Simulation Study of Electron Beam Acceleration With The Non-Gaussian Transverse Profile For AWAKE RUN 2

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On behalf of
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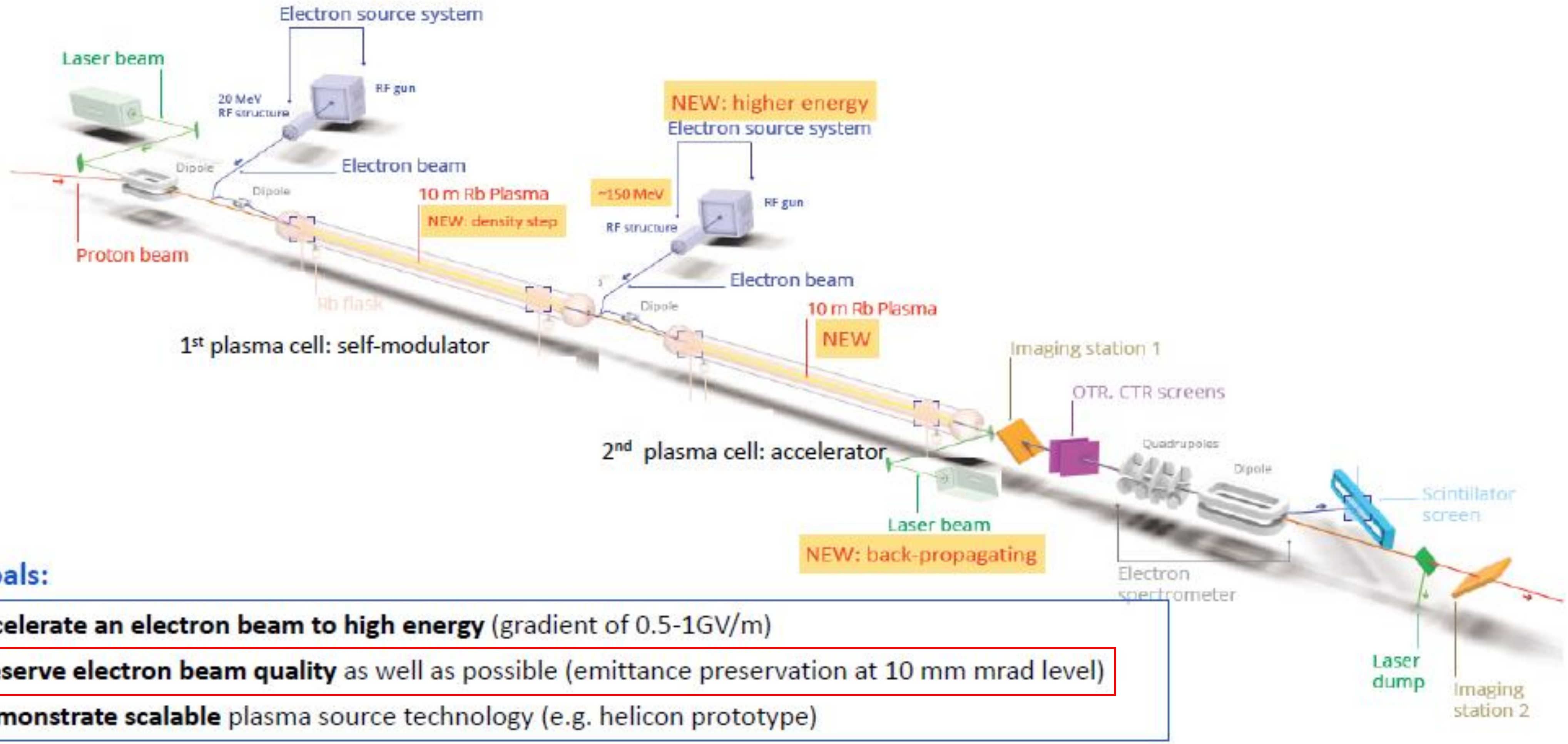
AWAKE Run 2

➔ Demonstrate possibility to use AWAKE scheme for high energy physics applications in mid-term future!



