

PROSPECTS OF PLASMA ACCELERATION @ DESY

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Plasma accelerators allow for extreme electric fields

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Laser Electron Accelerator

T. Tajima and J. M. Dawson

Department of Physics, University of California, Los Angeles, California 90024

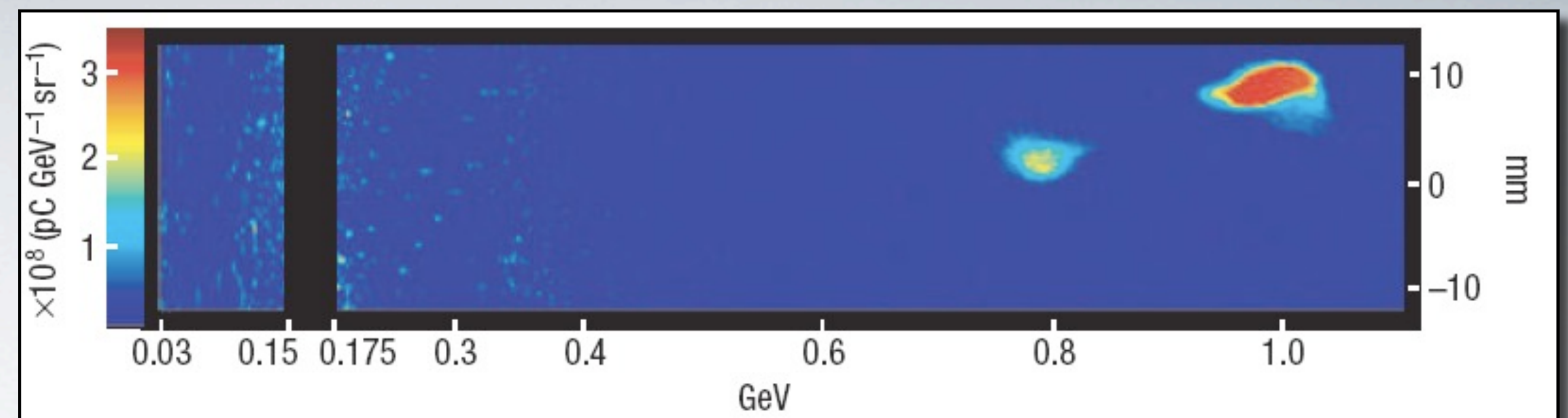
(Received 9 March 1979)

An intense electromagnetic pulse can create a wave of plasma oscillations through the action of the nonlinear ponderomotive force. Electrons trapped in the wake can be accelerated to high energy. Existing glass lasers of power density 10^{18} W/cm^2 shone on plasmas of densities 10^{18} cm^{-3} can yield gigaelectronvolts of electron energy per centimeter of acceleration distance. This acceleration mechanism is demonstrated through computer simulation. Applications to accelerators and pulsers are examined.

40 TW laser pulse ($3 \times 10^{18} \text{ W/cm}^2$)
inside plasma with $n_e = 4.3 \times 10^{18} \text{ cm}^{-3}$

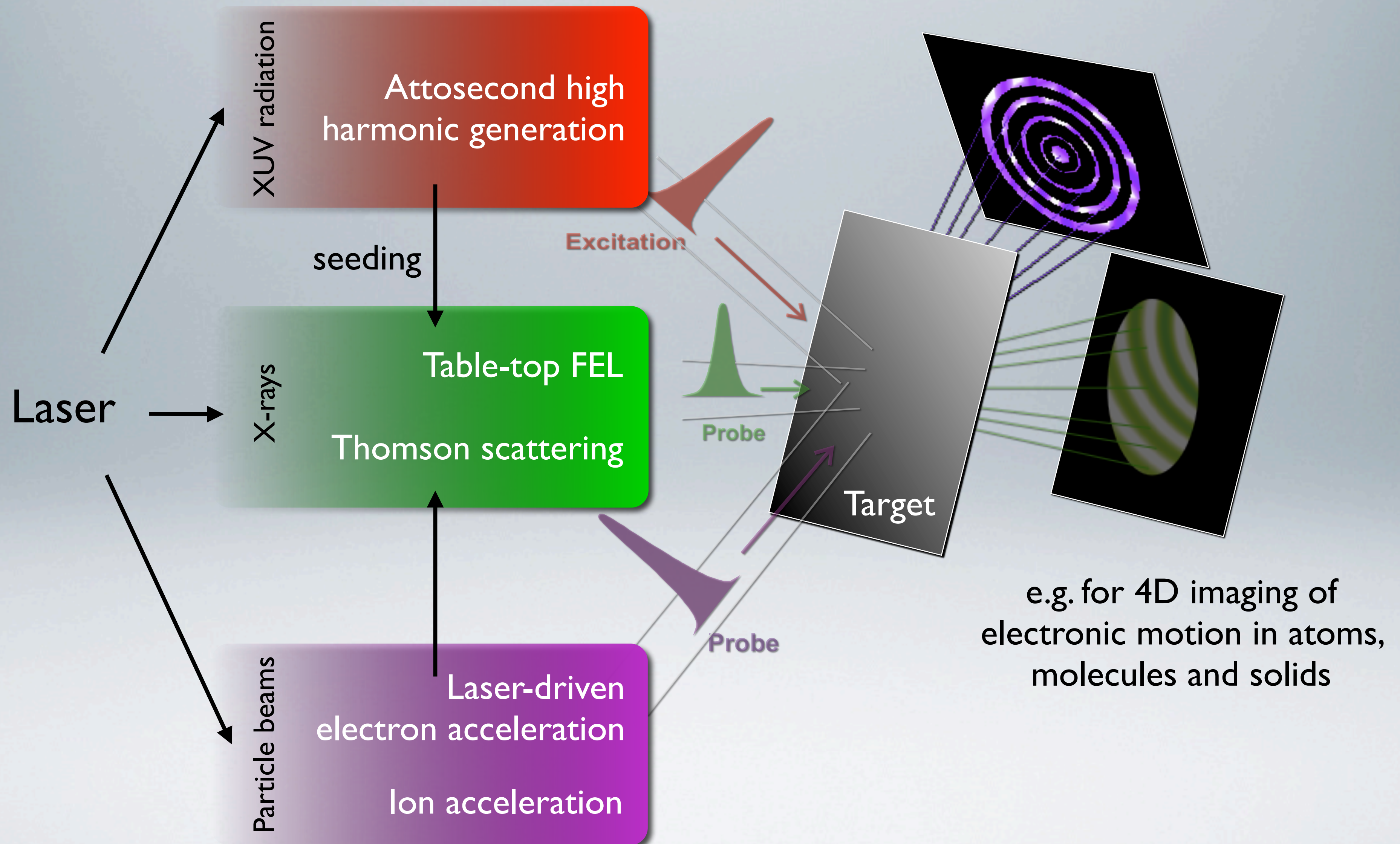
→ 30 pC of electrons at 1 GeV

accelerated over a distance $< 3 \text{ cm}$
(with $> 33 \text{ GV/m}$ fields)



Leemans et al., Nature Physics 2, 696 (2006)

