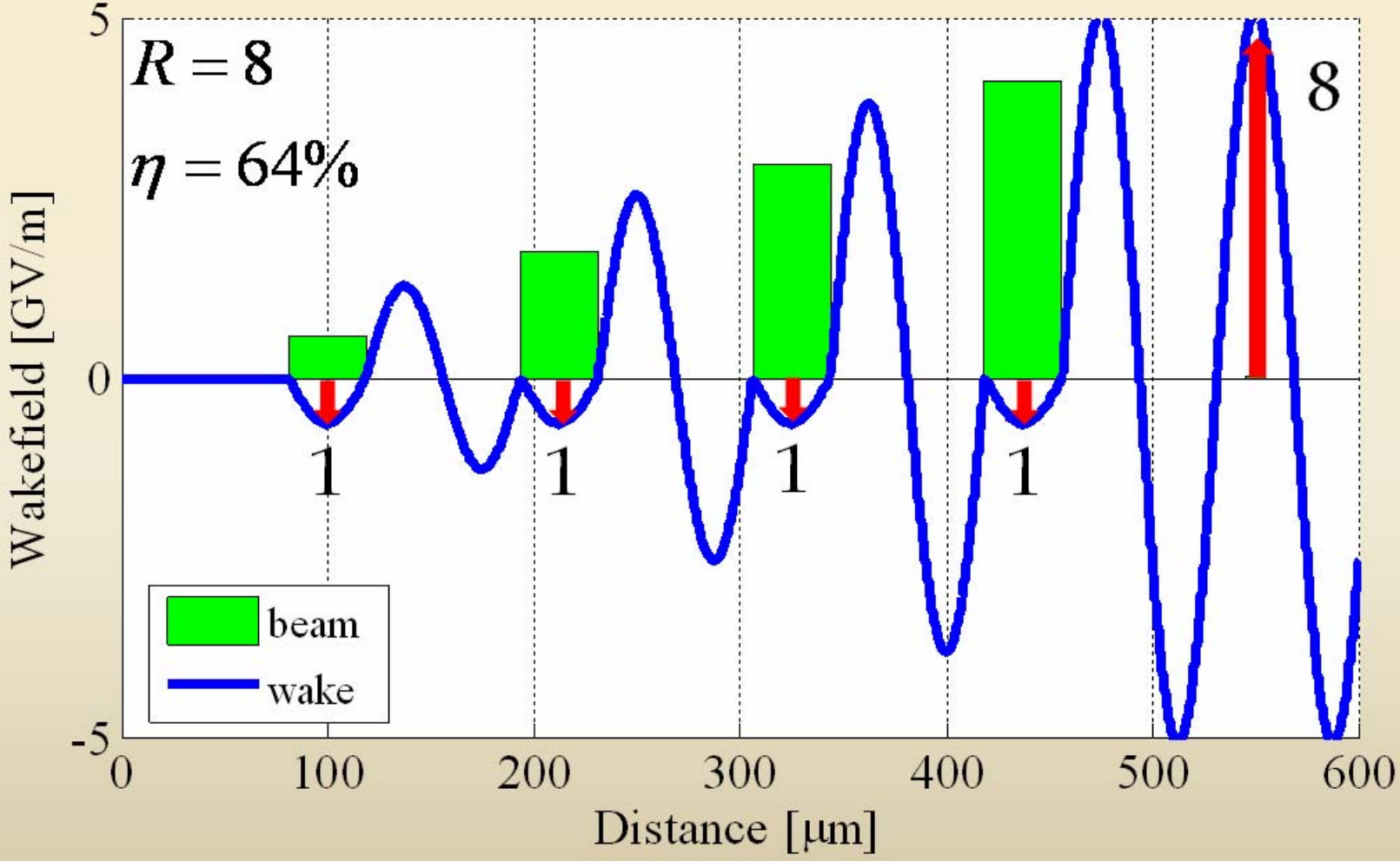
Getting High Transfomer Ratio



Laziev et al., EPAC 1988

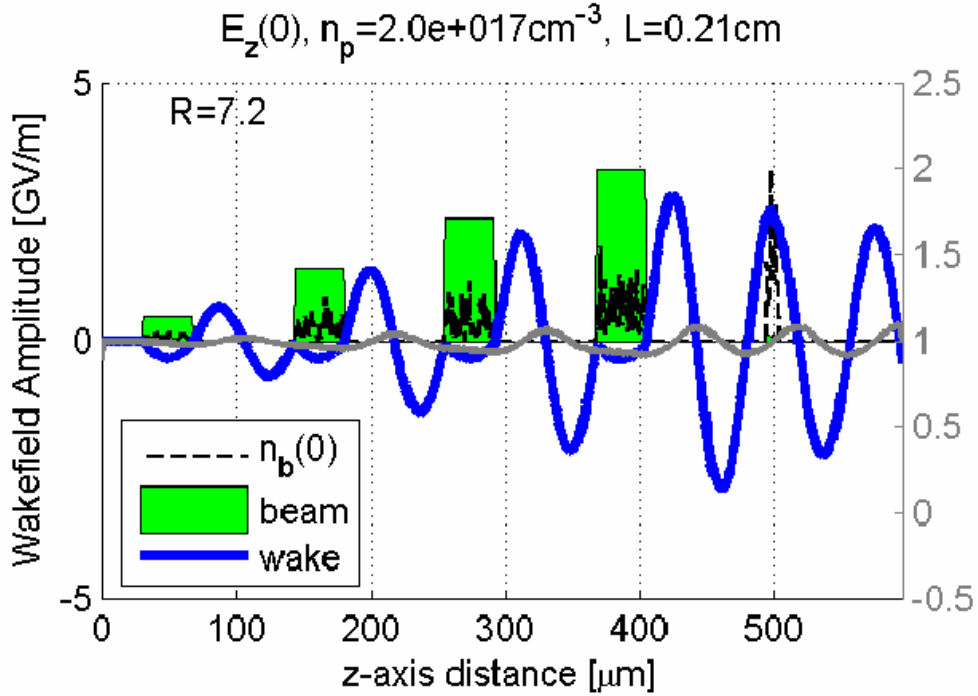
Jing et al., Phys. Rev. Lett. 2007

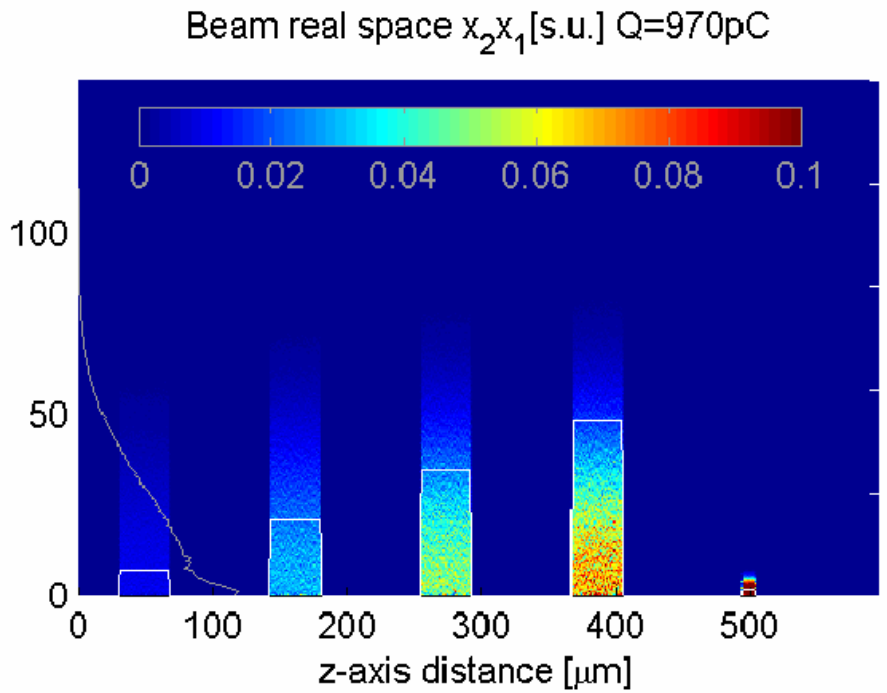
Getting High Transfomer Ratio

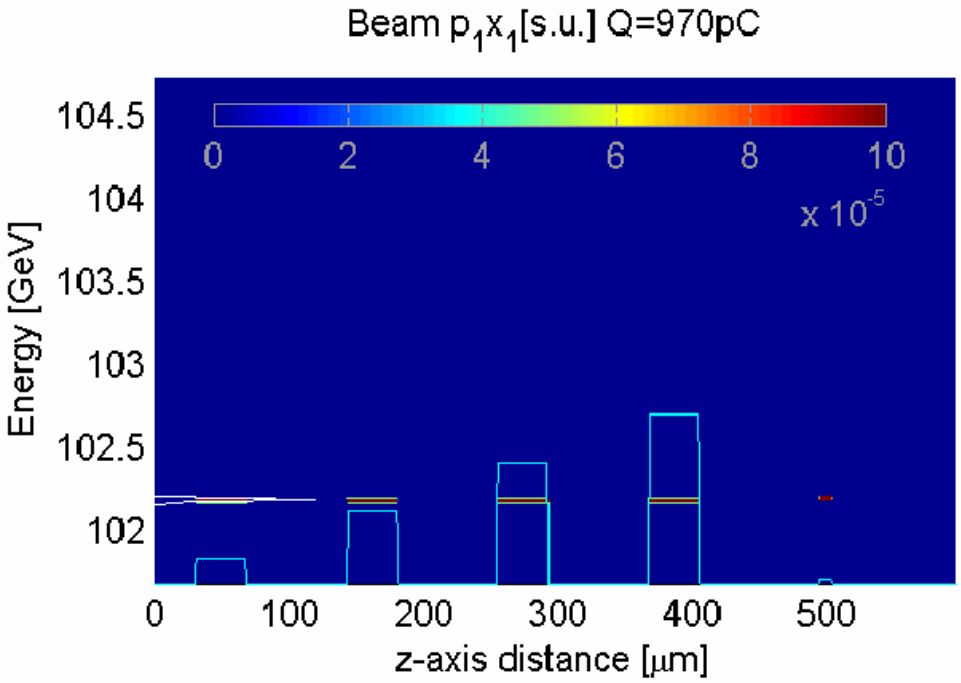


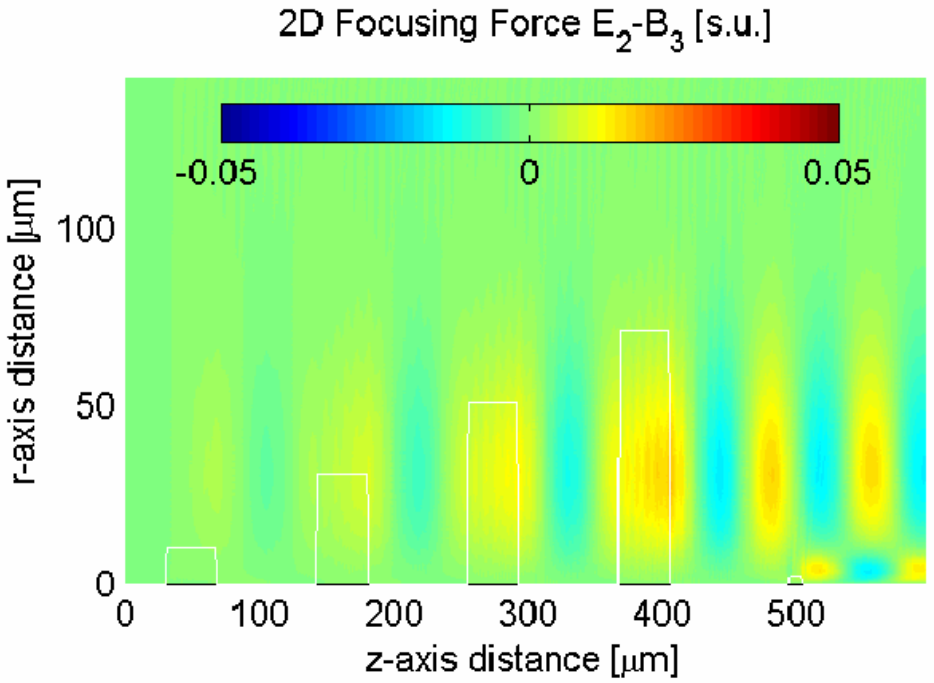
Lazieo et al., EPAC 1988

Jing et al., Phys. Rev. Lett. 2007