Goals:

Accelerate an electron beam to high energy (gradient of 0.5-1GV/m)

Preserve electron beam quality as well as possible (emittance preservation at 10 mm mrad level)

Demonstrate scalable plasma source technology (e.g. helicon prototype)

*Credit: Edda Gschwendtner, AWAKE Run 2 at CERN, Proc. IPAC'21, Campinas, Brazil, 24-28 May 2021, ID: 1768

Beam loading and matching

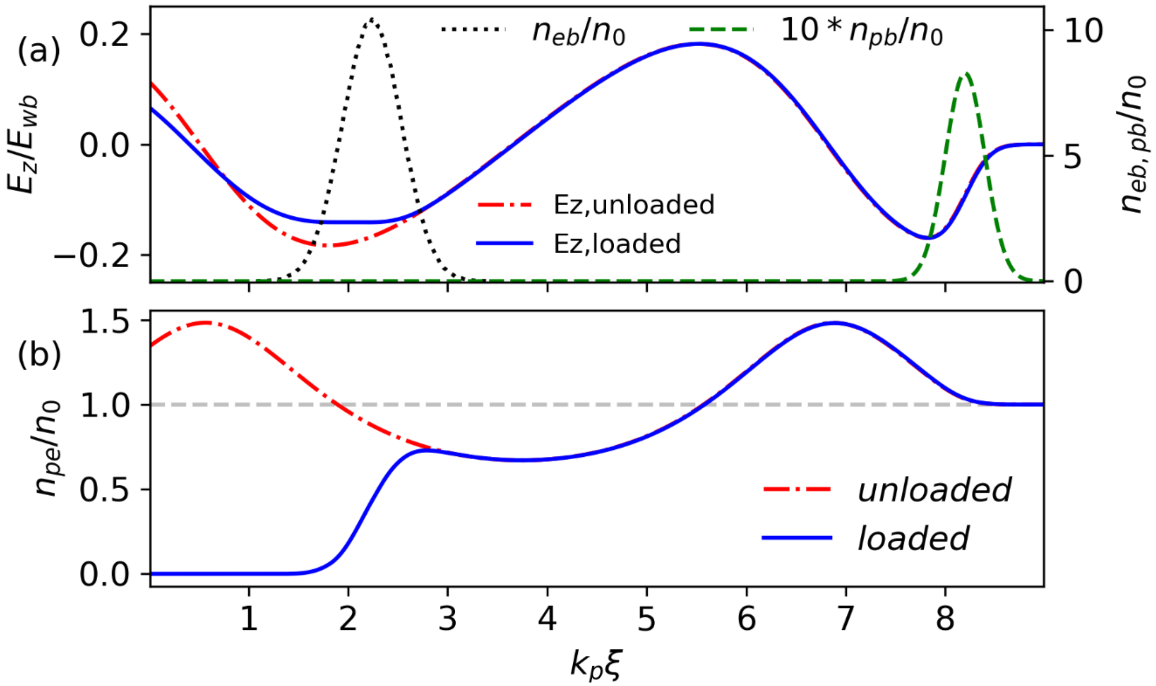


Figure 1: QV3D simulation results showing the plasma wakefields (a) and plasma electron density (b) on the propagation axis at the beginning (t = 0).

- Beam matching: to match the beam's self-defocusing force to the plasma focusing force to prevent intensive beam envelope oscillation.
- The matching condition (matched beam radius for Gaussian beam):