Lasers provide sub-femtosecond synchronization



Plasma acceleration is a two-step process

I. Wake excitation



Plasma acceleration is a two-step process

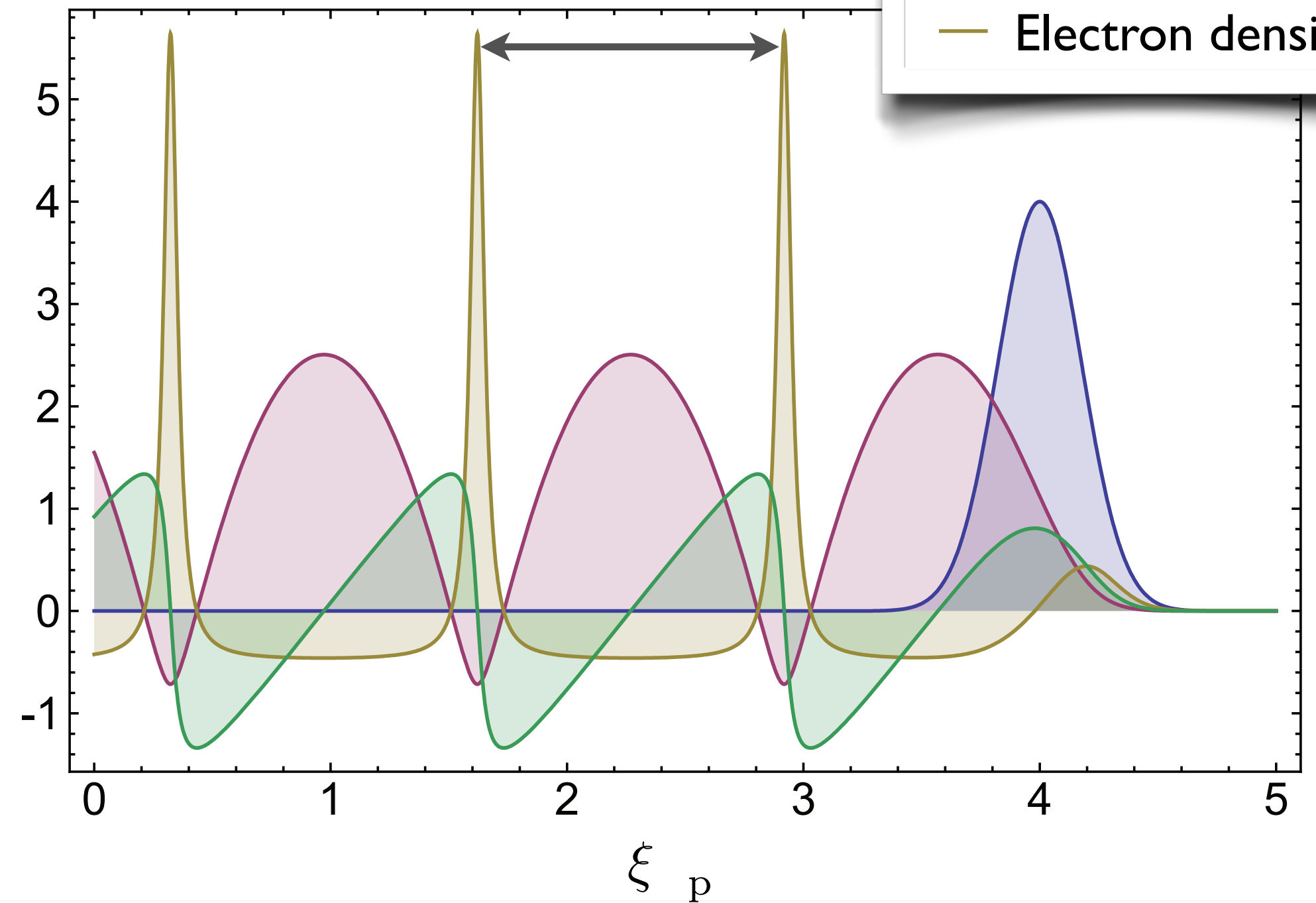
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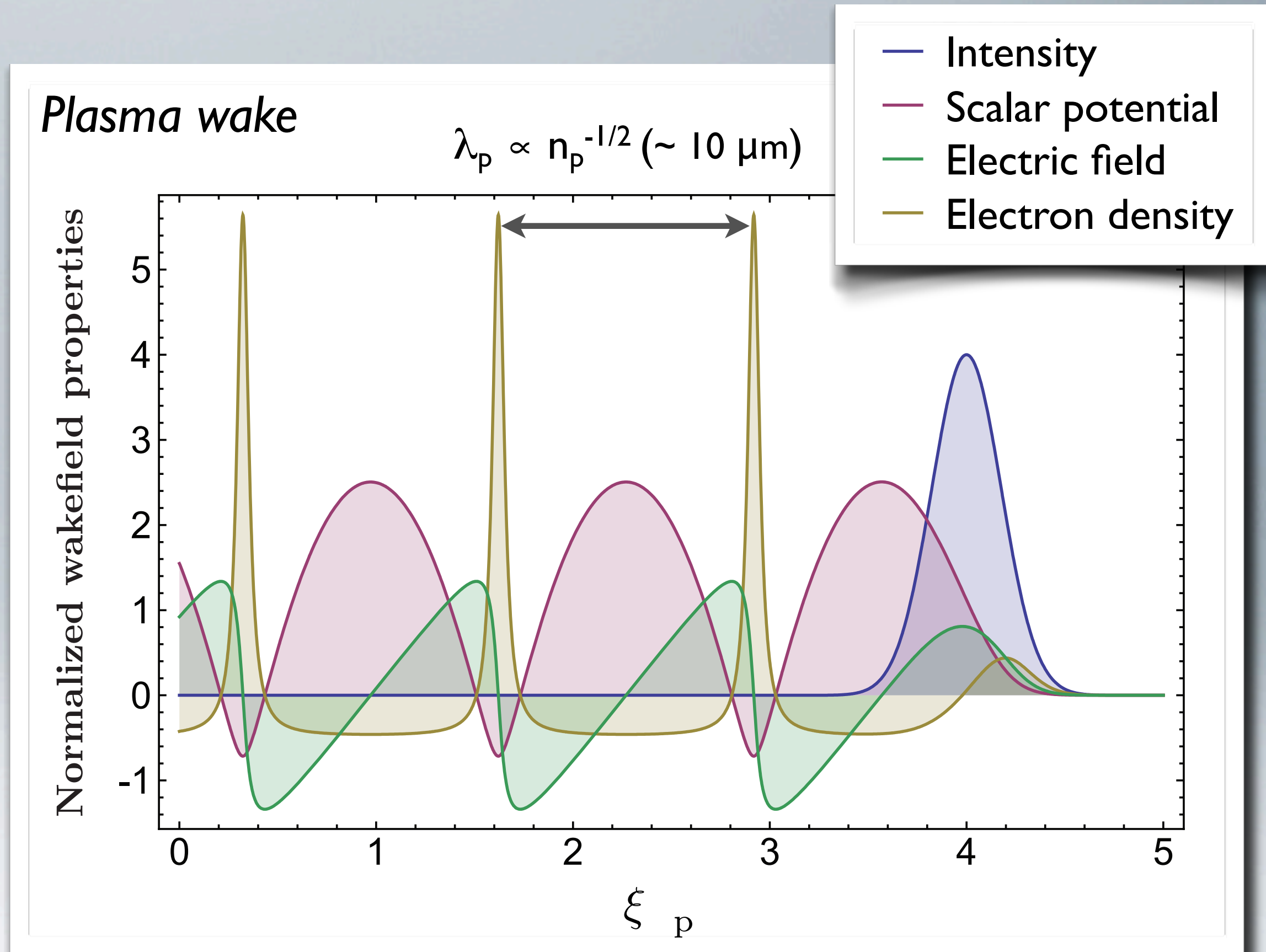
Plasma wake

