Energy deposited in the plasma by a long drive beam

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Motivation:

- Driver transfers its kinetic energy (K_{driver}) to wake potential and to the **plasma electrons** that gain kinetic energy (K_{plasma})

- Wakefield acceleration → Electrostatic field E
  → longitudinal component → accelerating field $\mathbf{E}_{acc}$
  → transverse component → focusing field E_{foc}

- Conservation of energy

$$K_{driver} + K_{plasma} + \frac{1}{2}\varepsilon_0\left(E_{acc}^2 + E_{foc}^2\right) = const.$$

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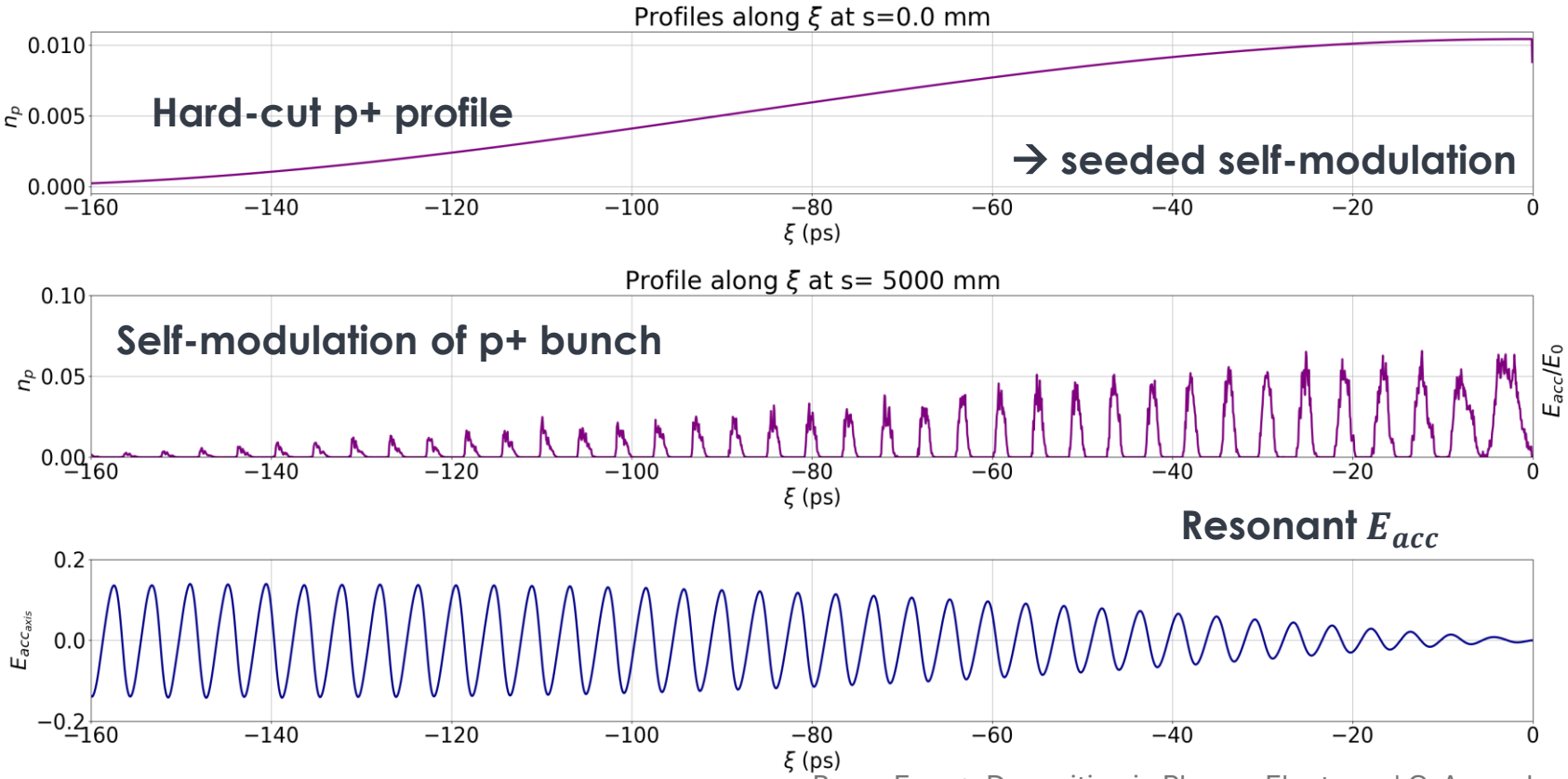
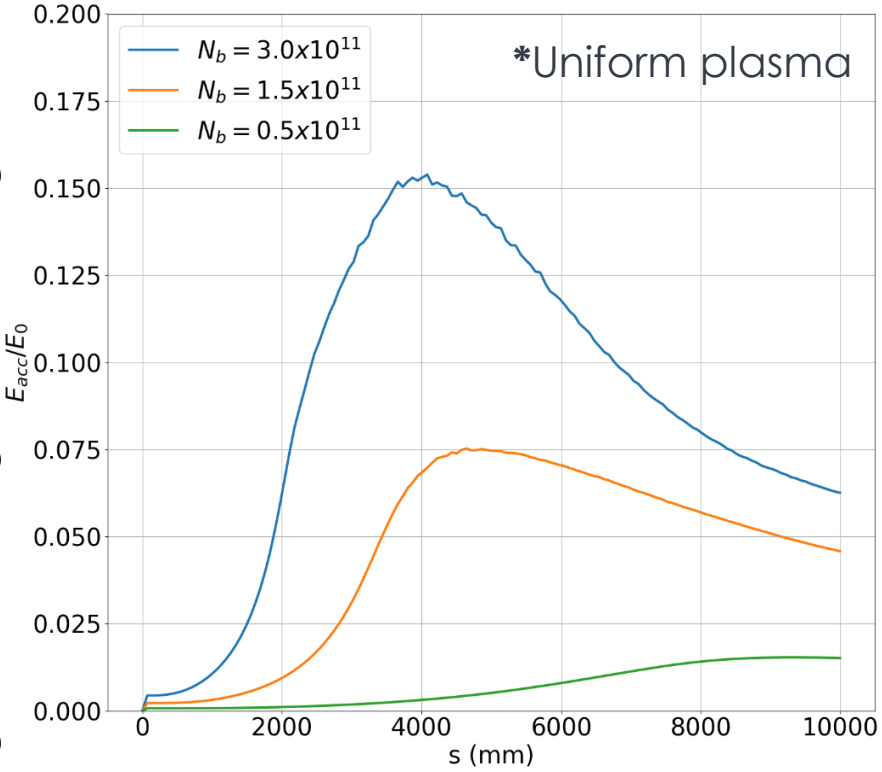
Long driver:

Wakefield grows resonantly along the bunch (ξ)

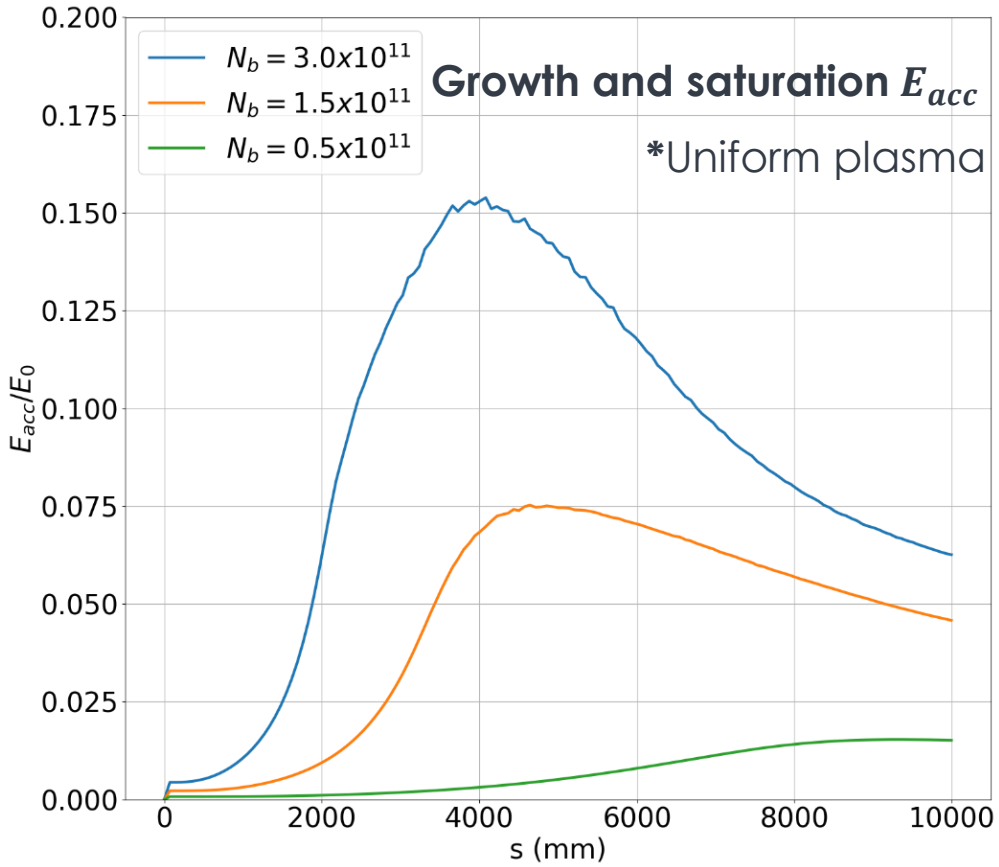
and along the plasma (s), until saturation