$E_z(0)$, n_p=2.0e+017cm^{-3}, L=0.21cm
R=7.2
Wakefield Amplitude [GV/m]
On-axis Plasma Density [s.u.]
$n_b(0)$
beam
wake
z-axis distance [μm]

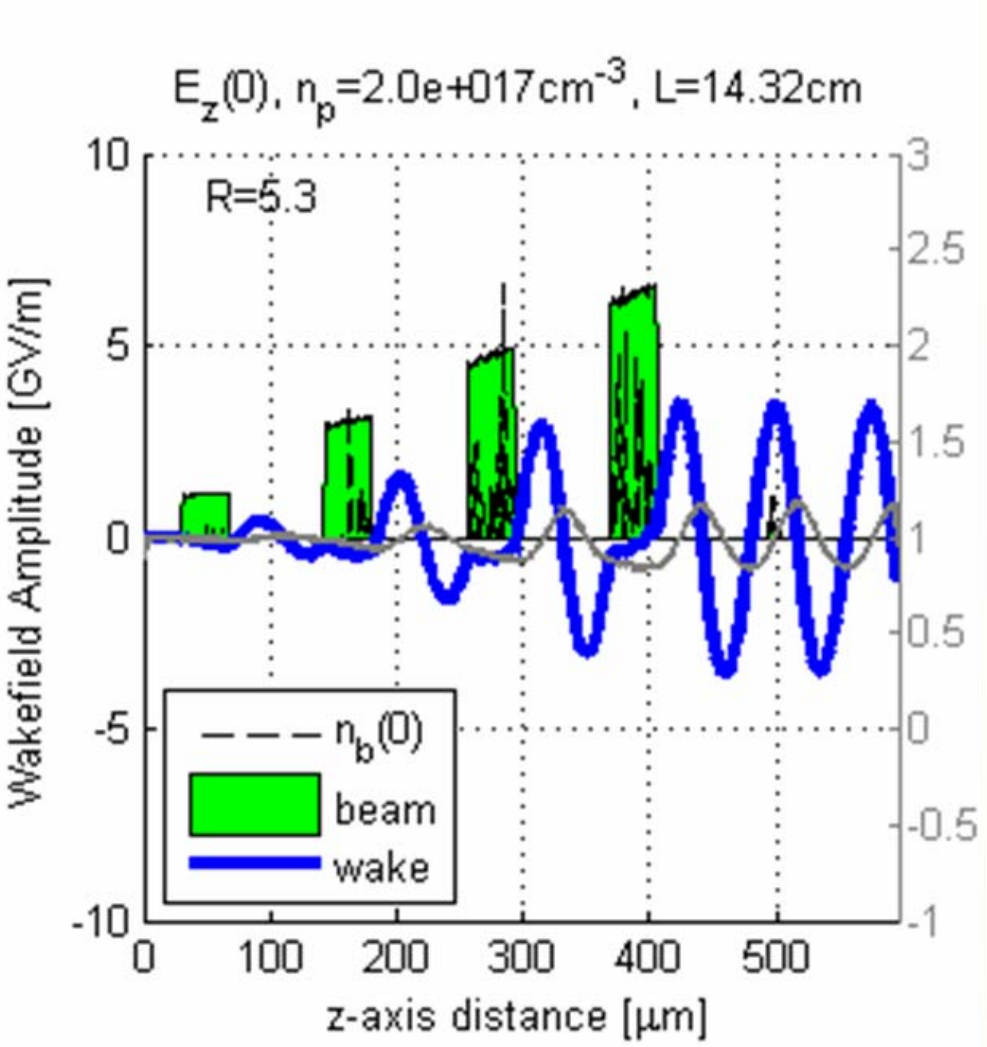

Beam real space x_2x_1[s.u.] Q=970pC
r-axis distance [μm]
z-axis distance [μm]

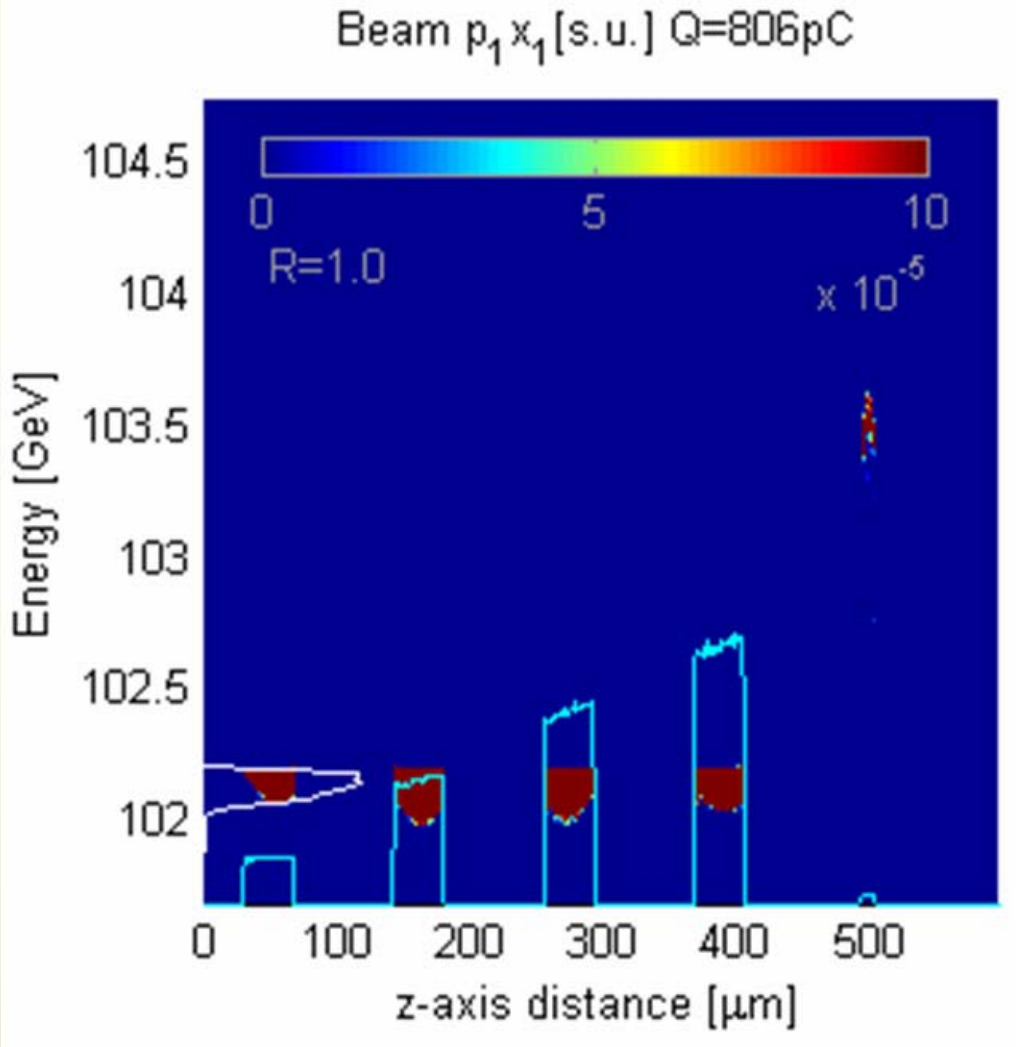

Beam p_1x_1[s.u.] Q=970pC
x 10^{-5}
Energy [GeV]
z-axis distance [μm]