$$\lambda_p \propto n_p^{-1/2} (\sim 10 \mu\text{m})$$

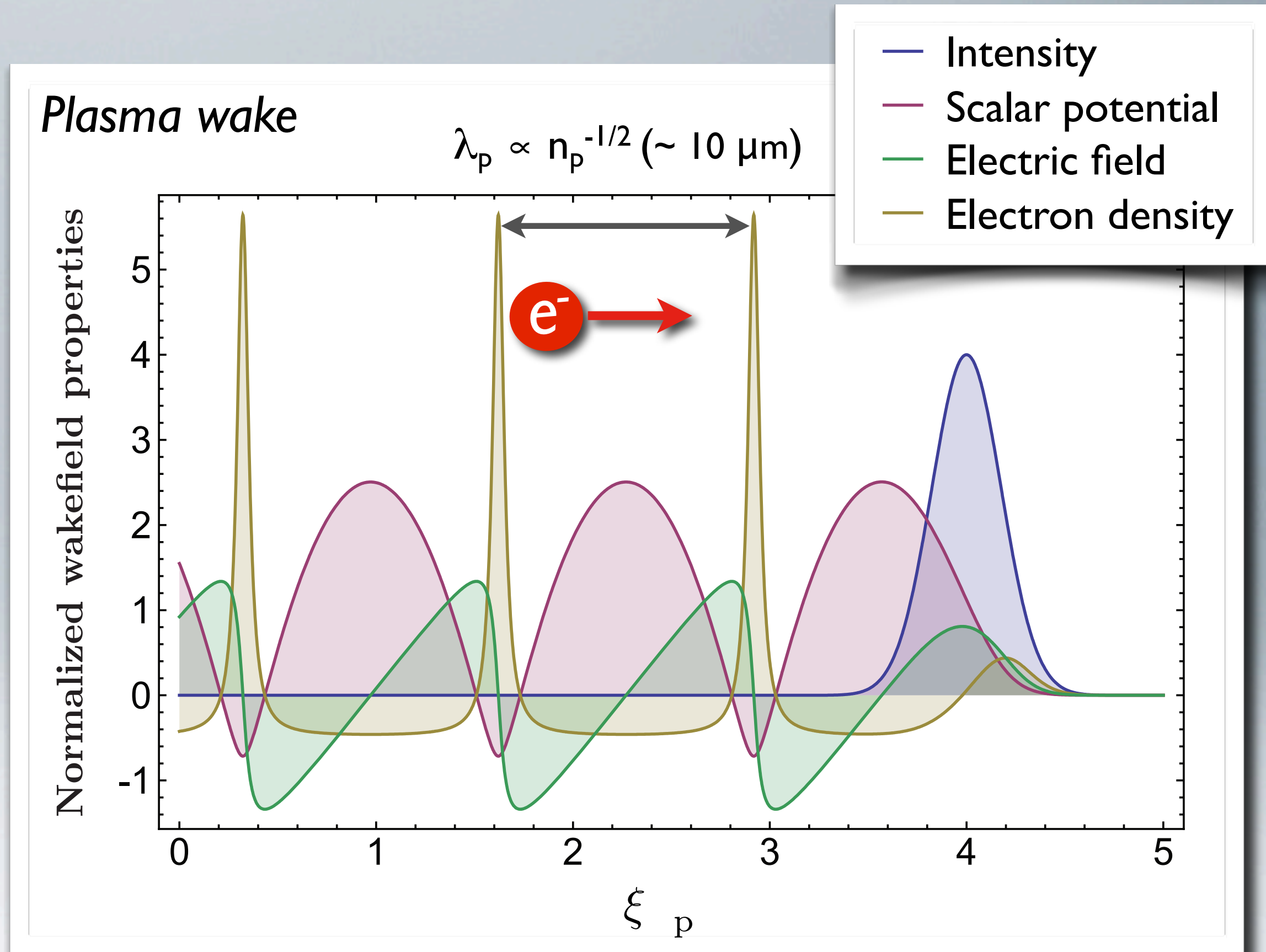
Normalized wakefield properties



Plasma acceleration is a two-step process



Plasma acceleration is a two-step process



A typical example of self-injection → hard to control

Laser pulse properties

$$a = 2$$

$$\lambda_c = 800 \text{ nm}$$

$$\Delta\tau = 25 \text{ fs FWHM}$$

$$w_0 = 23 \text{ }\mu\text{m FWHM}$$

Plasma background density

$$n_p \leq 5 \times 10^{18} \text{ cm}^{-3}$$

Runtime: ~14 days on 512 CPUs

→ ~170000 CPU hours