$$\sigma_{r,m} = \sqrt[4]{\frac{2}{\gamma}}\sqrt{\frac{\epsilon_n}{k_p}}$$

*PhysRevAccelBeams.21.011301

Super-Gaussian and halo factor

$$n(y) \sim \exp(-|y|^p)$$

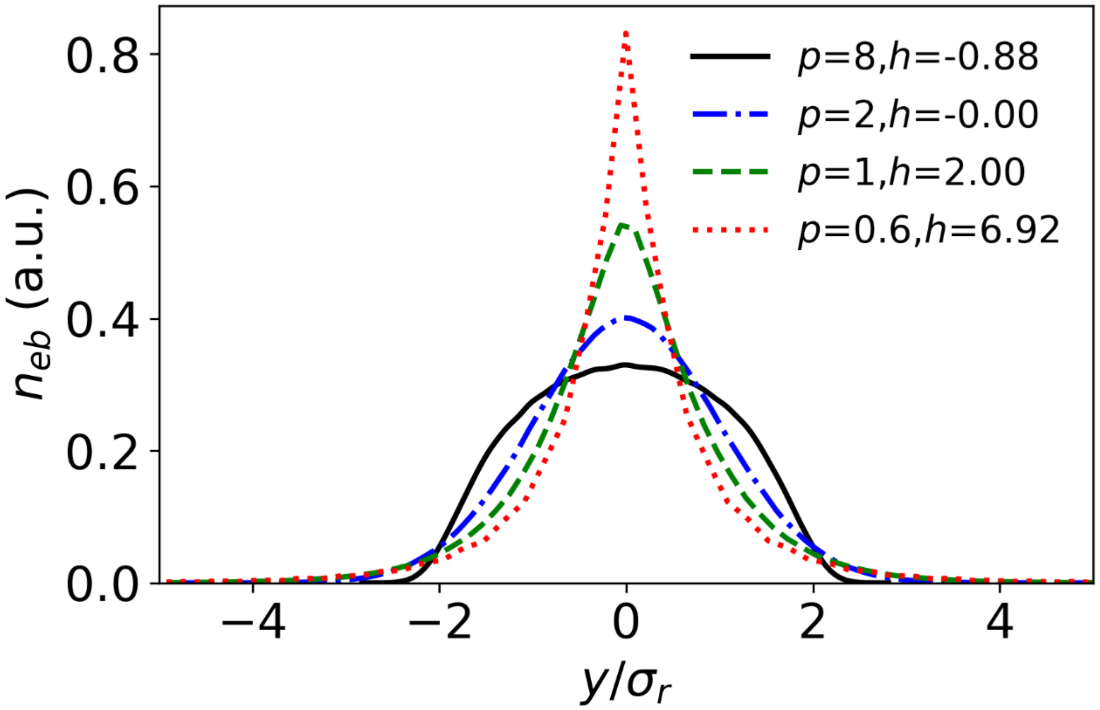


Figure 2: The 1D density distribution for the super Gaussian transverse beam profile with identical r.m.s. beam size, i.e., $\sigma_y = \sigma_{r,m}$ for all cases.

Parameters for quantifying beam halo:

- Kurtosis *h*

$$h = \frac{\langle x^4 \rangle}{\langle x^2 \rangle^2} - 3$$

- Halo parameters *H*

$$I_2 = \langle x^2 \rangle \langle x'^2 \rangle - \langle x x' \rangle$$

$$I_4 = \langle x^4 \rangle \langle x'^4 \rangle + 3\langle x^2 x'^2 \rangle^2 - 4\langle x x'^3 \rangle \langle x^3 x' \rangle$$

$$H = \frac{\sqrt{3 I_4}}{2 I_2} - 3$$

*C. K. Allen and T. P. Wangler, “Parameters for Quantifying Beam Halo”, in *PAC’01*, 2001, paper TPPH032, pp. 1732-1734.

Normalized Emittance

*Geometric mean of the normalized emittance: $\epsilon_n = \sqrt{\epsilon_{ny} * \epsilon_{nz}}$