2D Focusing Force E_2-B_3 [s.u.]
r-axis distance [μm]
z-axis distance [μm]

OSIRIS Simulation

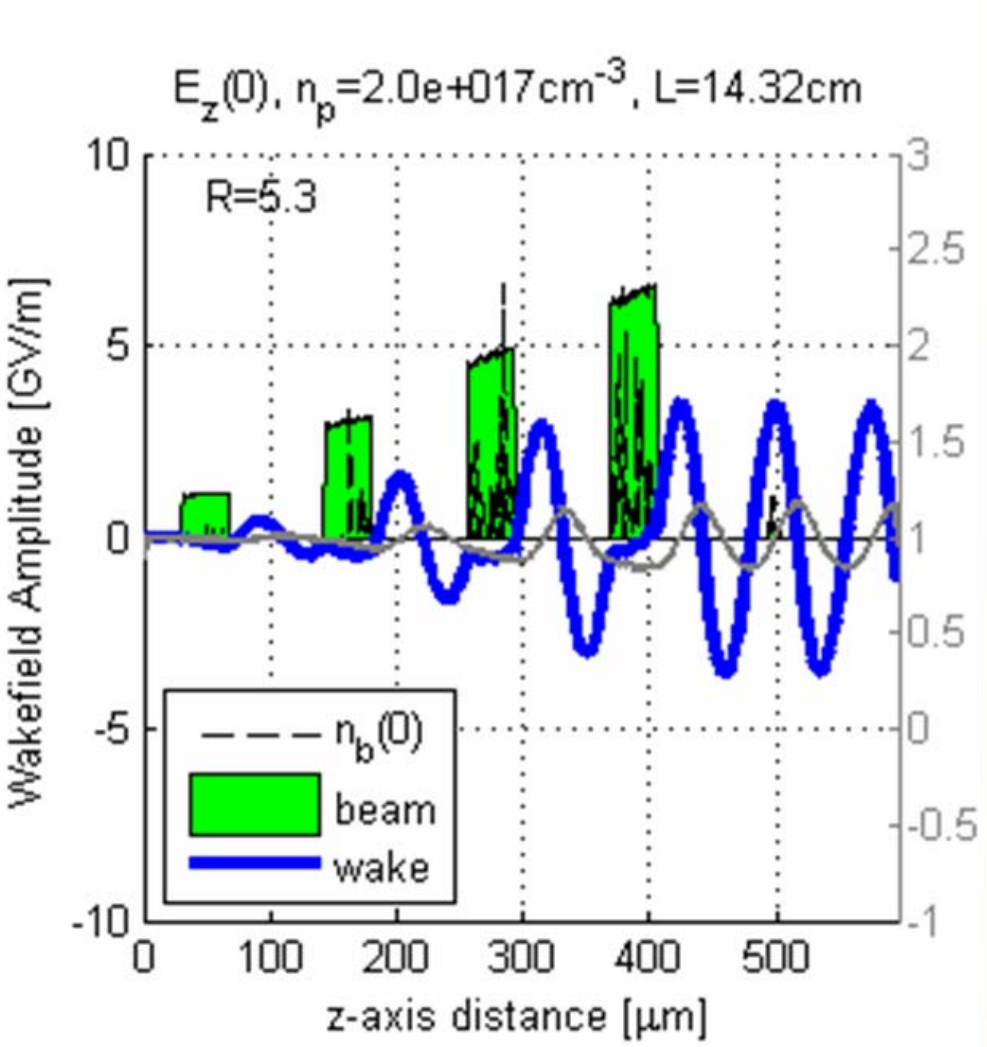
After 43 cm of plasma

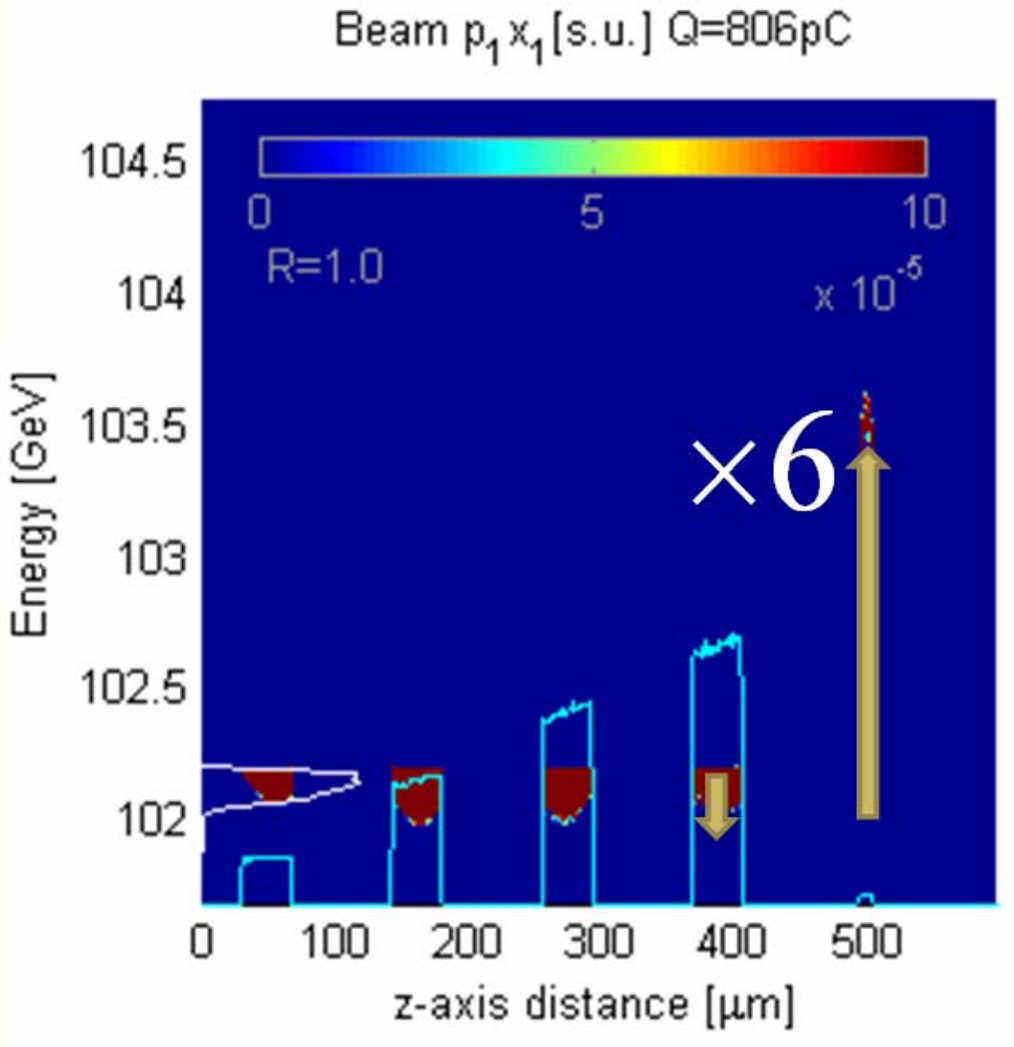




OSIRIS Simulation