Growth and saturation E_{acc}



Key Question:



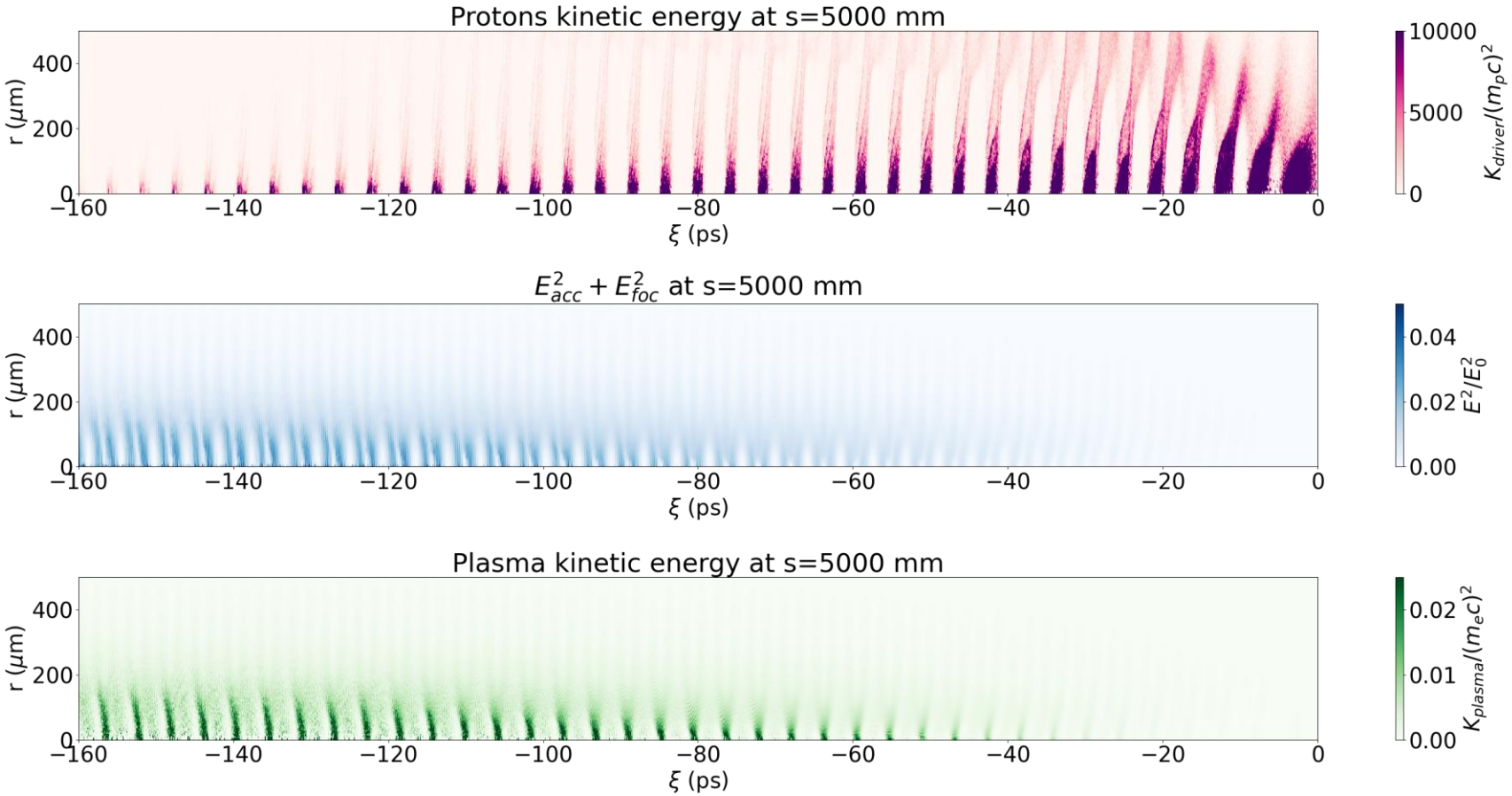
Can E_{acc} be assessed through K_{plasma} (energy deposited in the plasma)?

