Study of external electron beam injection into proton driven plasma wakefields for AWAKE Run2

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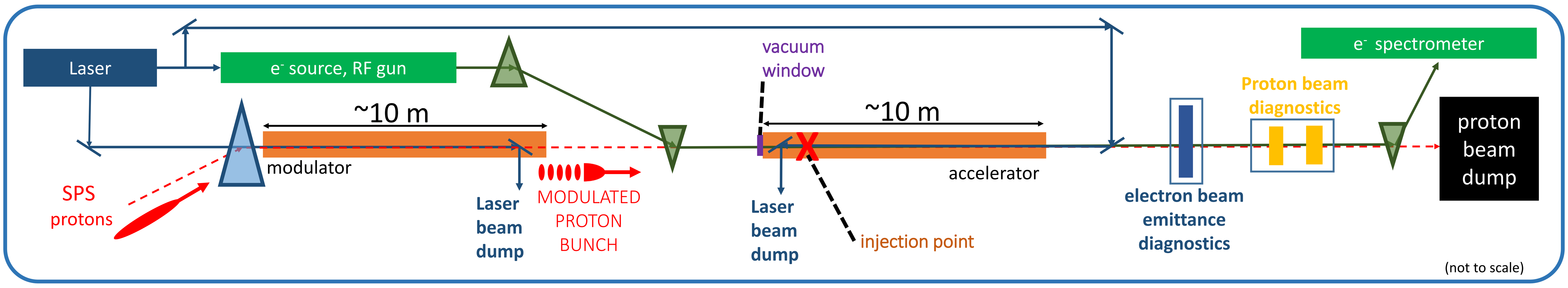
Abstract

During its first experimental run (2016-2018), AWAKE [1] reached two important milestones: the demonstration of the seeded self-modulation of the 400 GeV/c proton bunch delivered by the CERN Super Proton Synchrotron [2,3], and the acceleration of externally injected electrons from 19 MeV to 2 GeV [4]. The goal of the second run (starting in 2021) is to accelerate an electron bunch with a narrow final energy spread (%-level) and preserving its incoming emittance. To do so, we will exploit beam loading of the wakefields, full blow out of the plasma electrons by the accelerated bunch and beam matching to the plasma ion column [5]. Thus, at the injection point the electron bunch density has to be much higher than the plasma electron density and the beam beta function parameters matched to the plasma focusing. For AWAKE Run2 it is planned to use two separated plasma sections: one dedicated to the self-modulation of the proton bunch and one for the electron acceleration. We therefore investigate the injection properties and geometry of the electron bunch into the second one, including foils and suitable diagnostics for beam transverse size and vector measurements given the spatial constraints of the vapor source.