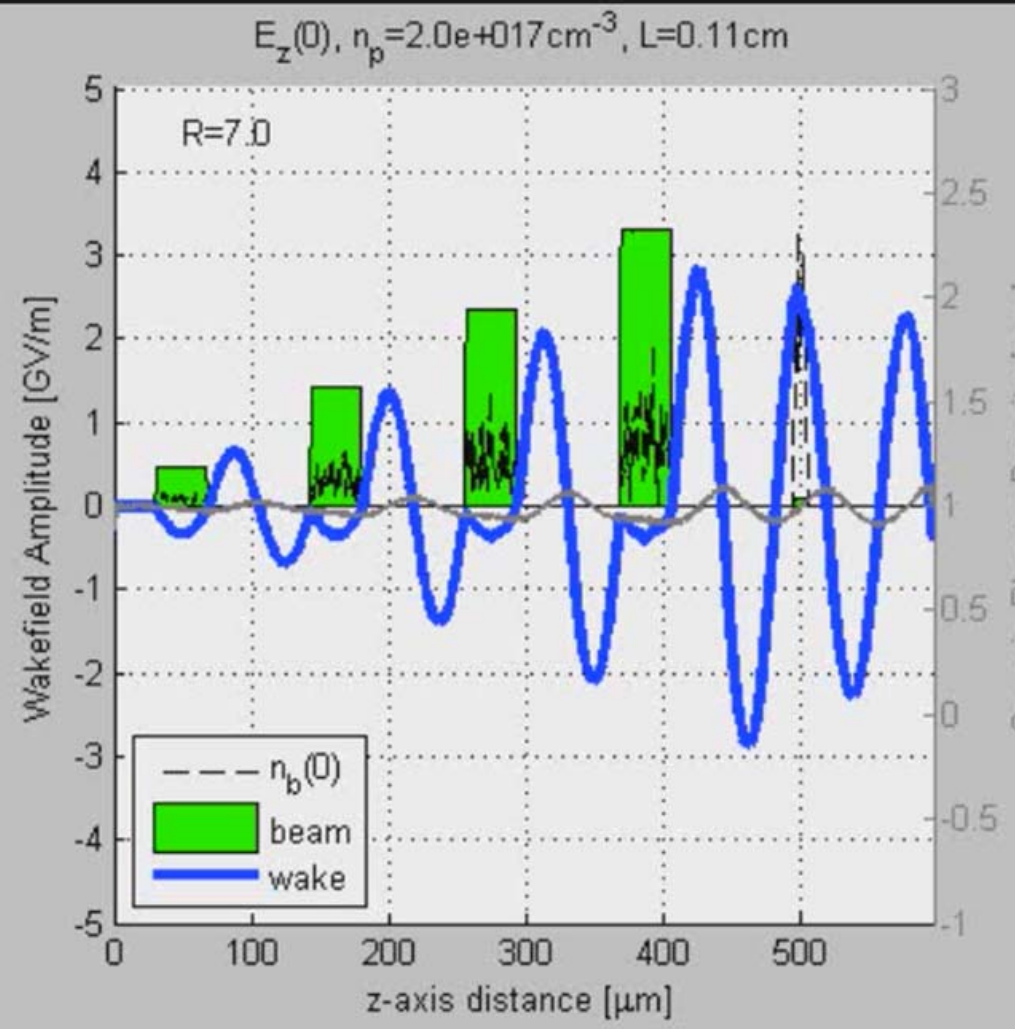
After 43 cm of plasma

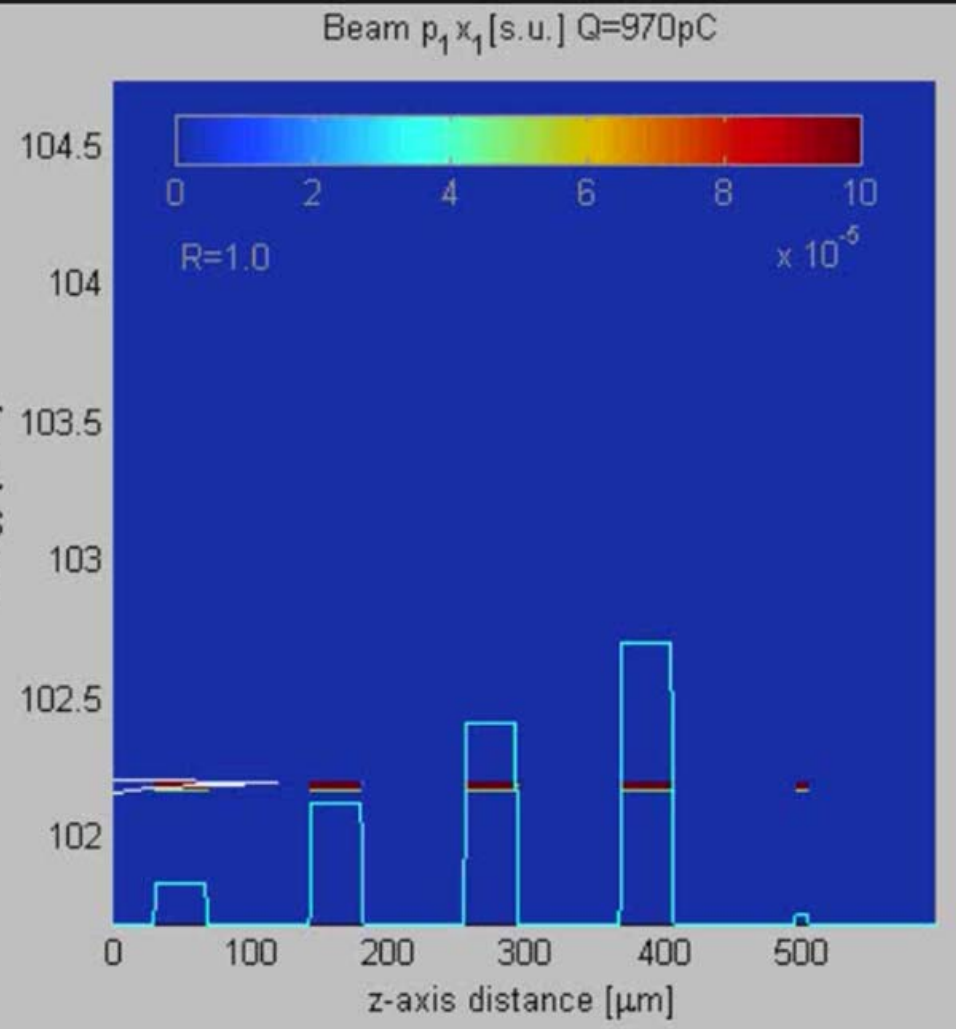


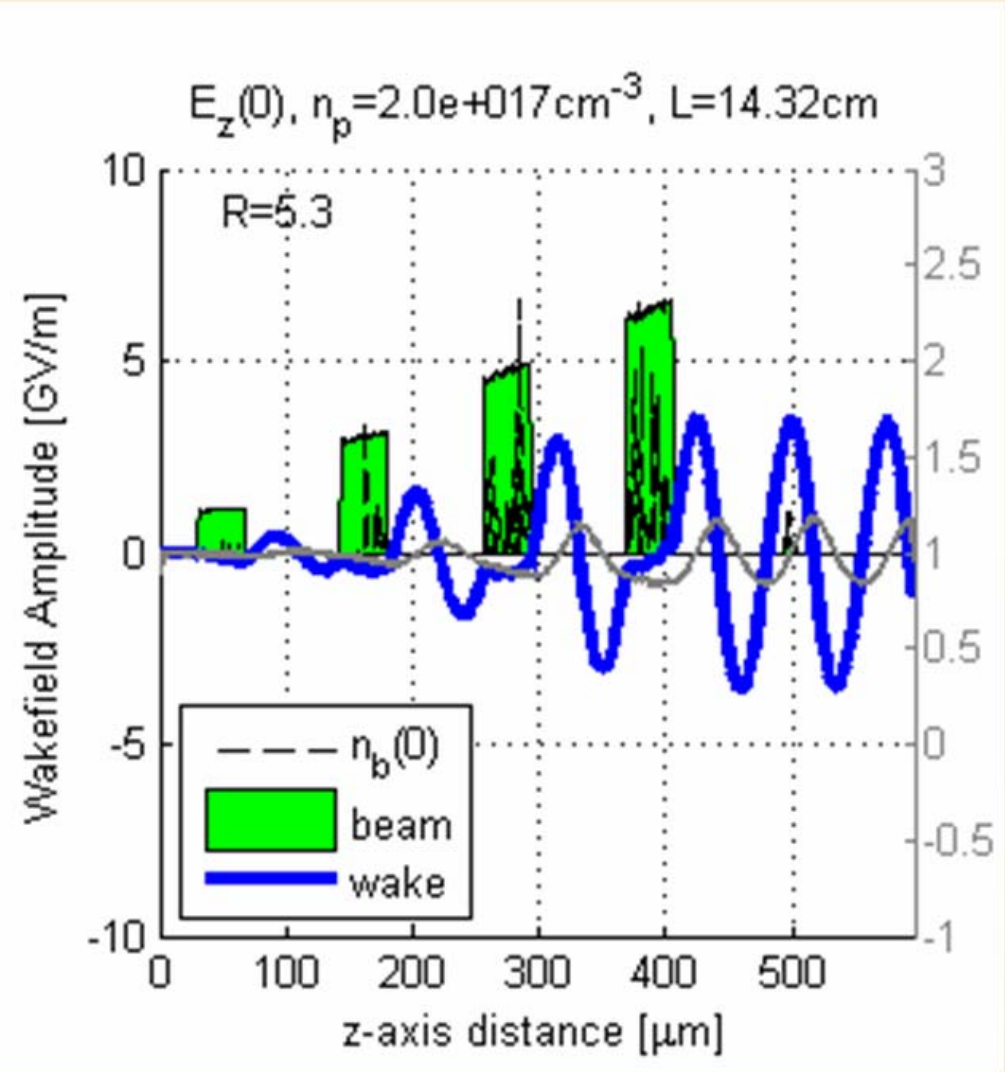


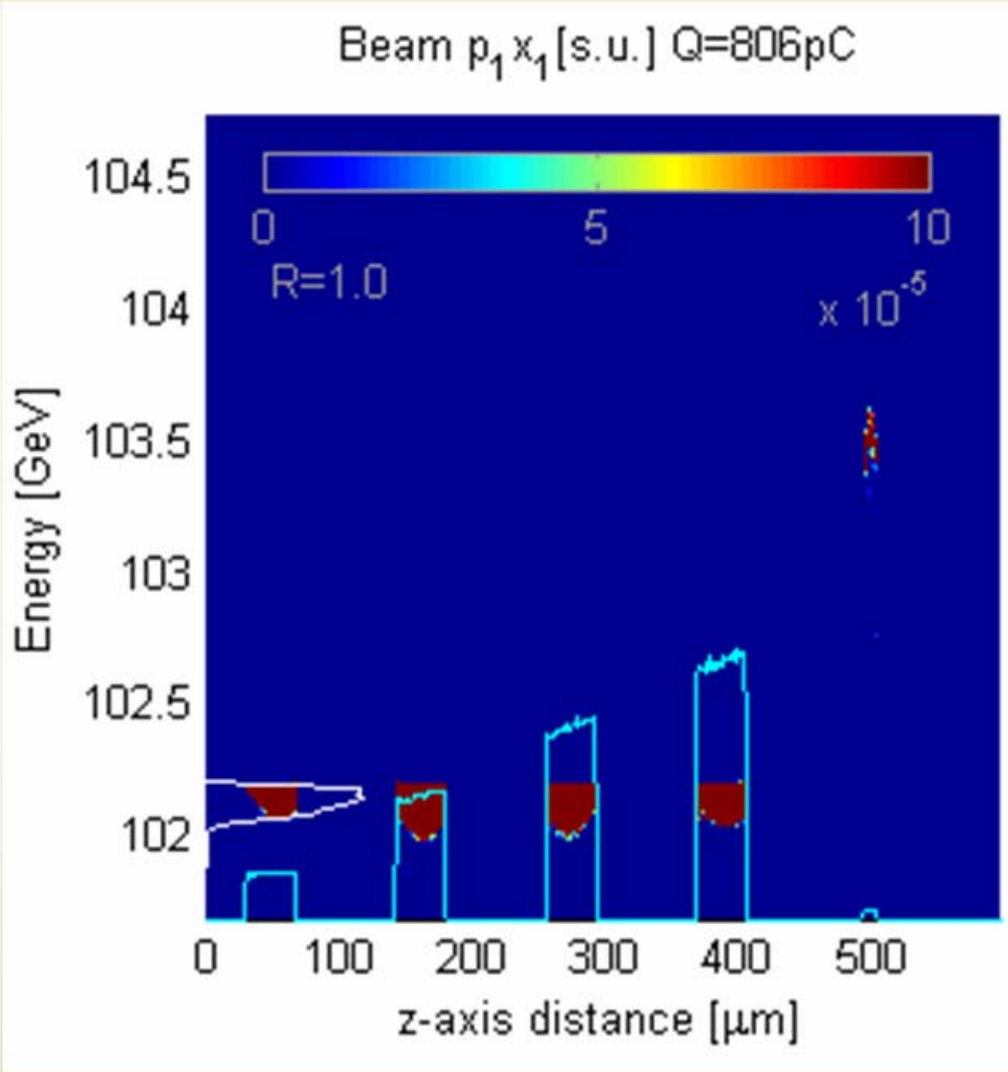

Thank you!