Motivation: Light as a diagnostics for wakefields

spectral energy released by the plasma as optical diagnostic for plasma wakefield accelerators

E. Öz et al., AIP Conf. Proc. 877, 687 (2006).
J .Mezger et al., Nucl. Instrum. Methods A 1075, 170426 (2025).

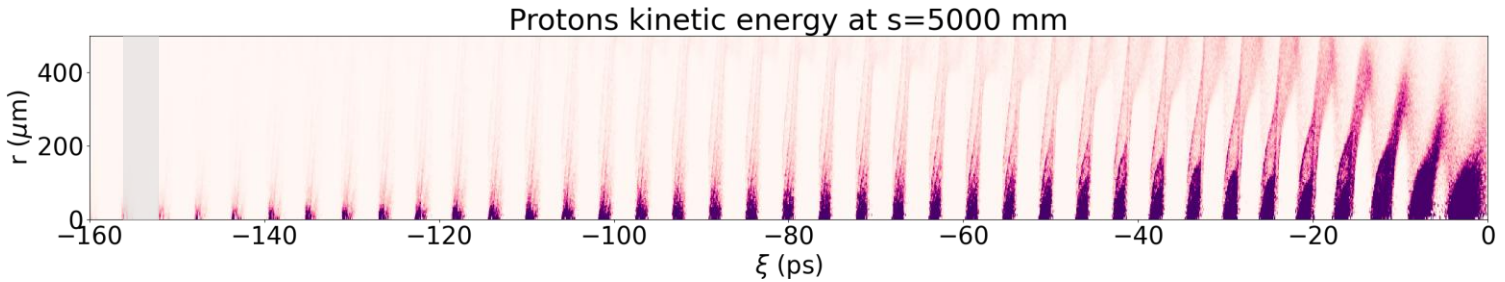
Key Question: $E_{acc} \propto K_{plasma}$?

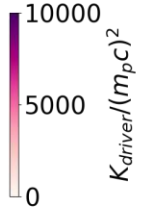


Conservation of energy

$$K_{driver} + \frac{1}{2}\left(E_{acc}^2 + E_{foc}^2\right) + K_{plasma} = const.$$

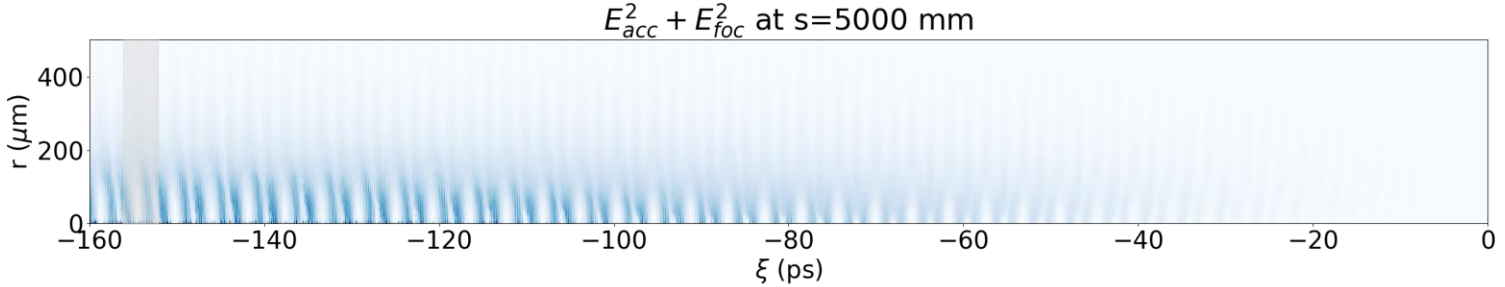
Key Question: $E_{acc} \propto K_{plasma}$?