osiris
v2.0



INSTITUTO
SUPERIOR
TÉCNICO



UCLA

3D particle-in-cell (PIC) simulation

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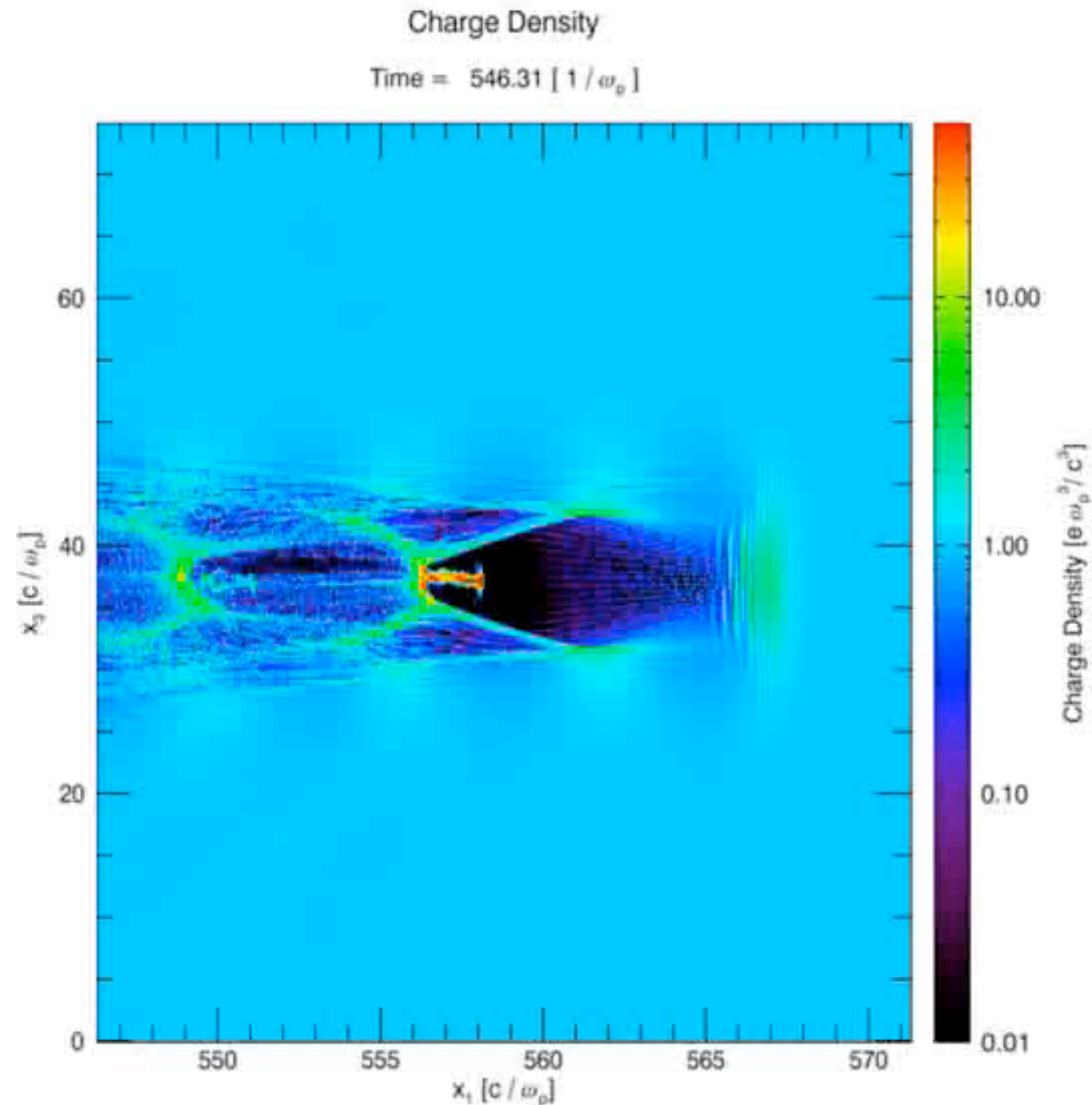
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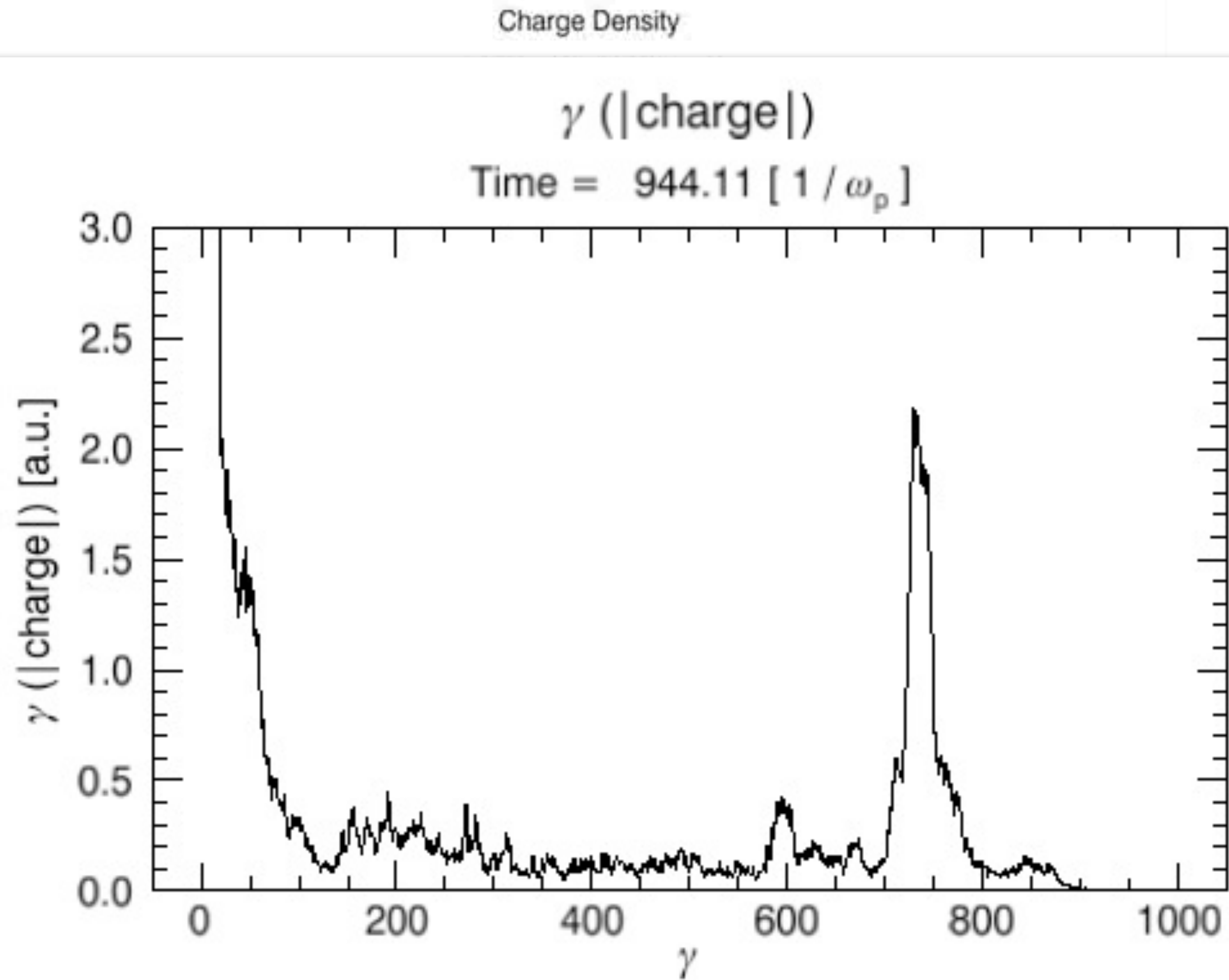
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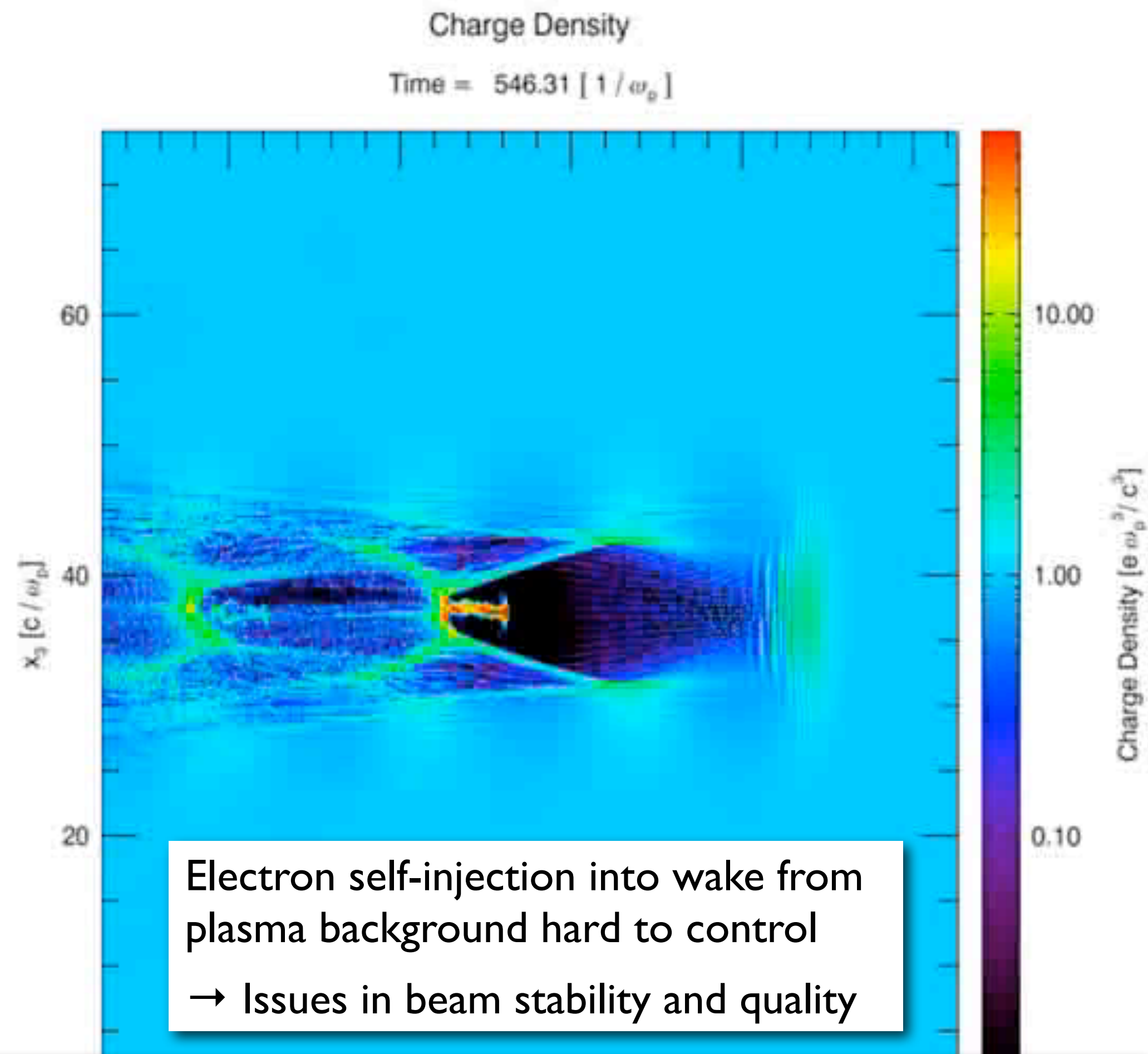
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Why not provide a high quality beam from a conventional source, capture it, and use the plasma accelerator as a booster?