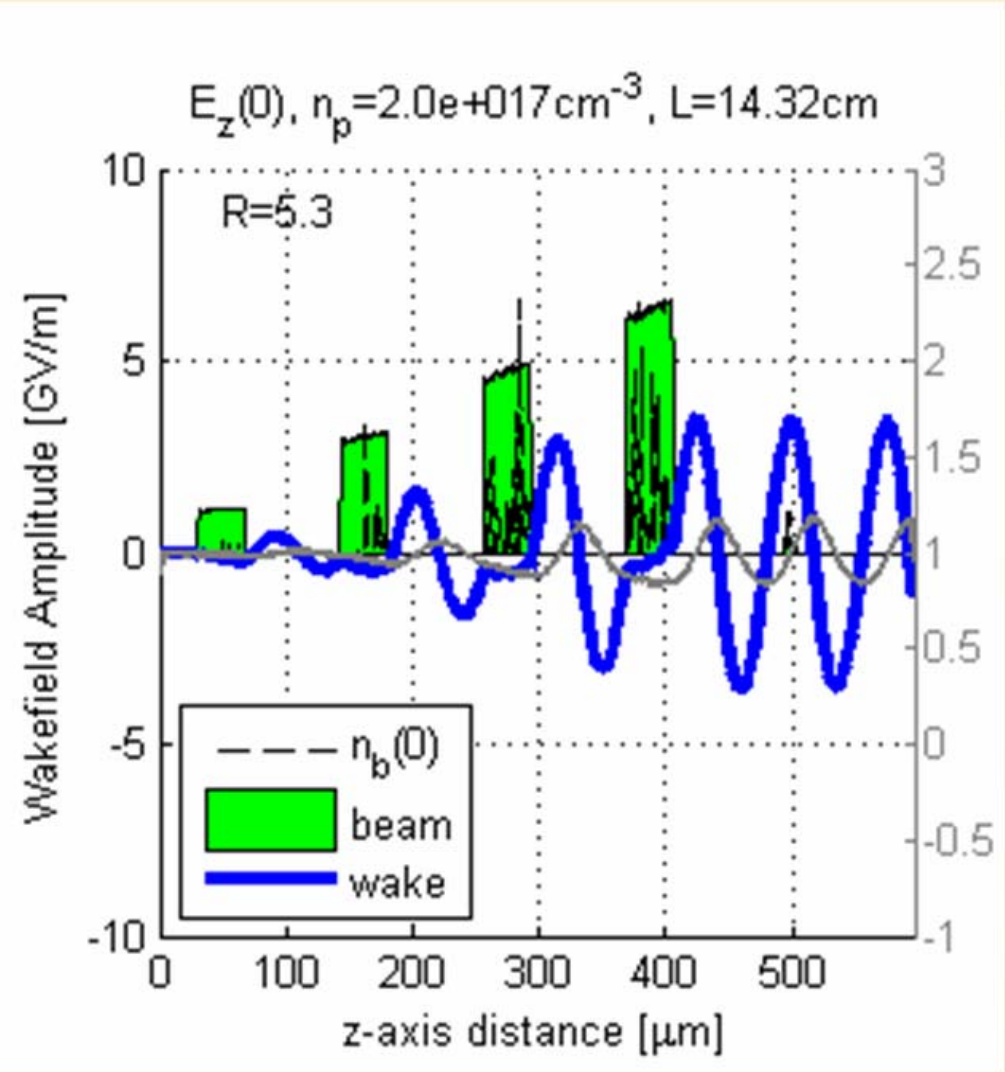
BACKUP SLIDES!

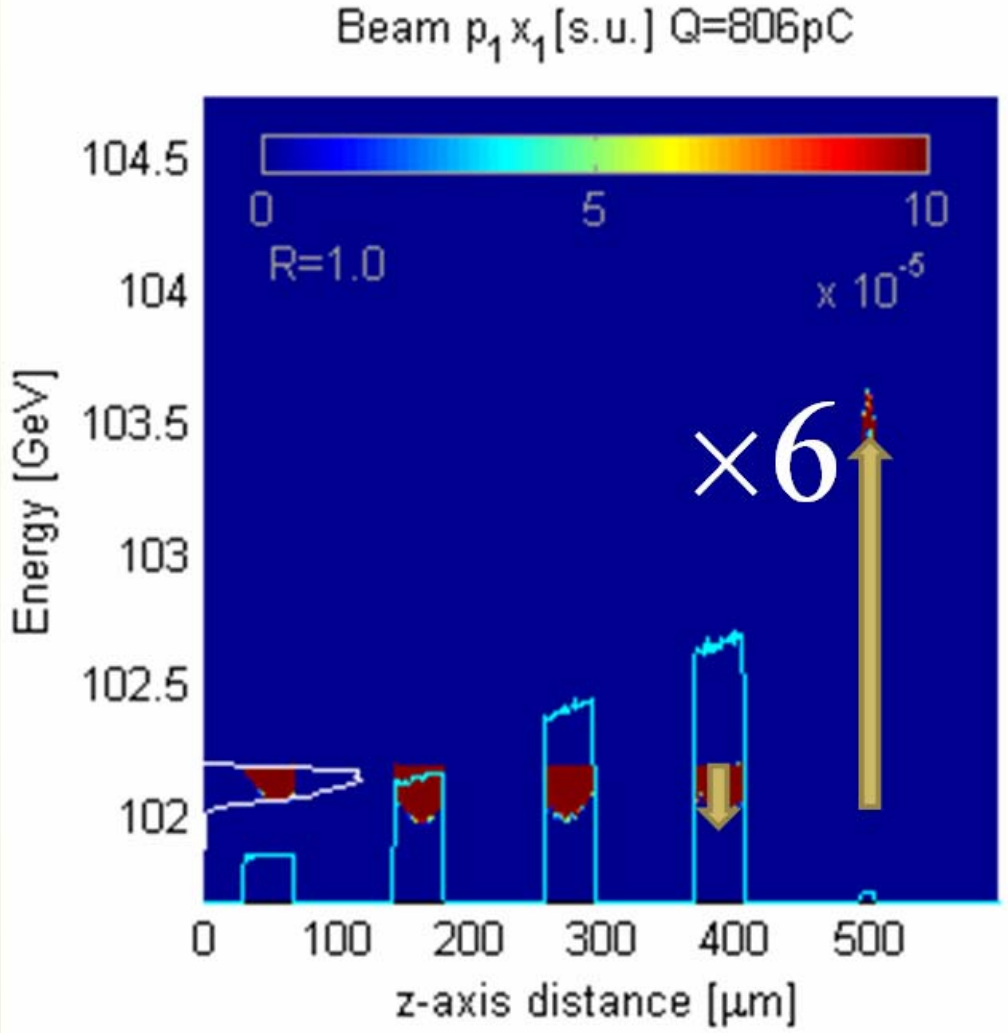

$E_z(0)$, n_p=2.0e+017cm^{-3}, L=0.11cm
R=7.0
Wakefield Amplitude [GV/m]
On-axis Plasma Density [s.u.]
$n_b(0)$
beam
wake
z-axis distance [μm]