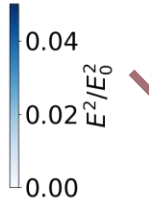


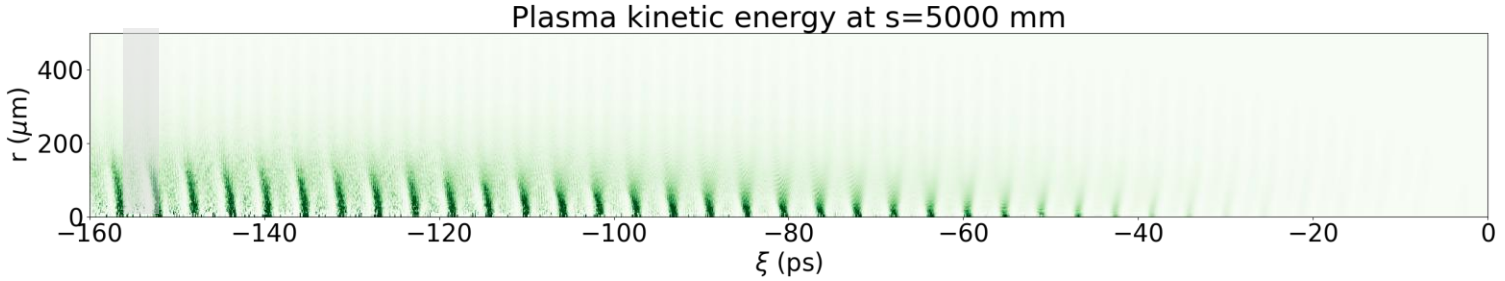


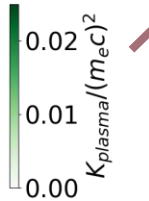
After the beam

$\mathbf{K_{driver} \rightarrow 0}$









$$\left[E_{acc}^2 + E_{foc}^2\right] \propto K_{plasma}$$

(over 1 λ_{pe})

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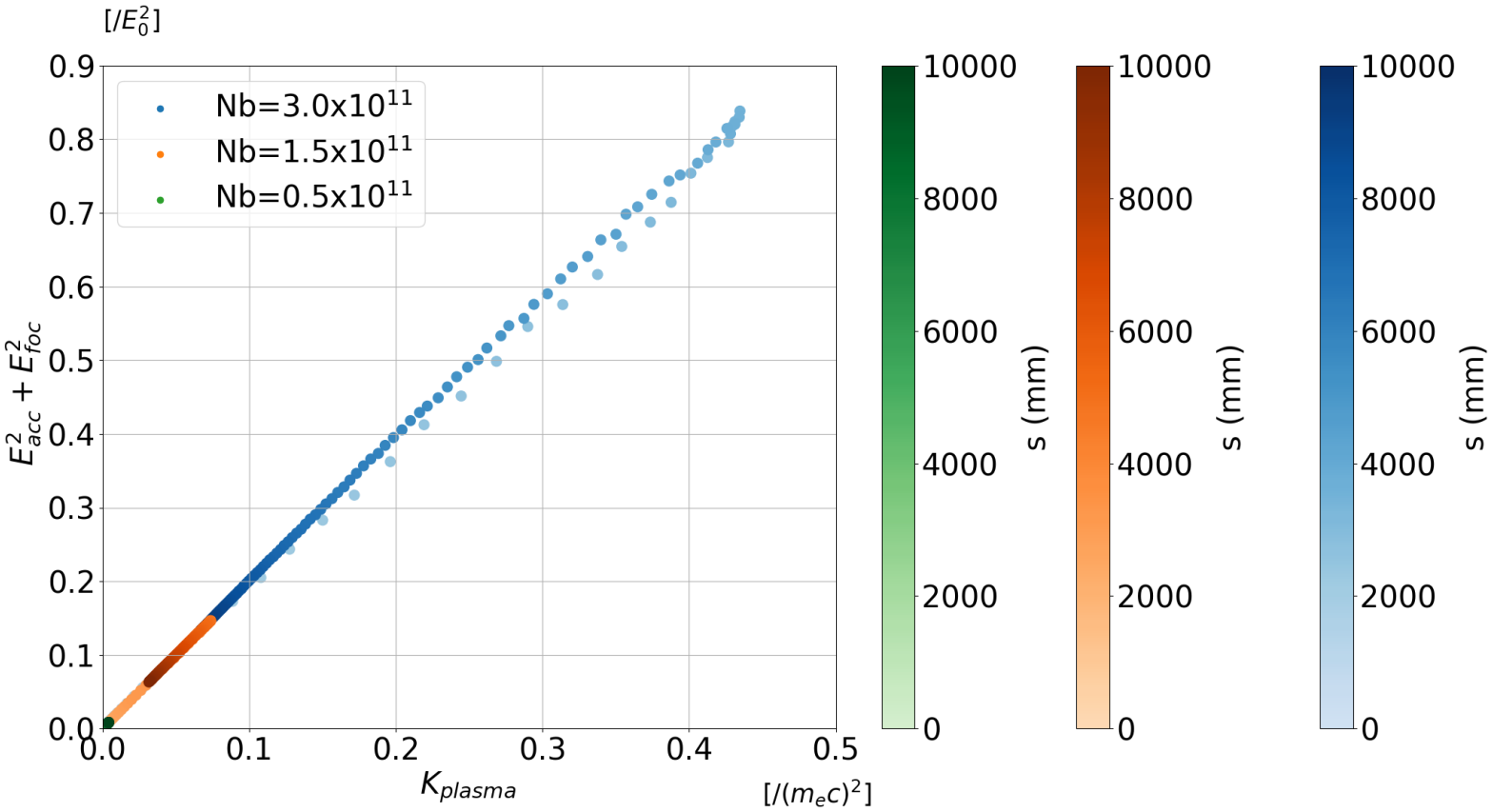