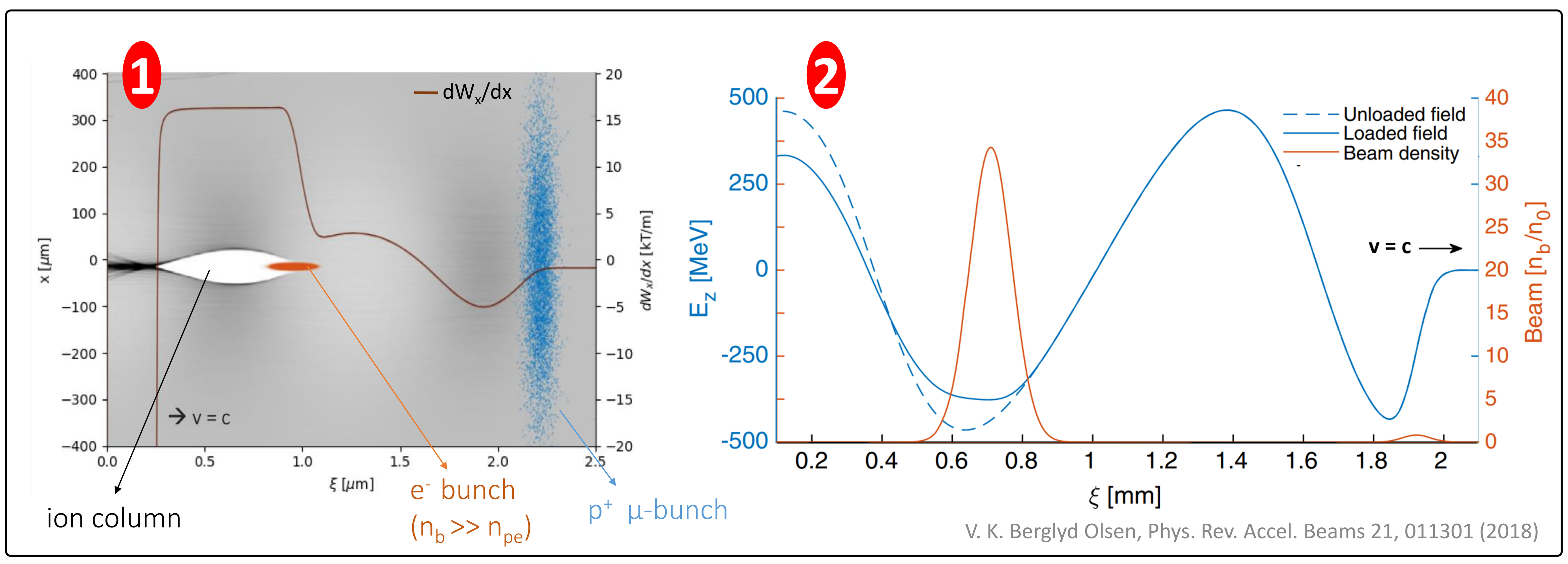
[1] P. Muggli et al. (The AWAKE Collaboration), Plasma Physics and Controlled Fusion, 60(1) 014046 (2017), [2] M. Turner et al. (The AWAKE Collaboration), Phys. Rev. Lett. 122, 054801 (2019), [3] E. Adli et al. (The AWAKE Collaboration), Phys. Rev. Lett. 122, 054802 (2019), [4] E. Adli et al. (The AWAKE Collaboration), Nature 561, 363–367 (2018), [5] V.B. Olsen et al., Phys. Rev. Accel. Beams 21, 011301 (2018)

AWAKE RUN2 SETUP:



AWAKE RUN2 GOALS:

- Scalability of the concept:
  → the longer the accelerator, the higher the final energy
- Preserving incoming emittance: (1)
  → non-linear (blowout) regime
- %-level energy spread: (2)
  → beam loading of the wakefields



V. K. Berglyd Olsen, Phys. Rev. Accel. Beams 21, 011301 (2018)

Beam matching is a necessary condition

$$\sigma''(z) + \left(K_\beta^2 - \frac{\varepsilon_g^2}{\sigma^4(z)}\right)\sigma(z) = 0$$