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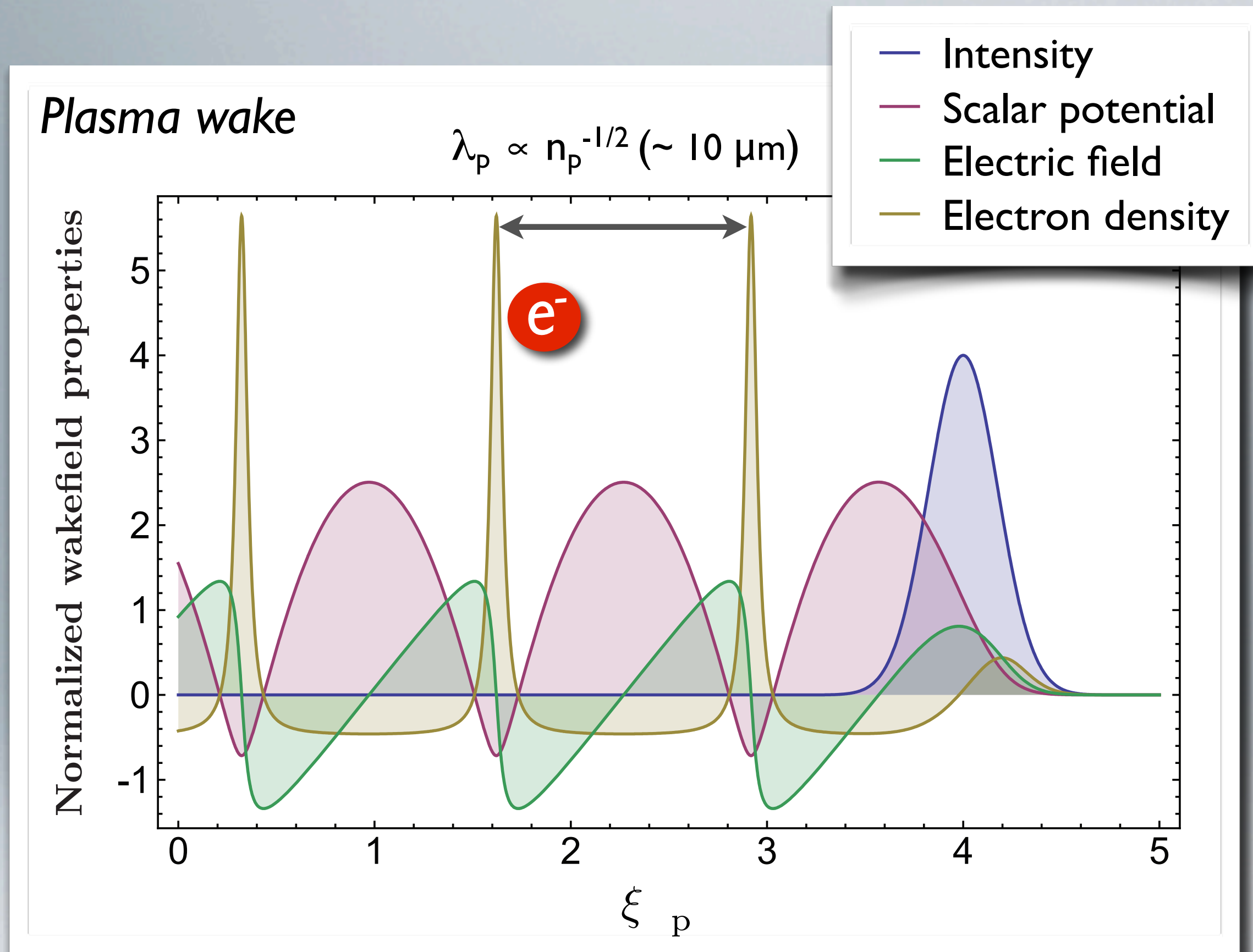
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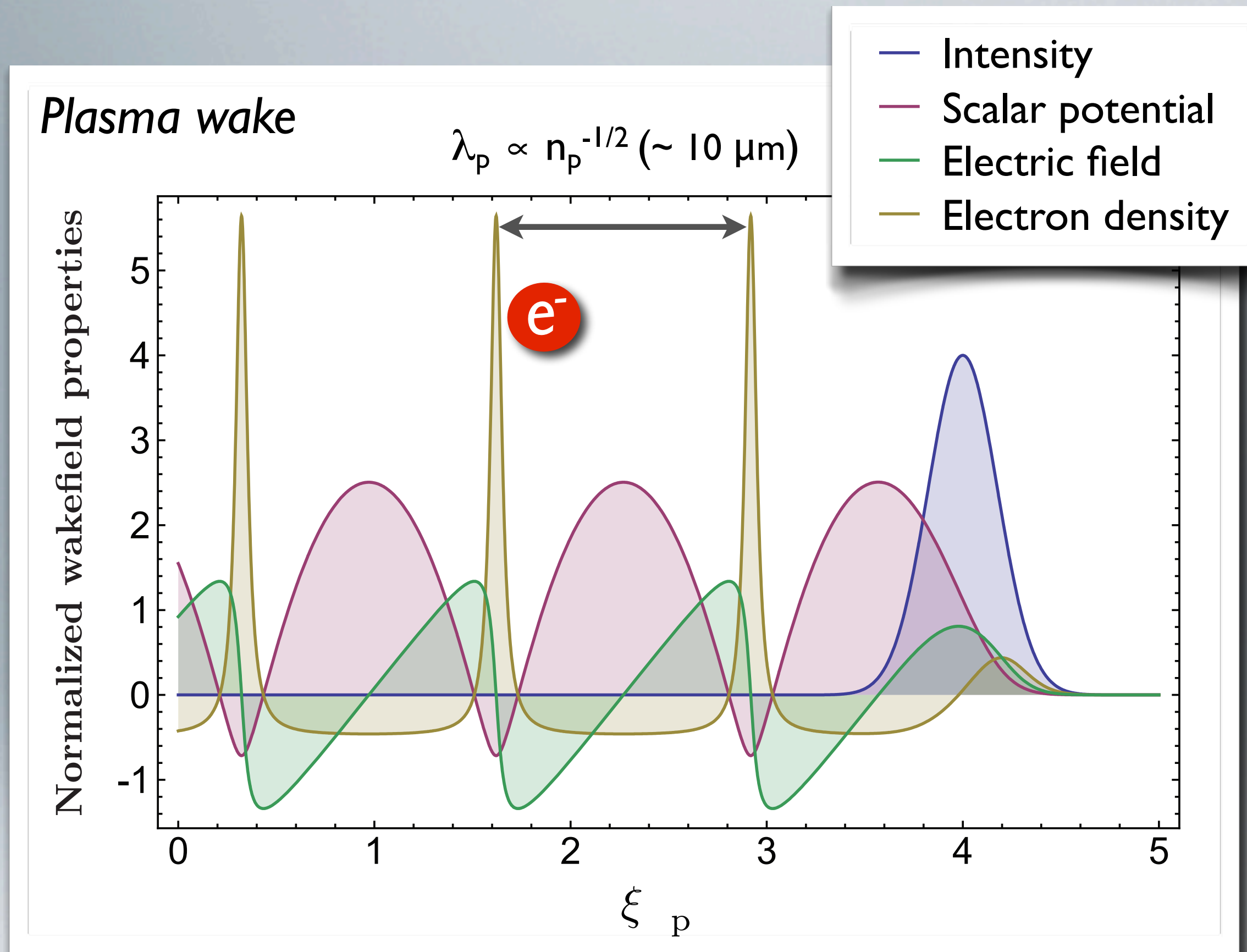
External injection requires short and low-jitter beams