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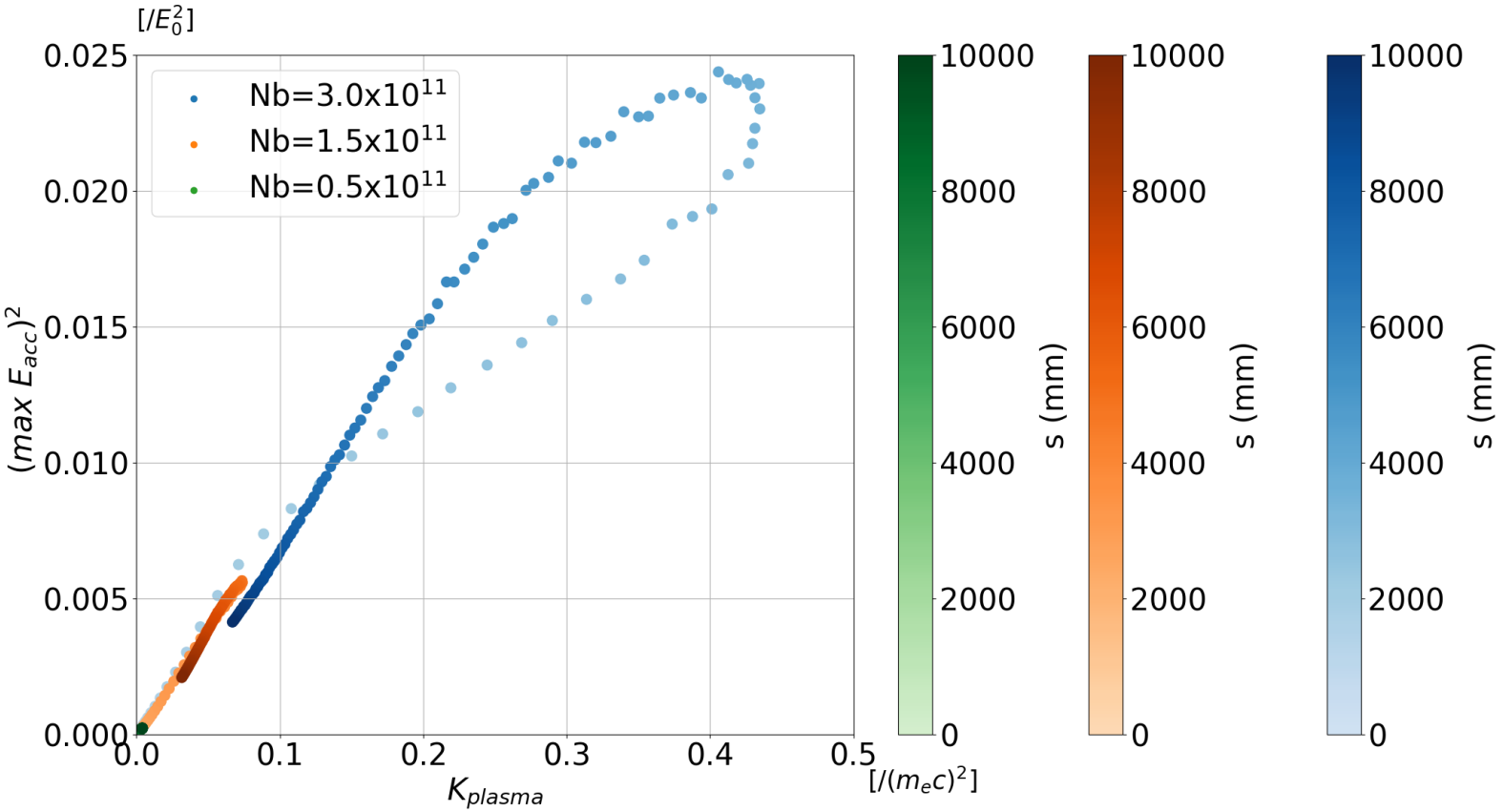