→ beam envelope equation, $K_\beta = \frac{\omega_{pe}}{c\sqrt{2\gamma}}$

- The beam is injected at the waist

$$\sigma'(0) = 0, \qquad \sigma(0) = \sqrt{\varepsilon_g \beta_0}$$

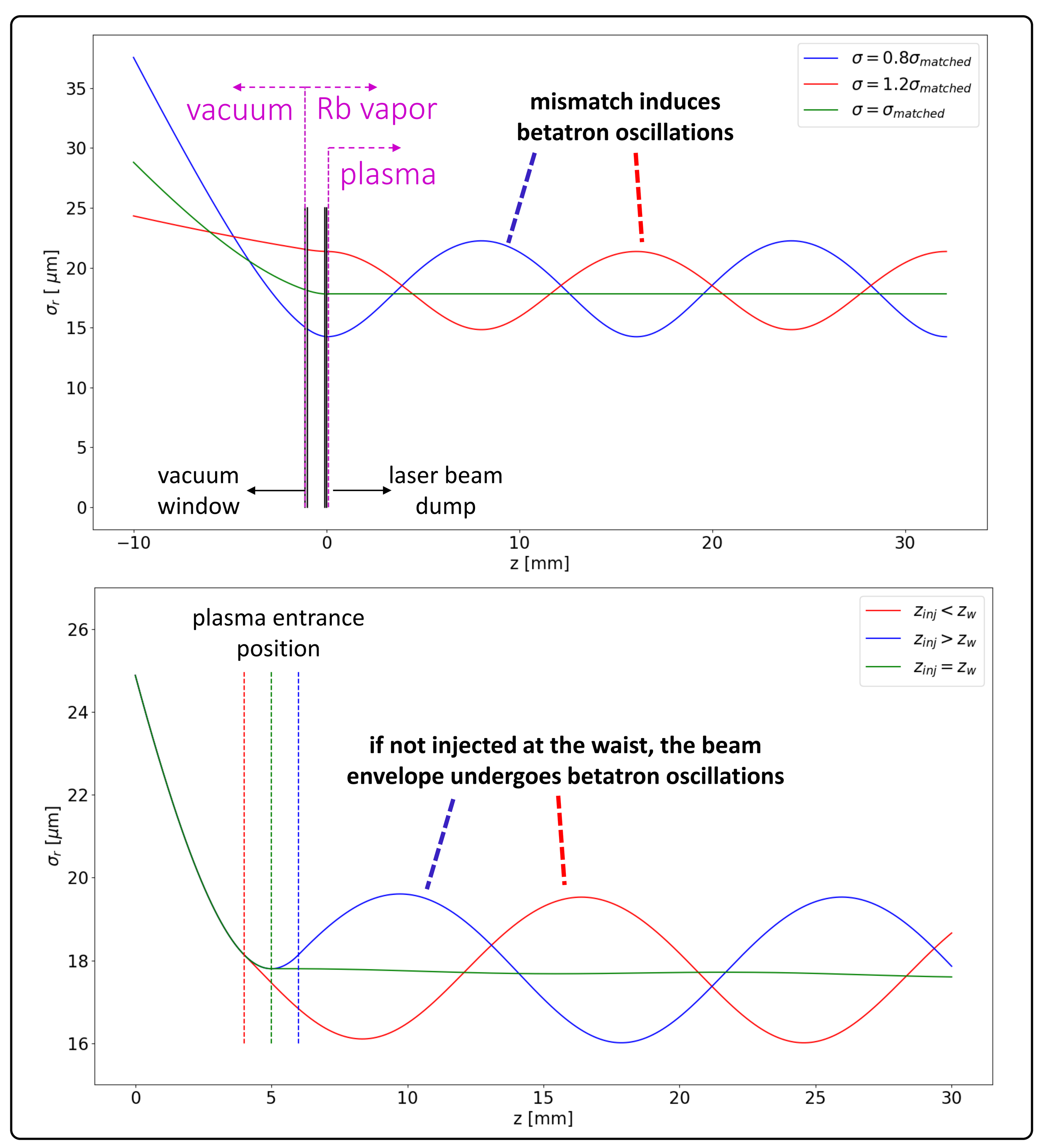
- The plasma focusing force exactly balances the beam divergence