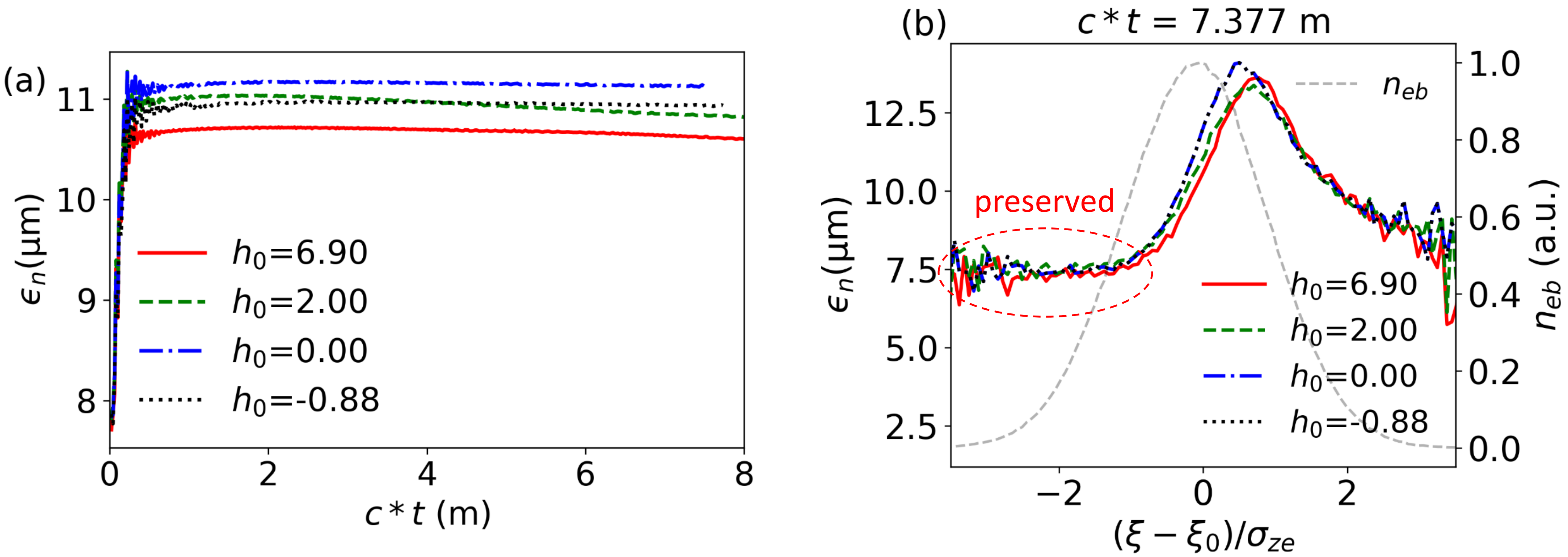


Figure 3: The geometric mean of the normalized projected emittance (a) and the corresponding slice value (b) along the beam that sampled at c ∗ t = 7.377 m. h_0 is the initial kurtosis.