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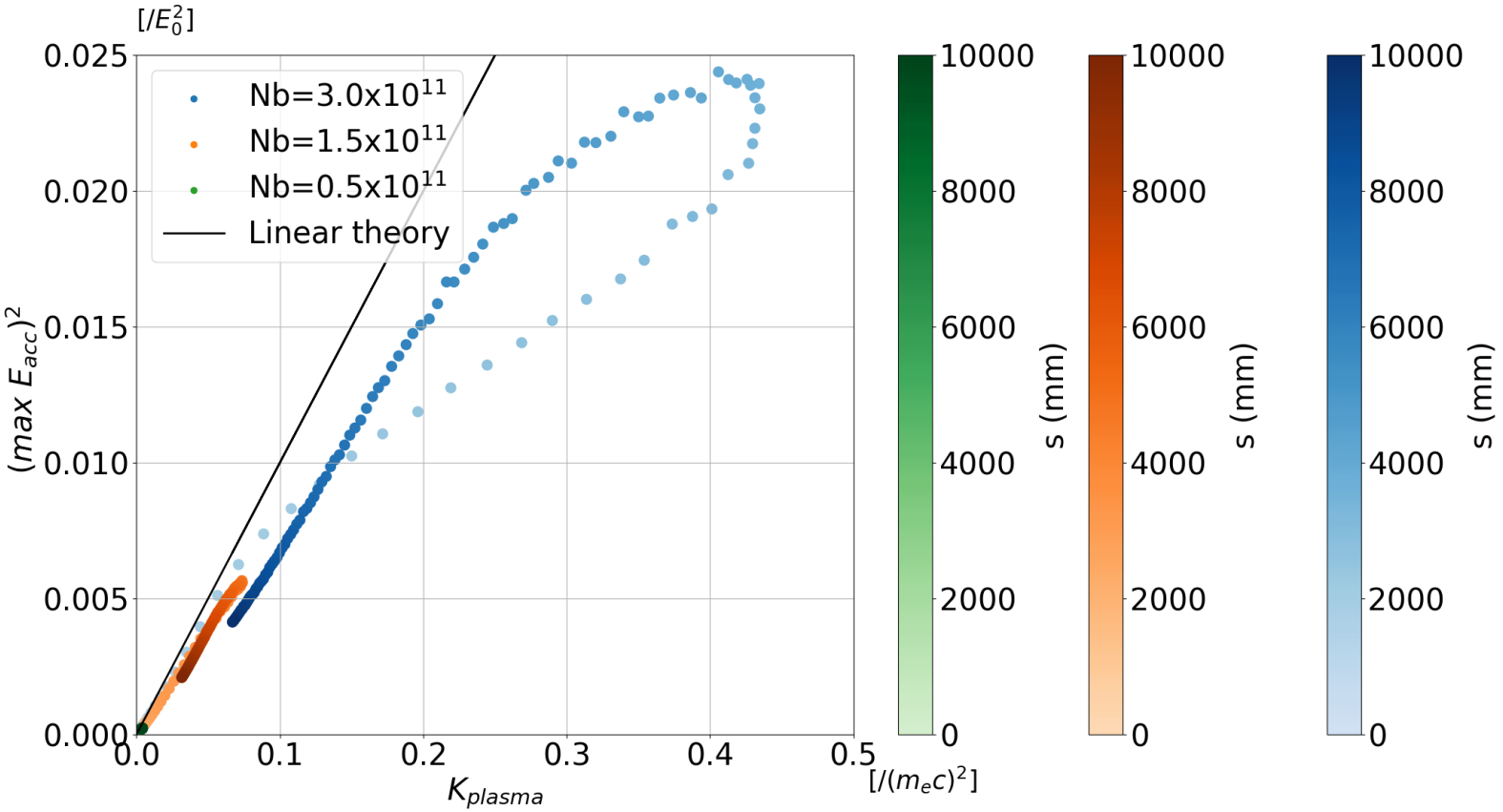


Discussion:

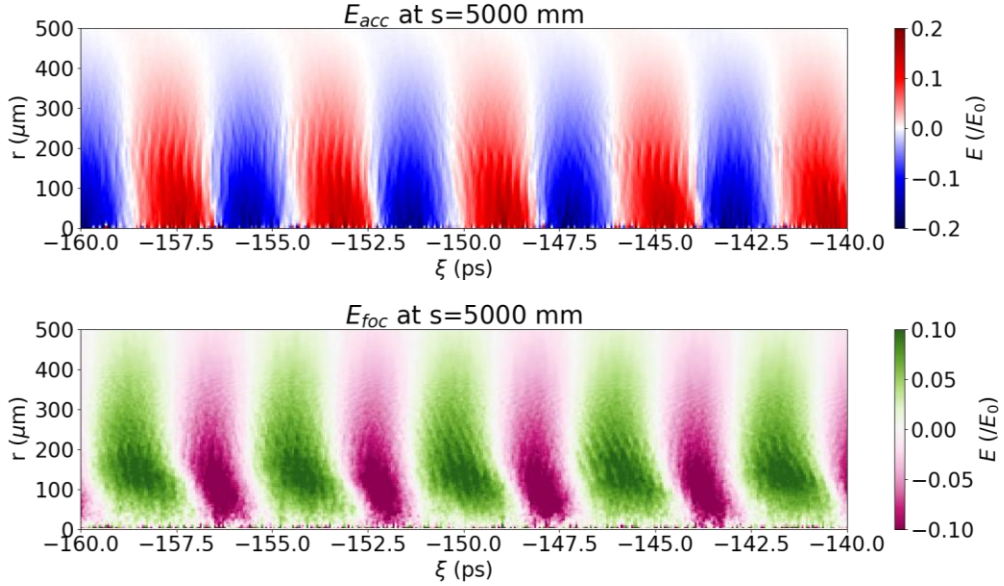
- In the linear regime:

  → $\max(E_{acc}) \propto \max(E_{foc}) \propto K_{plasma}$

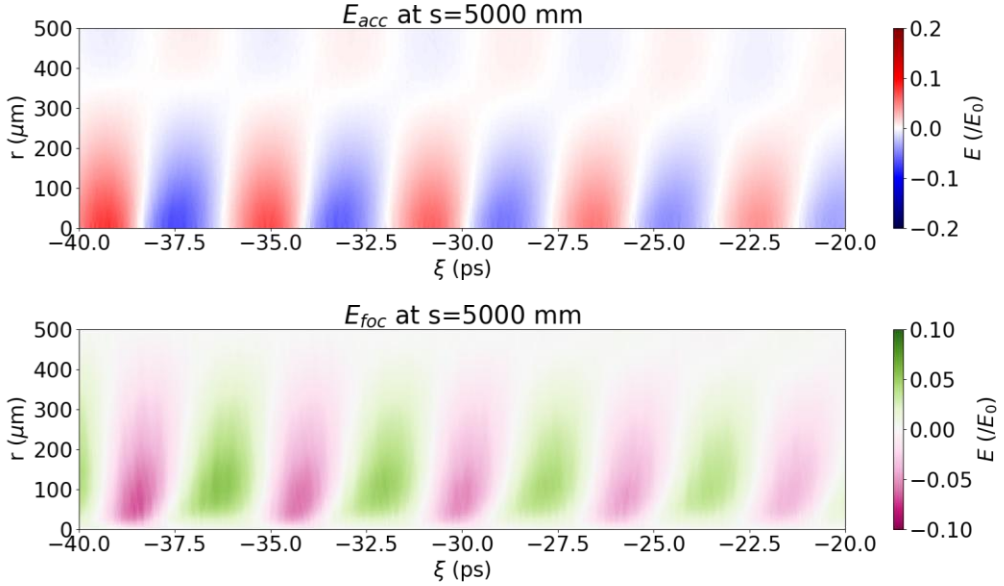
- Higher bunch population → larger wakefield → non-linearities break this relation

  → E_{foc} phase has radial dependence in tail p+ bunch→ breaks correlation $\max(E_{acc}) \propto K_{plasma}$

tail p+ bunch



front p+ bunch



Conclusions:

- max(E_{acc})∝ K$_{plasma}$: small wakefields
  (low bunch charge or early propagation)
- K_{plasma} is the energy deposited in the plasma after the beam (~ns)
- Energy dissipation by emission of light (etc) is a longer process (~ms)
- Radial dependence of E_{foc} → important for effective acceleration

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