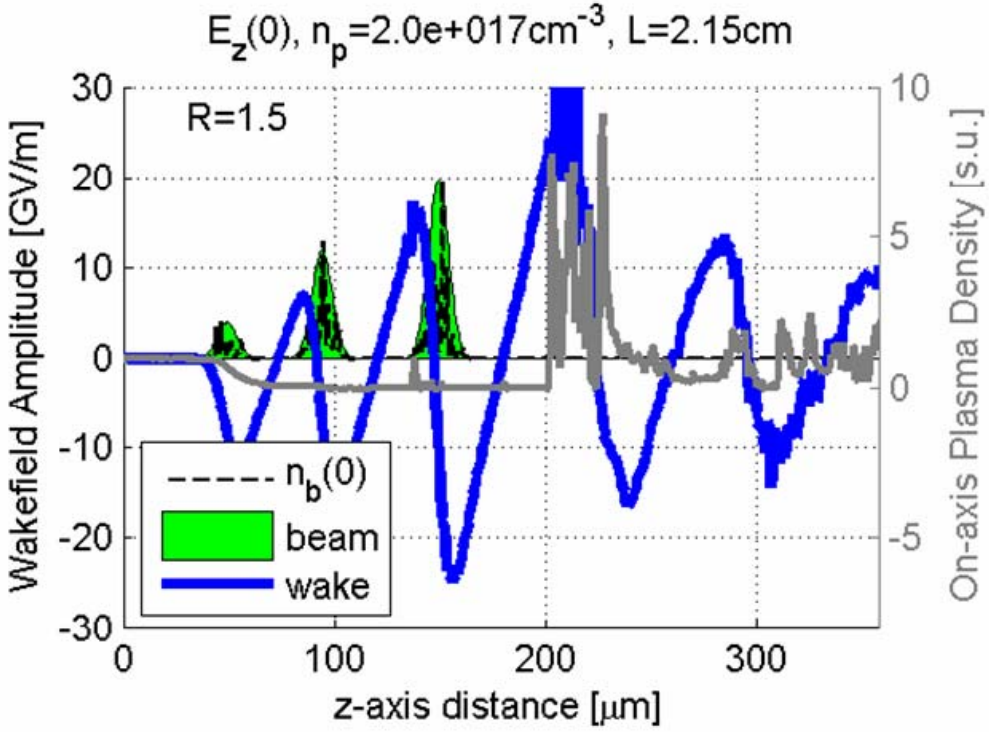

Beam p_1 x_1 [s.u.] Q=970pC
R=1.0
x 10^{-5}
Energy [GeV]
z-axis distance [μm]

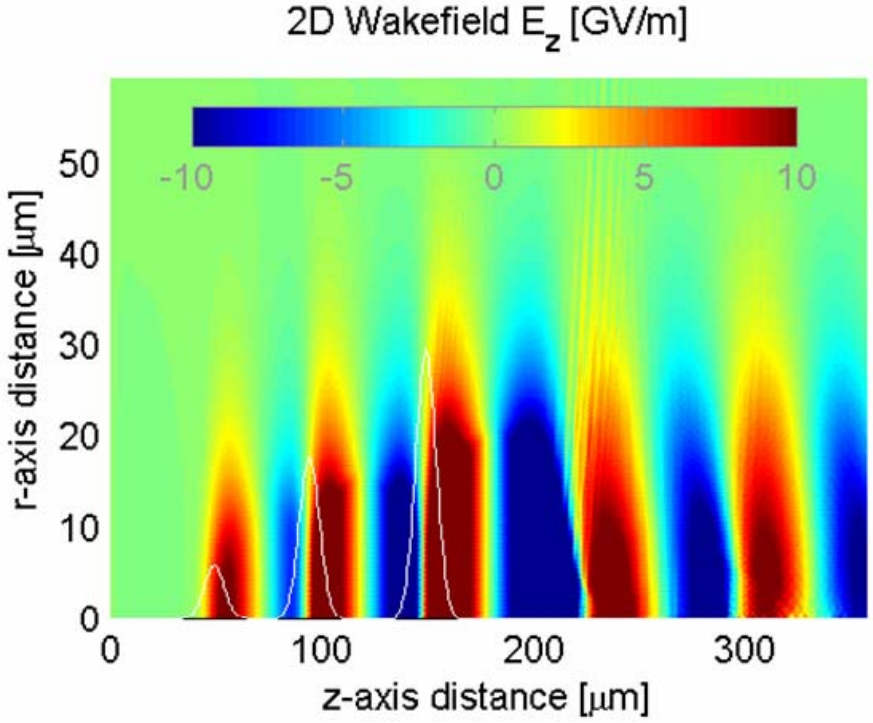

$E_z(0)$, n_p=2.0e+017cm^{-3}, L=14.32cm
R=5.3
Wakefield Amplitude [GV/m]
z-axis distance [μm]
$n_b(0)$
beam
wake

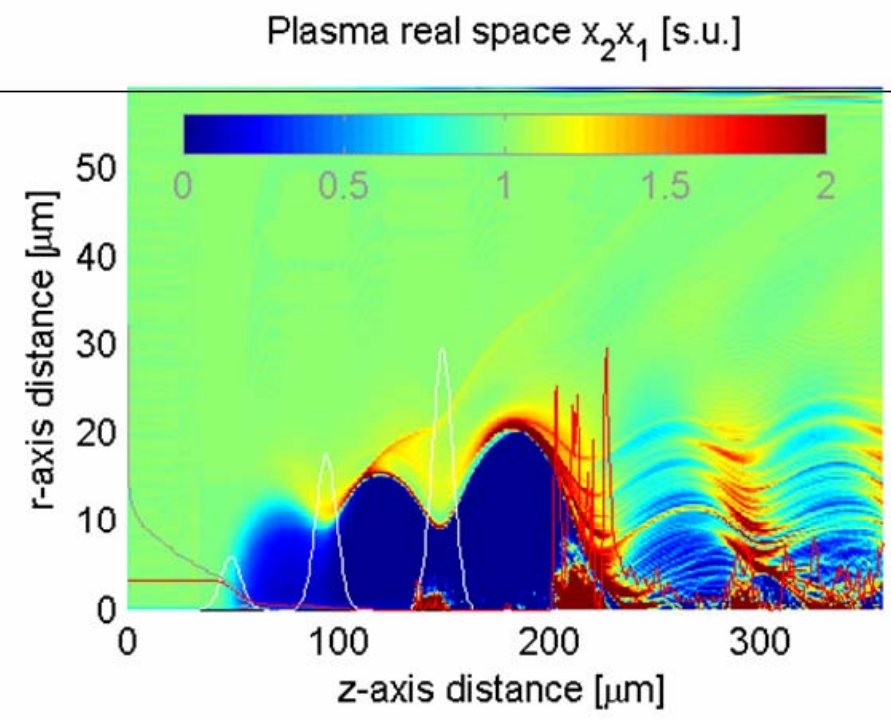

Beam p_1 x_1 [s.u.] Q=806pC
R=1.0
x 10^{-5}
Energy [GeV]
z-axis distance [μm]

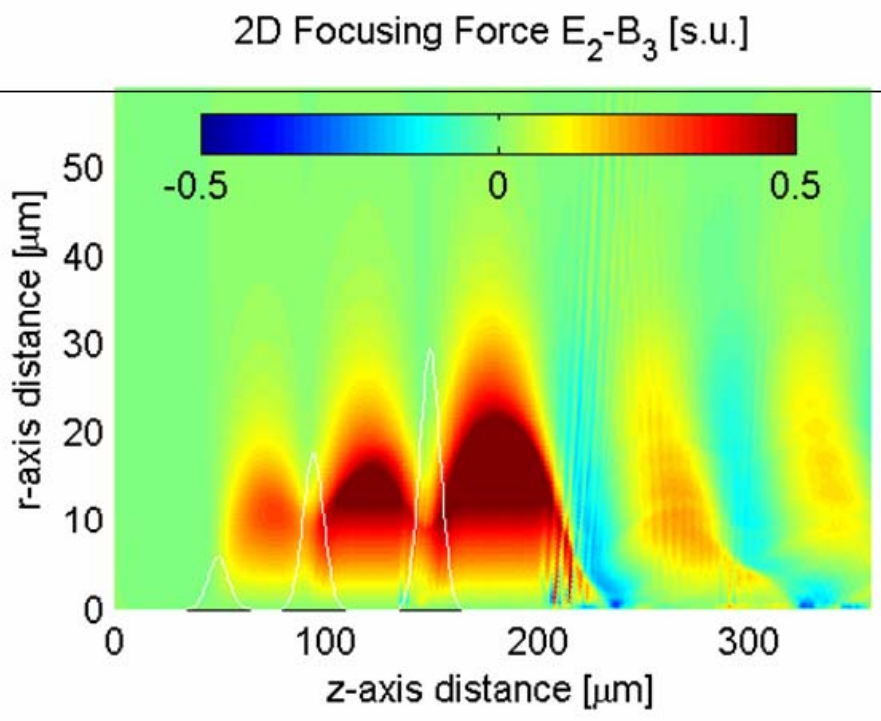

$E_z(0)$, n_p=2.0e+017cm^{-3}, L=14.32cm
R=5.3
Wakefield Amplitude [GV/m]
z-axis distance [μm]
$n_b(0)$
beam
wake


Beam p_1 x_1 [s.u.] Q=806pC
R=1.0
x 10^{-5}
×6
Energy [GeV]
z-axis distance [μm]