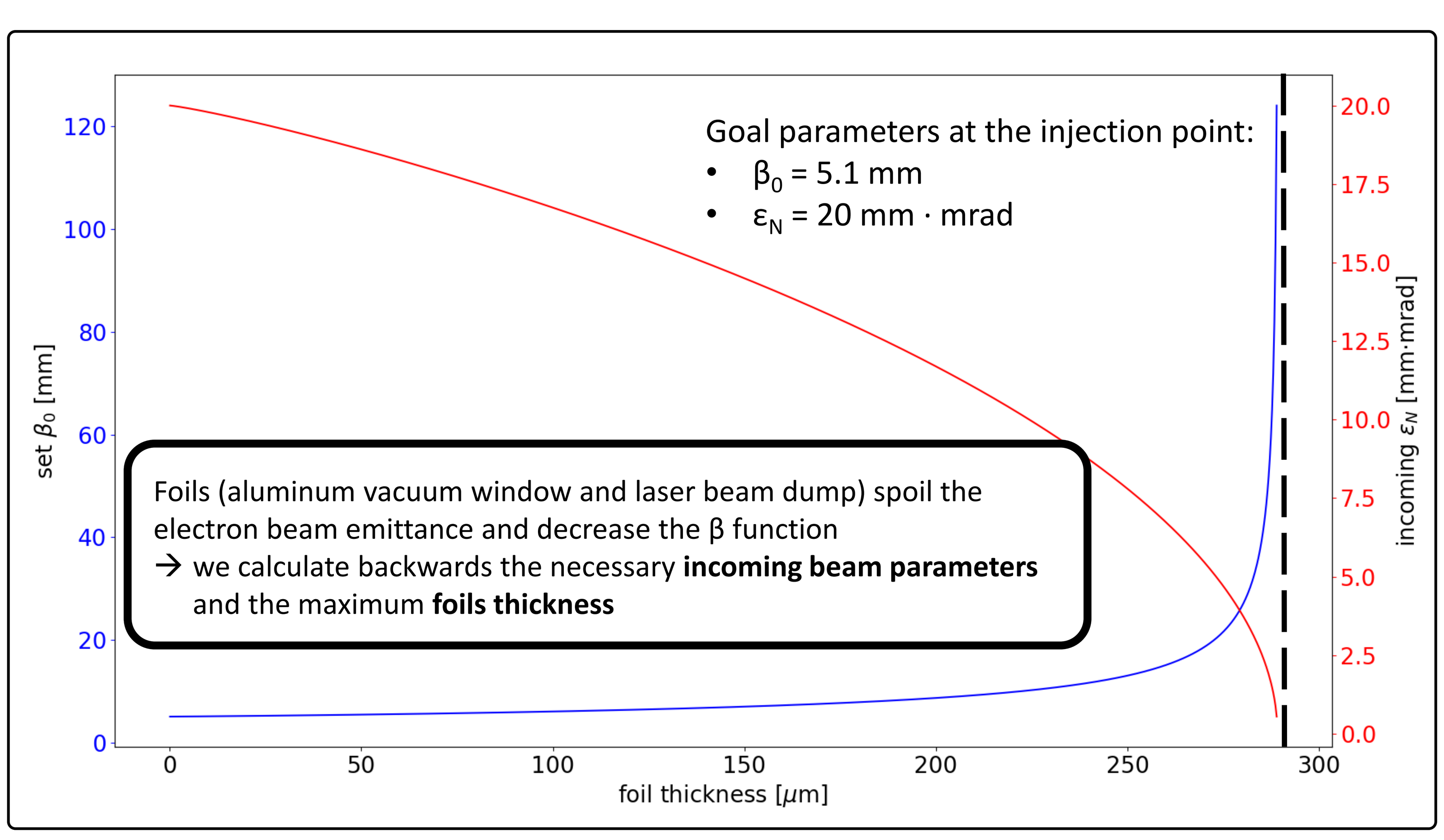
$$\frac{\varepsilon_N^2}{\gamma\,\sigma^4} \cdot \frac{1}{n_{pe}} = \frac{q^2}{2 m_e \epsilon_0 c^2}$$

β function at the waist

$$\beta_0 = \sqrt{\frac{2\,\epsilon_0\, m_e\, c^2\, \gamma}{n_e\, e^2}}$$

e.g. for E = 165 MeV and n_{pe}= 7· 10^{14} cm^{-3}, β_0 = 5.11 mm





Experimental challenges:

- measurements of the incoming beam parameters
  - ➢ beam size at the plasma entrance
  - ➢ beam position at the plasma entrance
  - ➢ position of the waist
- laser pulse – electron beam time alignment (picosecond resolution)
- proof of matching