→ Electron bunch length must be a fraction of the plasma wavelength
(the longer the initial electron bunch, the larger the final energy spread)

→ Timing jitter between electron bunch and laser must be a fraction of the inverse plasma frequency
(the larger the jitter, the larger the final energy fluctuations)

External injection requires short and low-jitter beams



*DESY strong in beam-to-laser sync
and short-pulse accelerator design*

- **FLASH at 1.2 GeV**
short bunch operation under investigation, laser synchronized to within 40 fs and improving
- **PITZ at 20 MeV**
short bunch operation with < 40 fs under investigation, laser synchronized
- **REGAE at 5 MeV**
explicitly being built for short bunch operation of ~ 10 fs at low charge, laser synchronized

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Simulations help to find best experimental conditions

Charge density

Laser pulse properties

$$a_0 = 1.7$$

$$\lambda = 800 \text{ nm}$$

$$\tau = 30 \text{ fs FWHM}$$

$$w = 60 \text{ }\mu\text{m FWHM}$$

Plasma background density

$$n = 1 \times 10^{17} \text{ cm}^{-3}$$

Electron beam properties

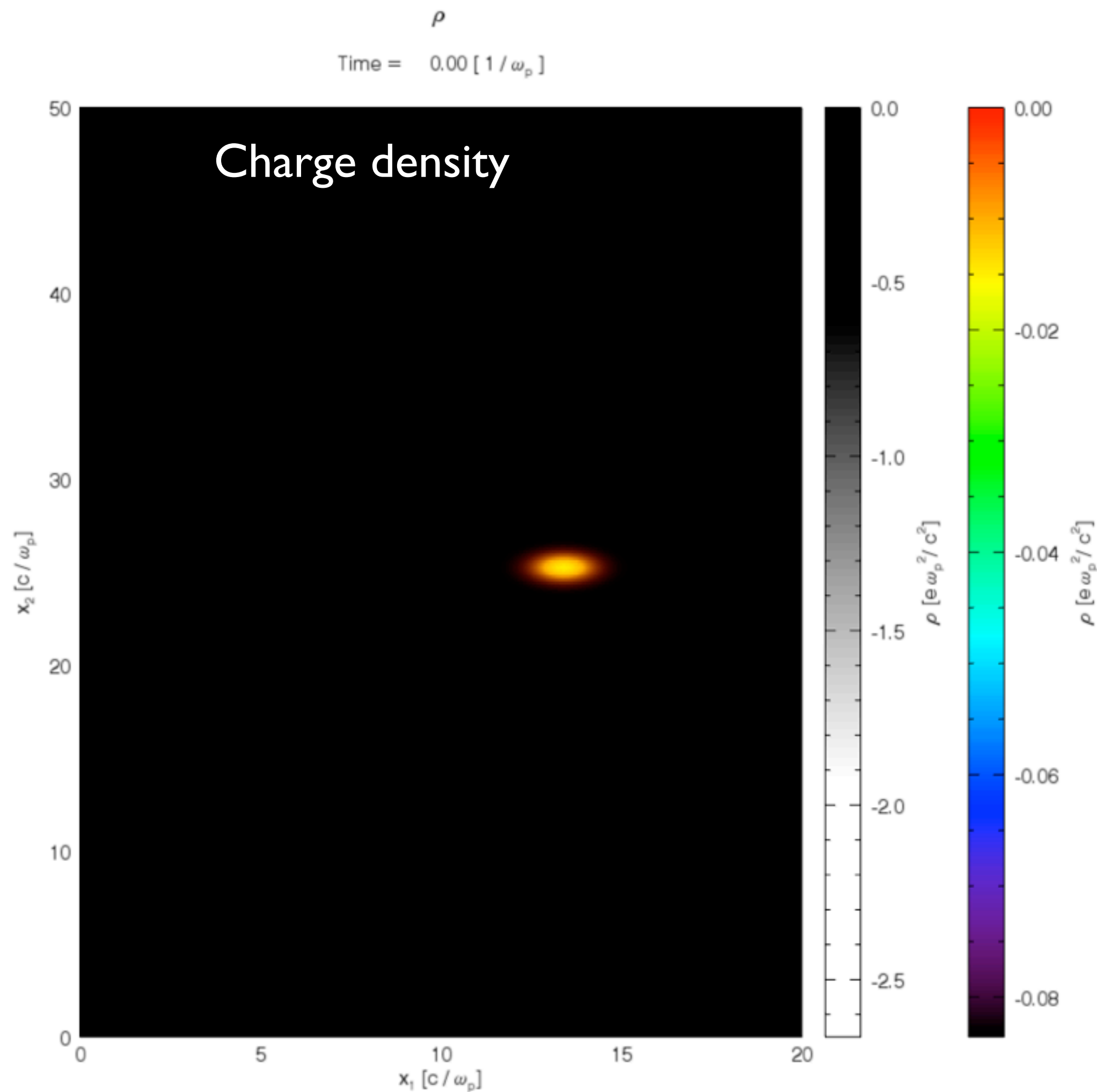
$$\tau = 20 \text{ fs RMS}$$

$$\sigma_{\text{trans}} = 10 \text{ }\mu\text{m}$$

$$Q = 1 \text{ pC}$$

...first 7 mm in 2d space

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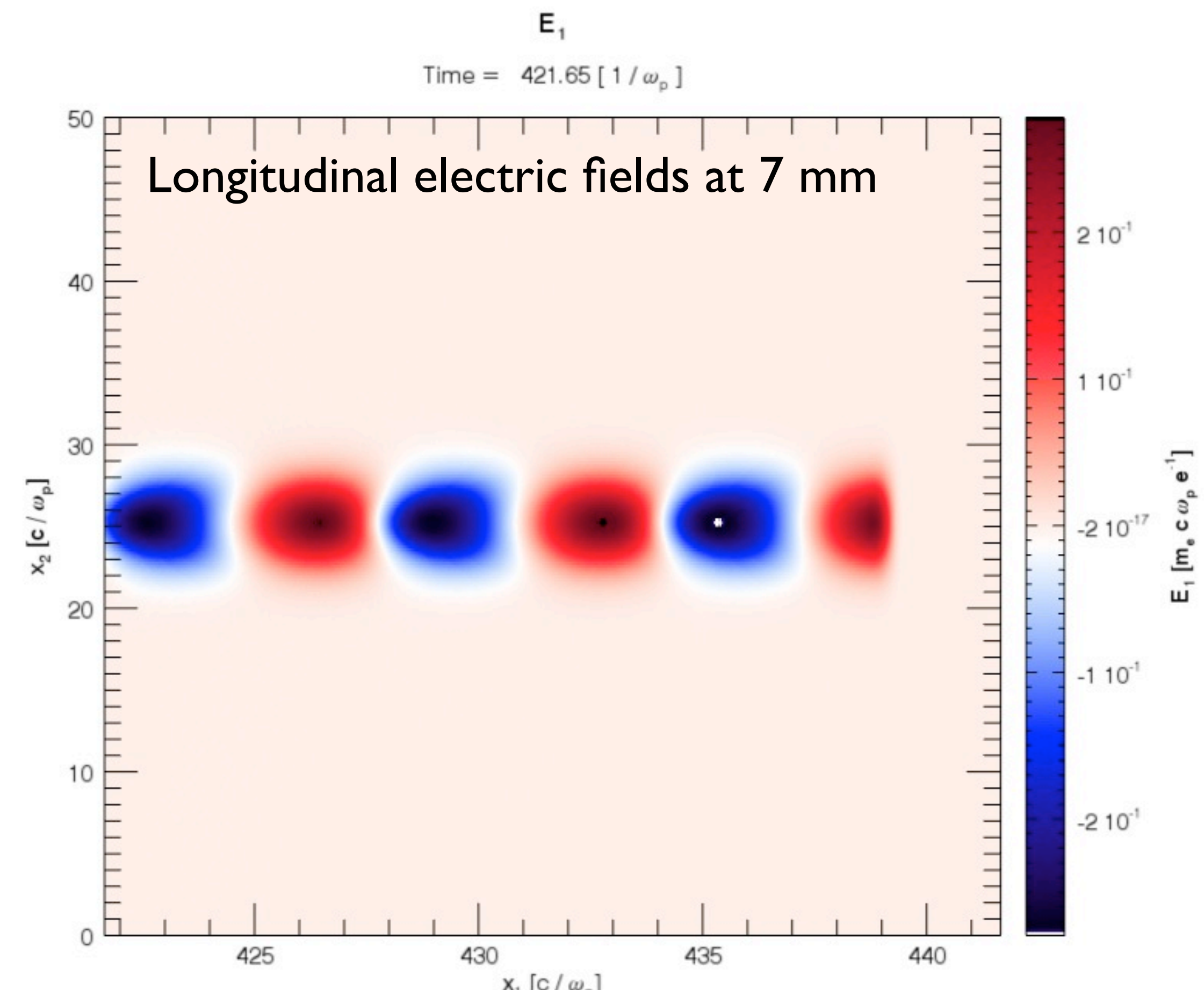
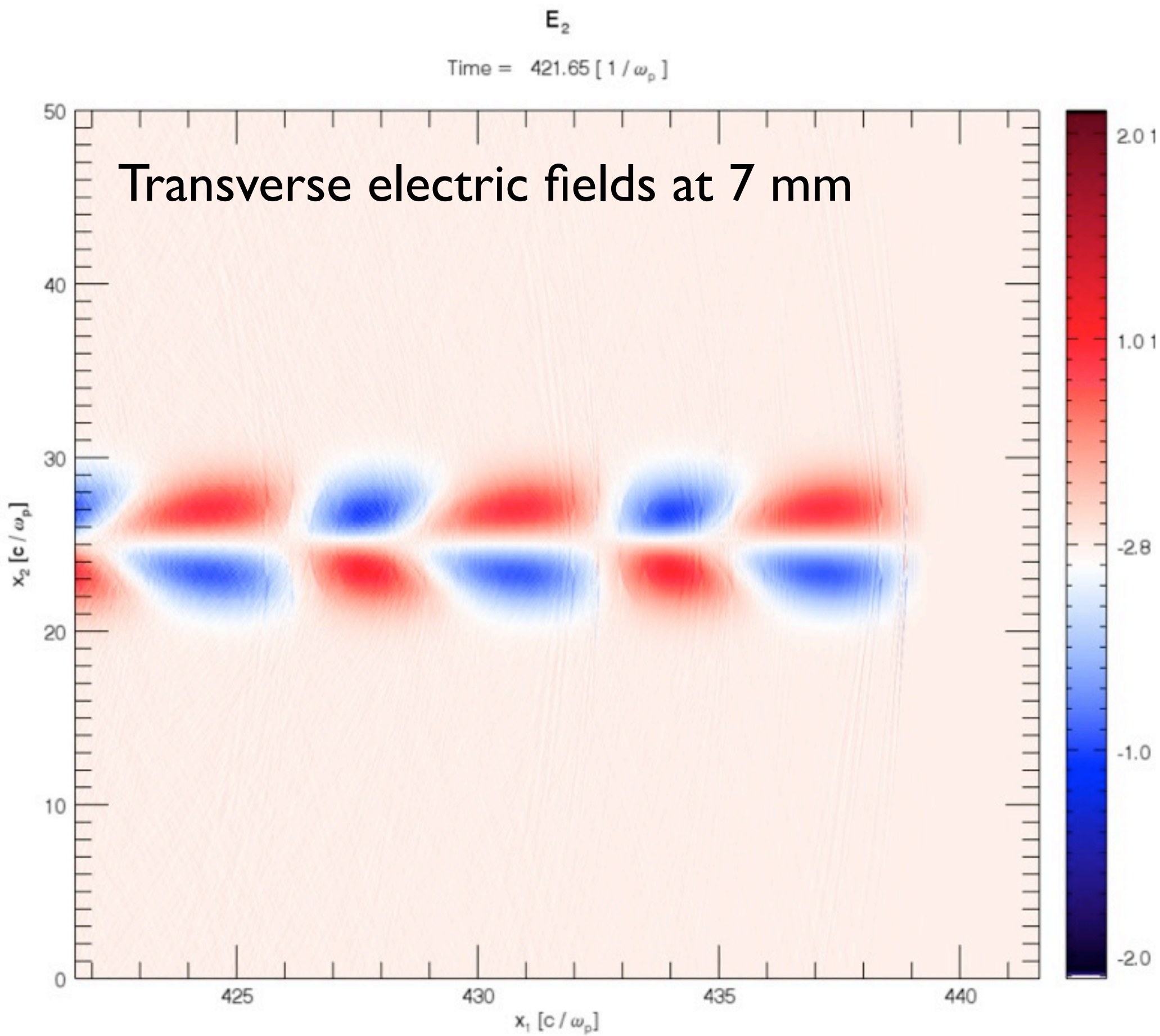
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Electric field normalization: $I \triangleq 30 \text{ GV/m}$