$E_z(0)$, n_p=2.0e+017cm^{-3}, L=2.15cm
R=1.5
$n_b(0)$
beam
wake
Wakefield Amplitude [GV/m]
On-axis Plasma Density [s.u.]
z-axis distance [μm]

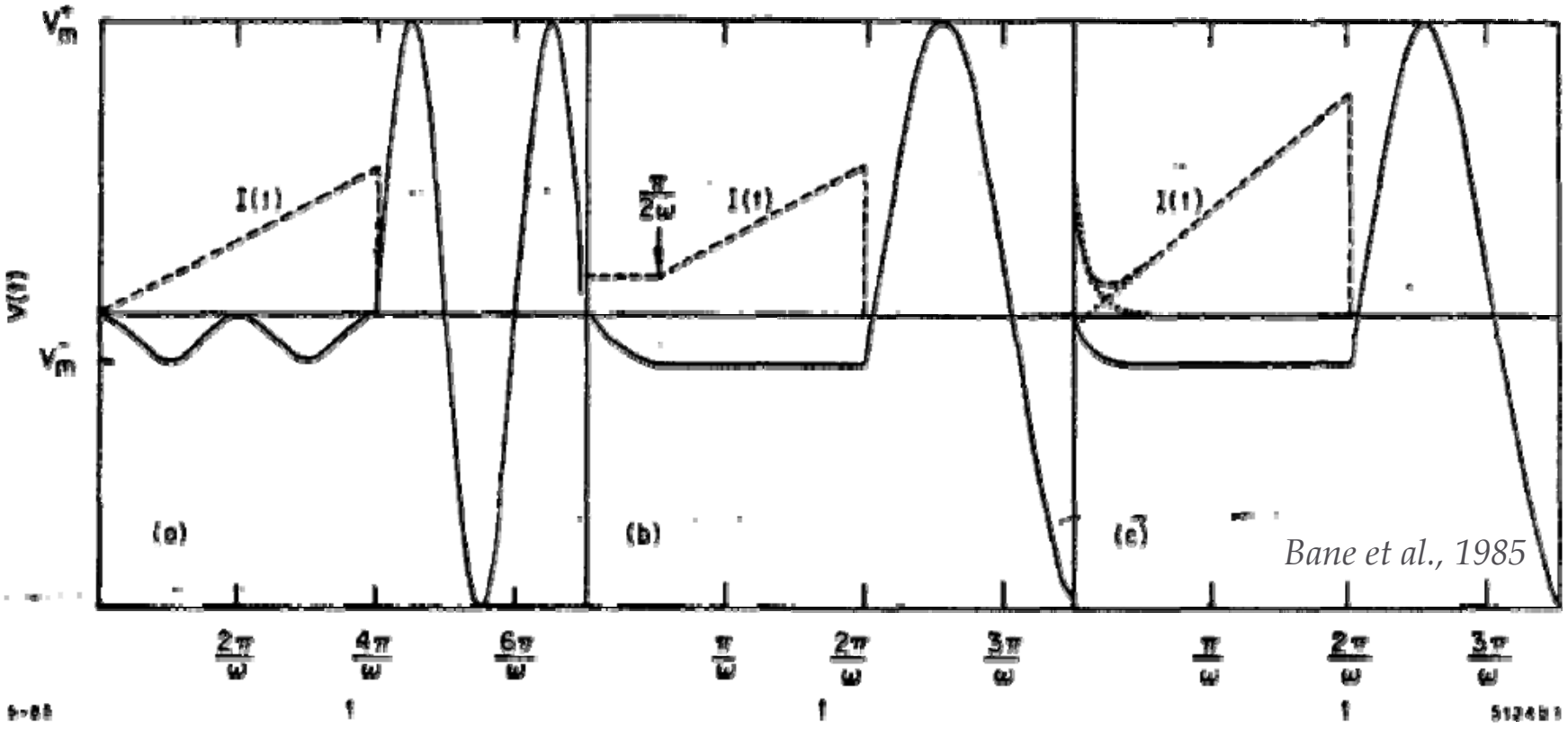

2D Wakefield E_z [GV/m]
r-axis distance [μm]
z-axis distance [μm]


Plasma real space x_2x_1 [s.u.]
r-axis distance [μm]
z-axis distance [μm]


2D Focusing Force E_2-B_3 [s.u.]
r-axis distance [μm]
z-axis distance [μm]

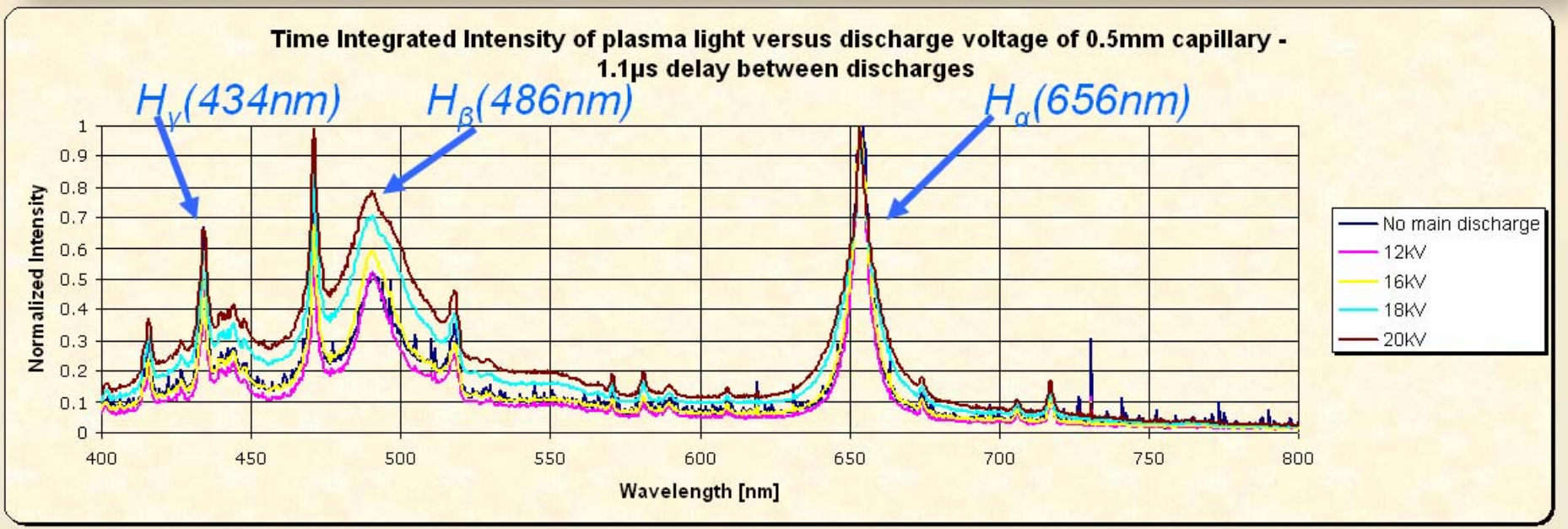
Ramped Distributions

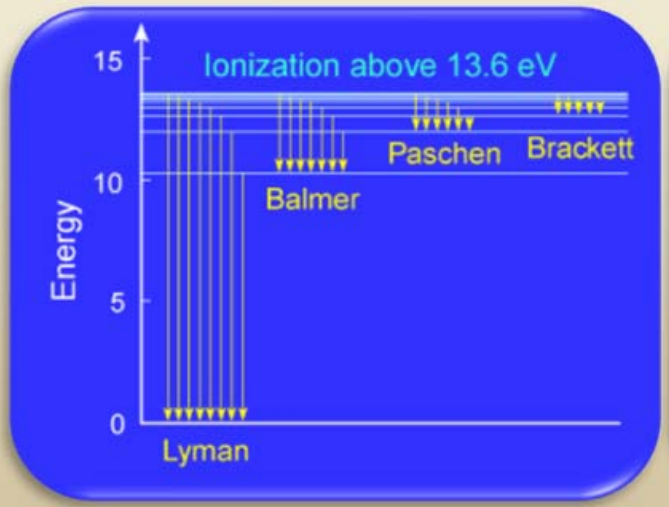
Transformer Ratio >2

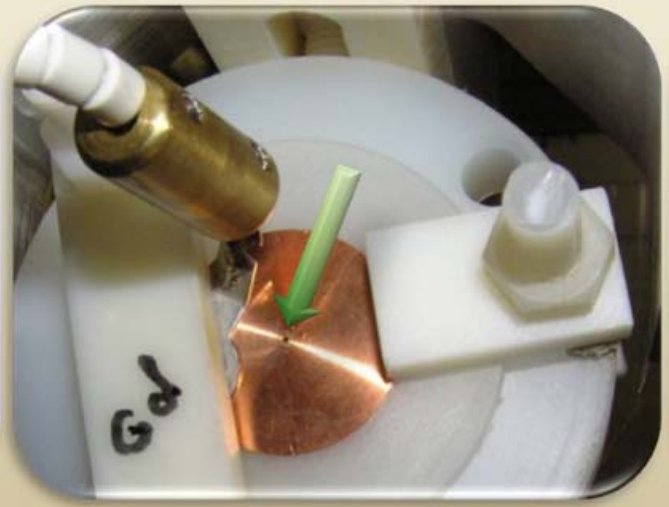


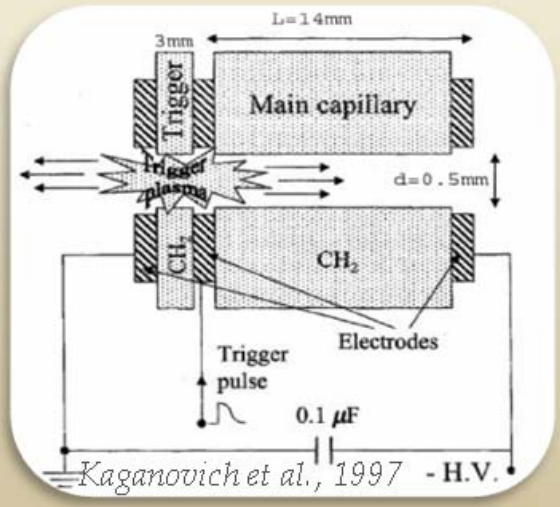
- The transformer ratio is 2π-times proportional to the number of plasma wavelengths under the beam
- Not trivial to create these beams!