Laser focal plane at 12 mm

Peak Accelerating electric field strength:
$$E \sim \left(\frac{mc\omega_p}{e} \right) \frac{a^2}{(1+a^2/2)} \approx (96\text{V/m}) \sqrt{n_0[\text{cm}^{-3}]} \frac{a^2}{(1+a^2/2)}$$
 $E \approx 20 \text{ GV/m}$ (for $n \approx 1 \cdot 10^{17} \text{ cm}^{-3}$, $a \approx 1$)

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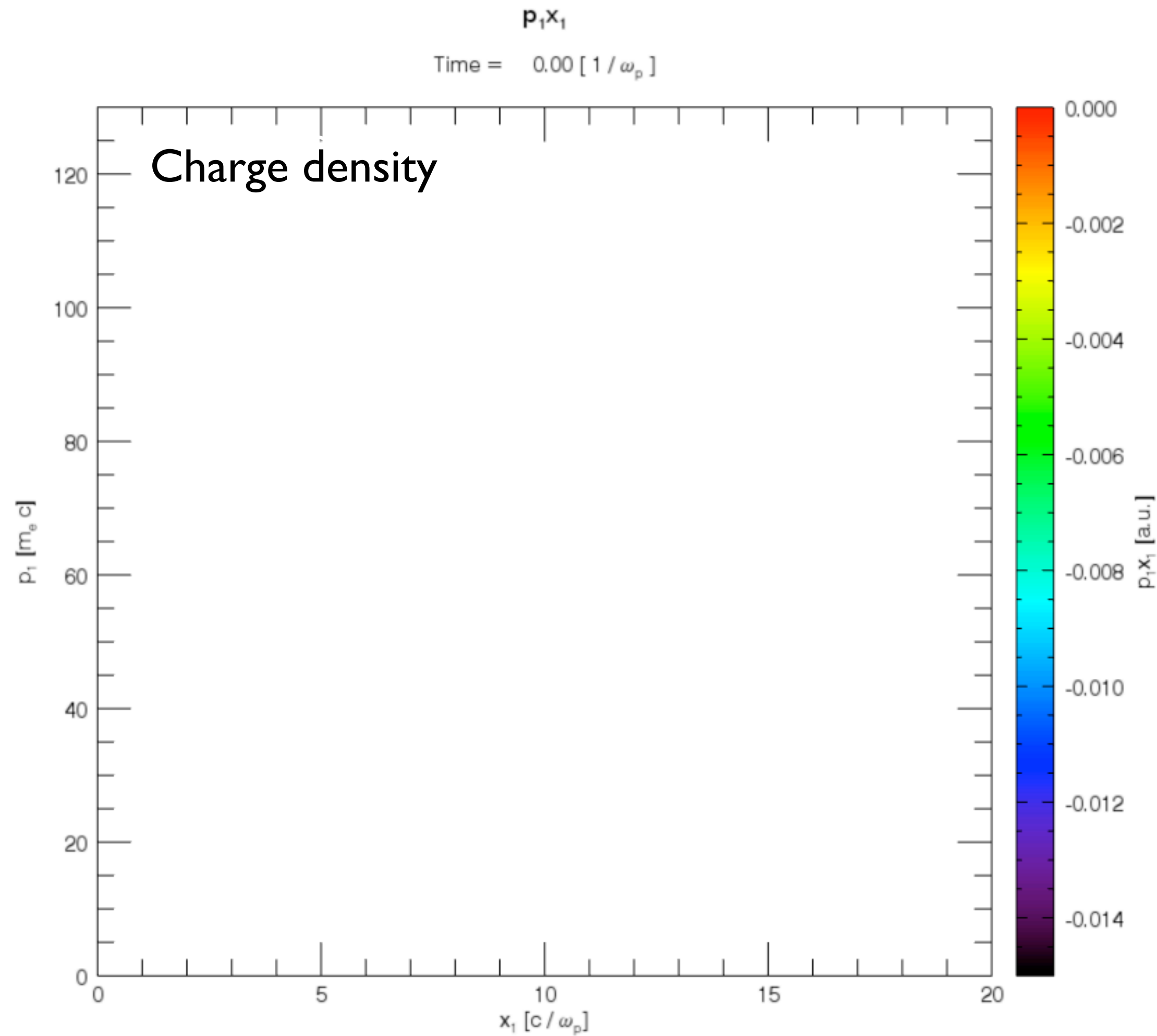
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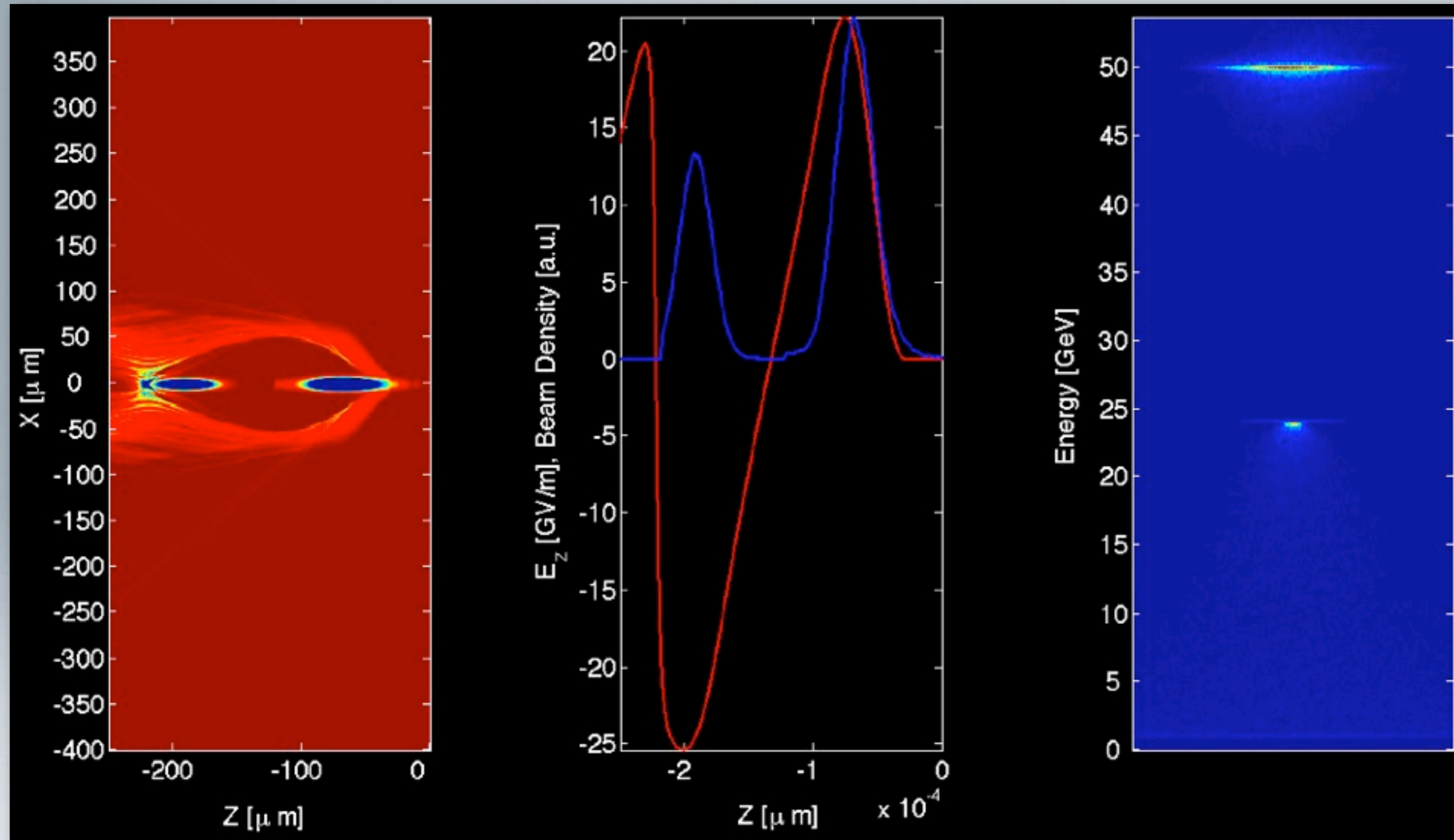
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High luminosity incompatible with today's laser technology

Laser average power and wall-plug efficiency too low for applications requiring high luminosity

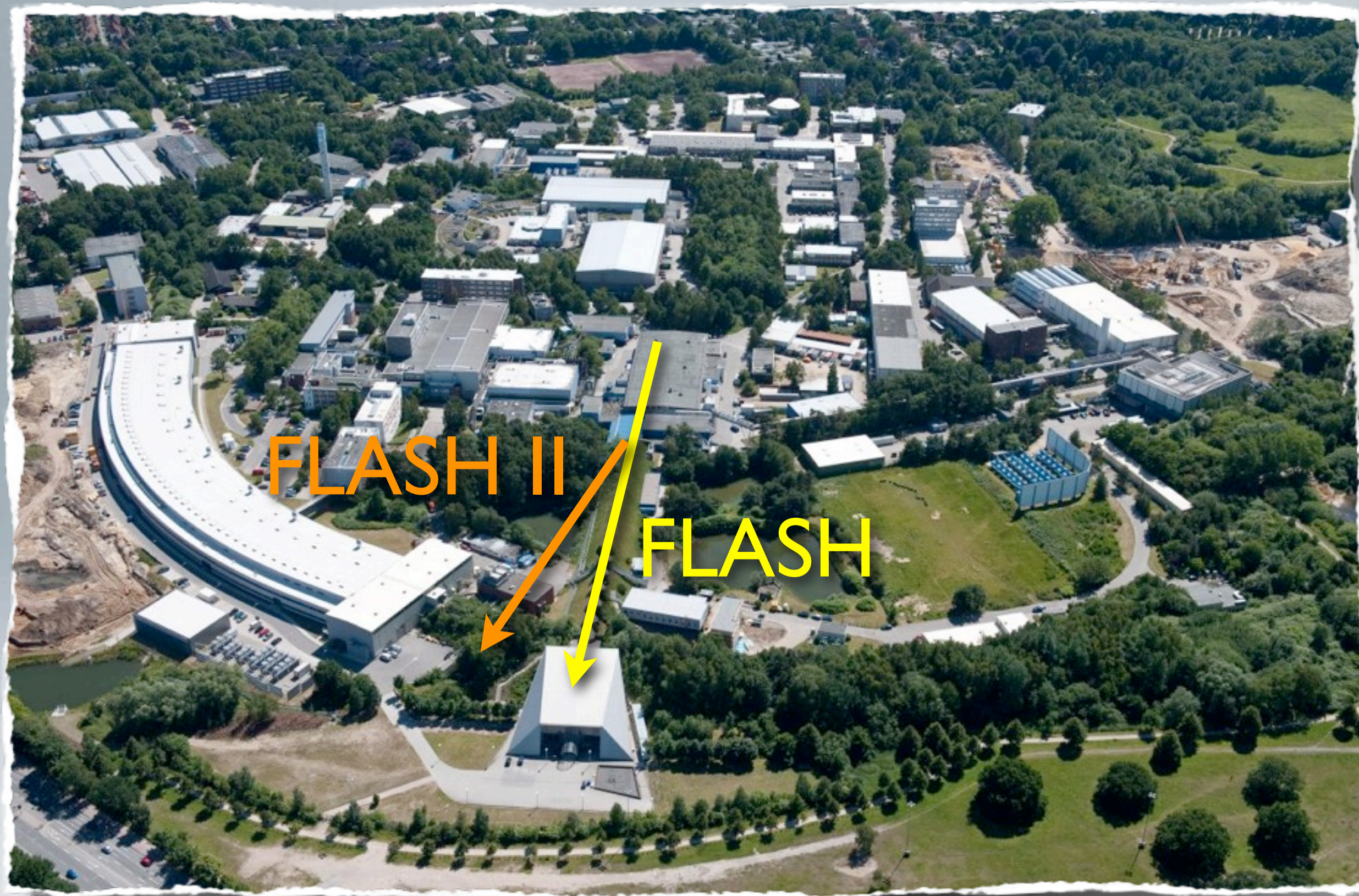


simulations by the
FACET team at SLAC

→ use short, stiff, high average power electron beam to excite plasma wake, second beam to witness energy gain

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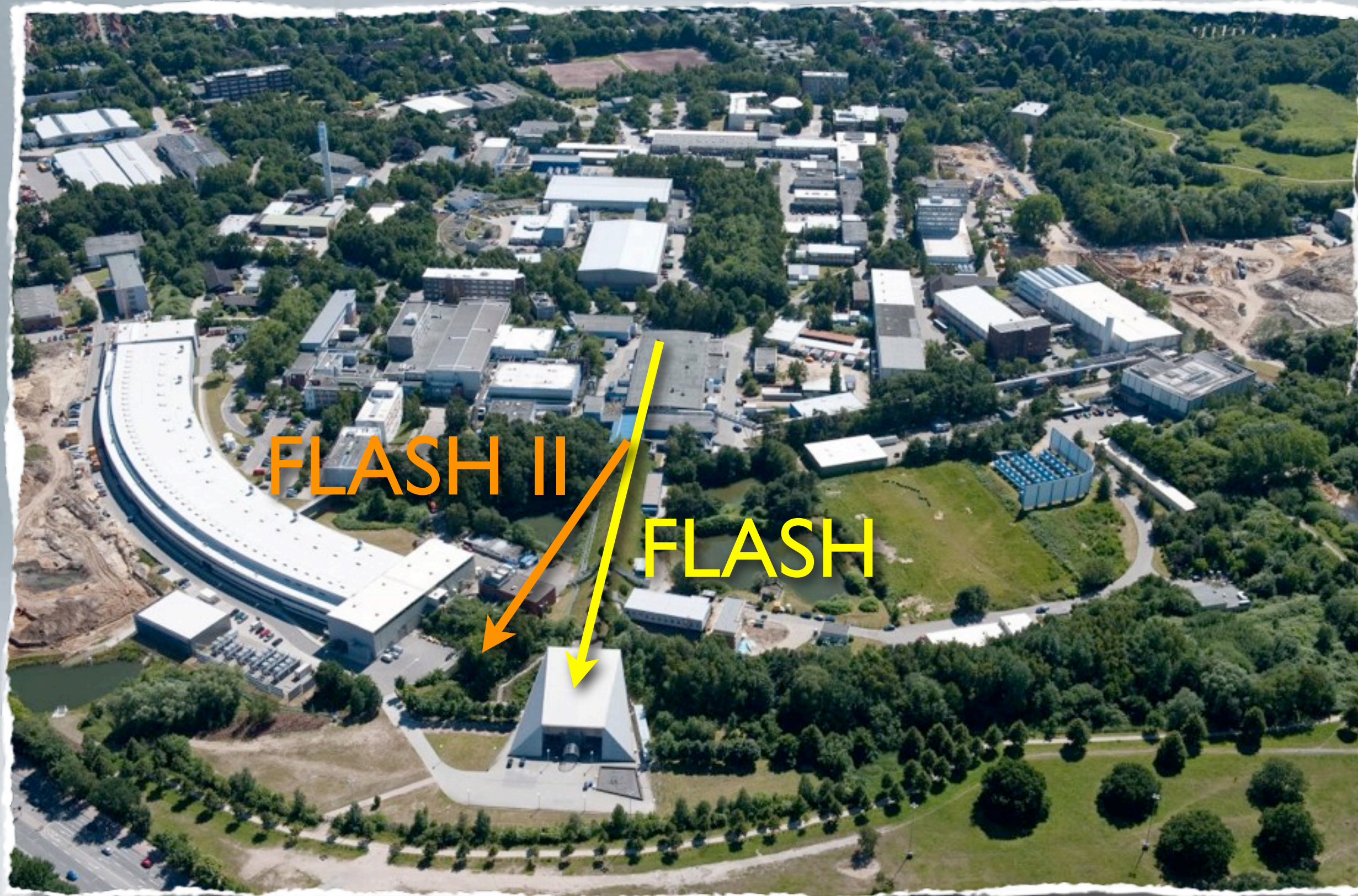


→ FLASH facility ideally suited

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FLASH plasma accelerator project would

- advance plasma accelerator science
- rely on and hence advance
 - short-pulse, low-charge beam operation
 - short-pulse, low-charge beam diagnostics
 - beam shaping capabilities (also interesting for FEL capabilities)

→ use short, stiff, high average power electron beam to excite plasma wake, second beam to witness energy gain

Summary and outlook

DESY efforts have just started to pursue and advance plasma acceleration technology:

- Laser-plasma boosting of conventional, high-quality electron beams
- Standalone laser-plasma acceleration (*not presented here*)
- Electron-beam driven plasma acceleration

Plasma acceleration might allow for > 10 GV/m fields and post-acceleration of pre-generated, high-quality beams from conventional sources and from plasma sources

In order to investigate this further, we have to

- conduct beam dynamics studies to identify realistic source parameters for plasma boosting and beam-driven acceleration
- run PIC simulations to study the desirable laser and plasma parameters for post-acceleration of the available electron beams
- do the experiments!

DESY with know-how in RF-gun, short-pulse accelerator design, beam diagnostics and synchronization is one of few places in the world, where such experiments might be successfully done

Thank you for your attention!