The Plasma Source
and Stark Broadening

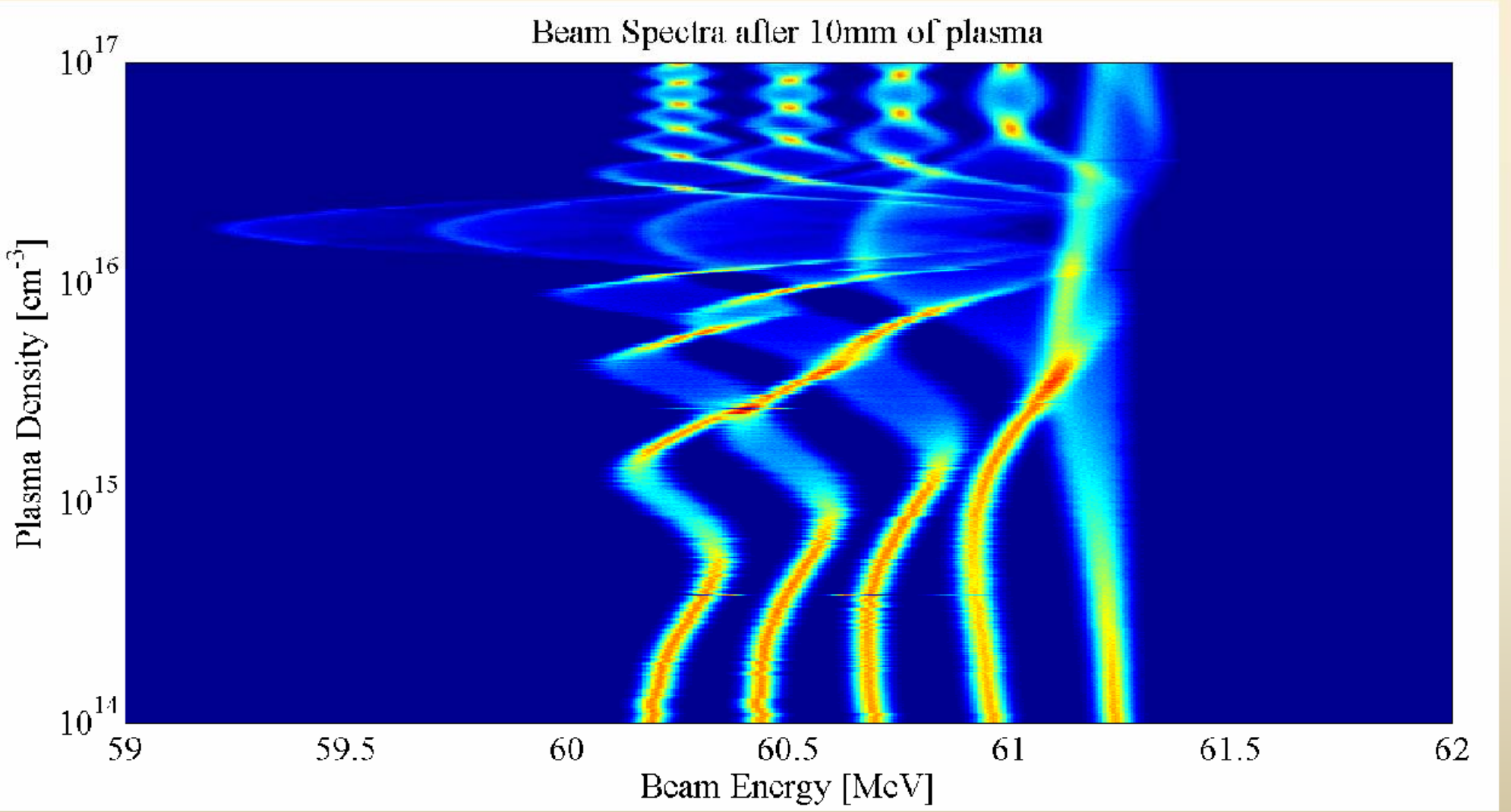




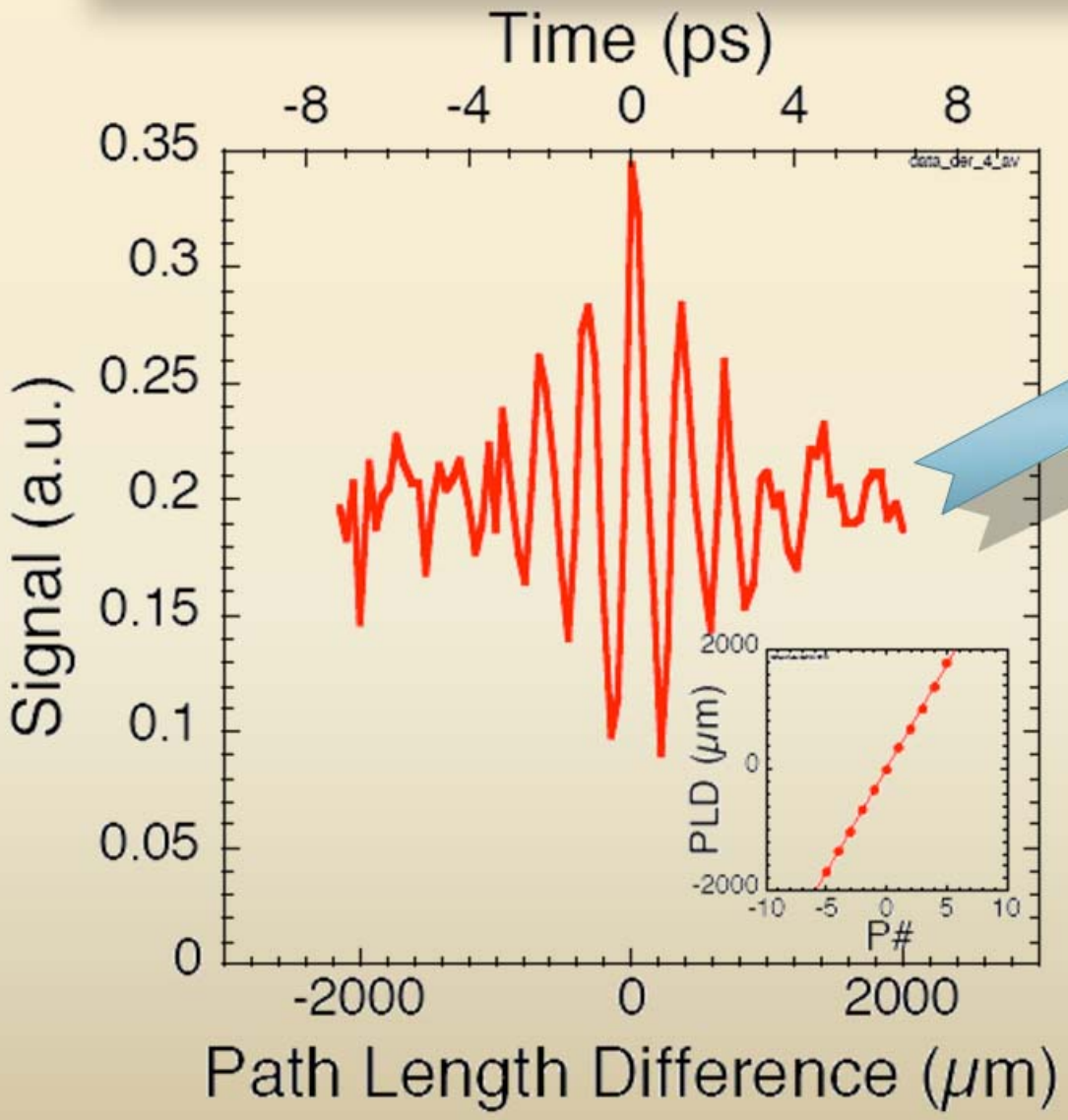


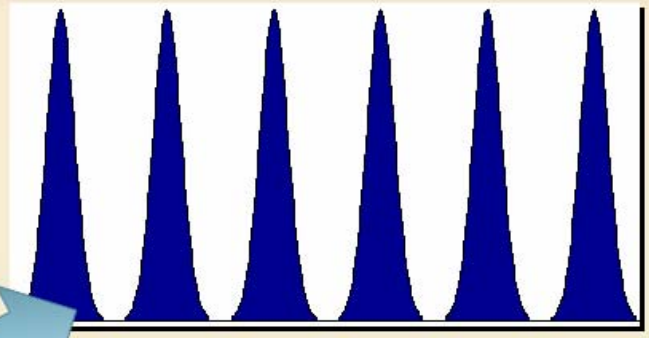


Energy Shifts
predicted, vs. Plasma Density



Diagnosing the microbunches





- 150 – 400 μm period
- 200 pC total charge

P. Muggli et al., Phys. Rev. Lett. 2008