Halo parameter

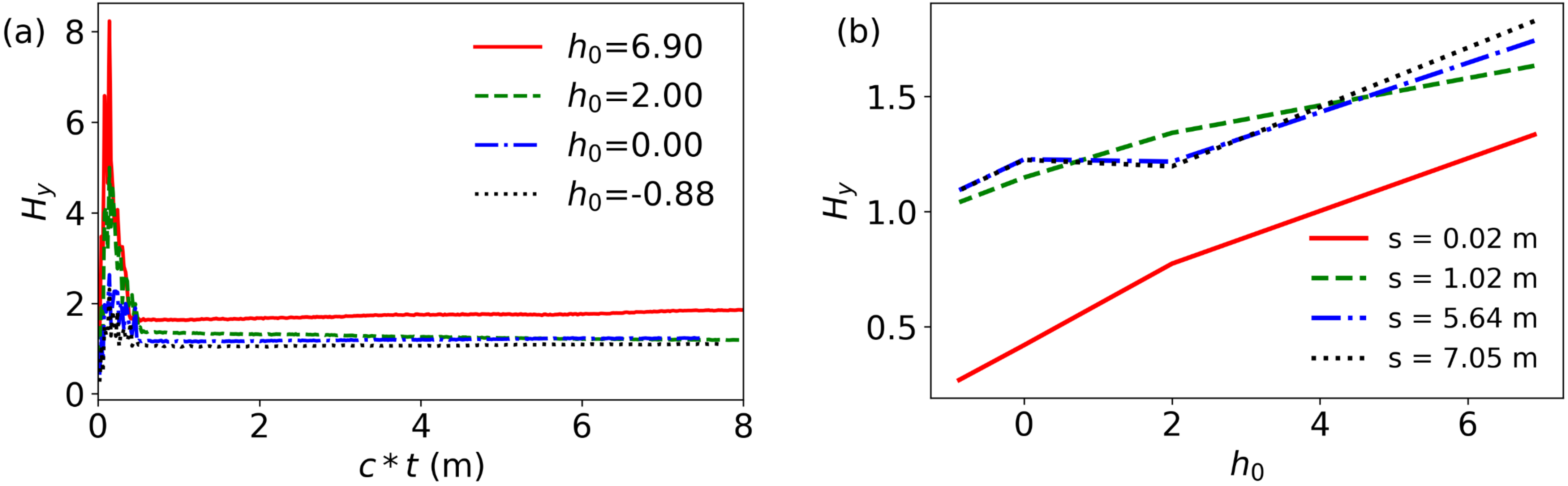


Figure 4: The halo parameter H in y-plane.

Beam brightness

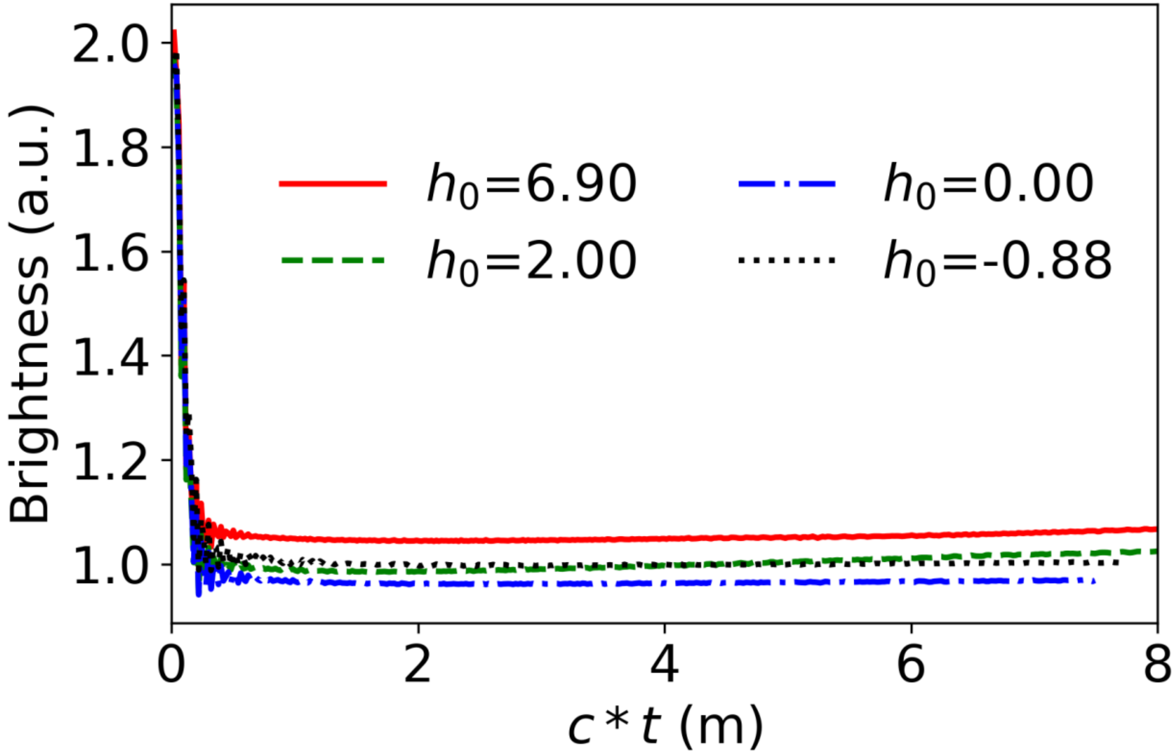


Figure 5: Brightness of the full beam (a) and the core (b) w.r.t. propagation distance.

- Beam with a high initial kurtosis will have a higher brightness.

Energy spread

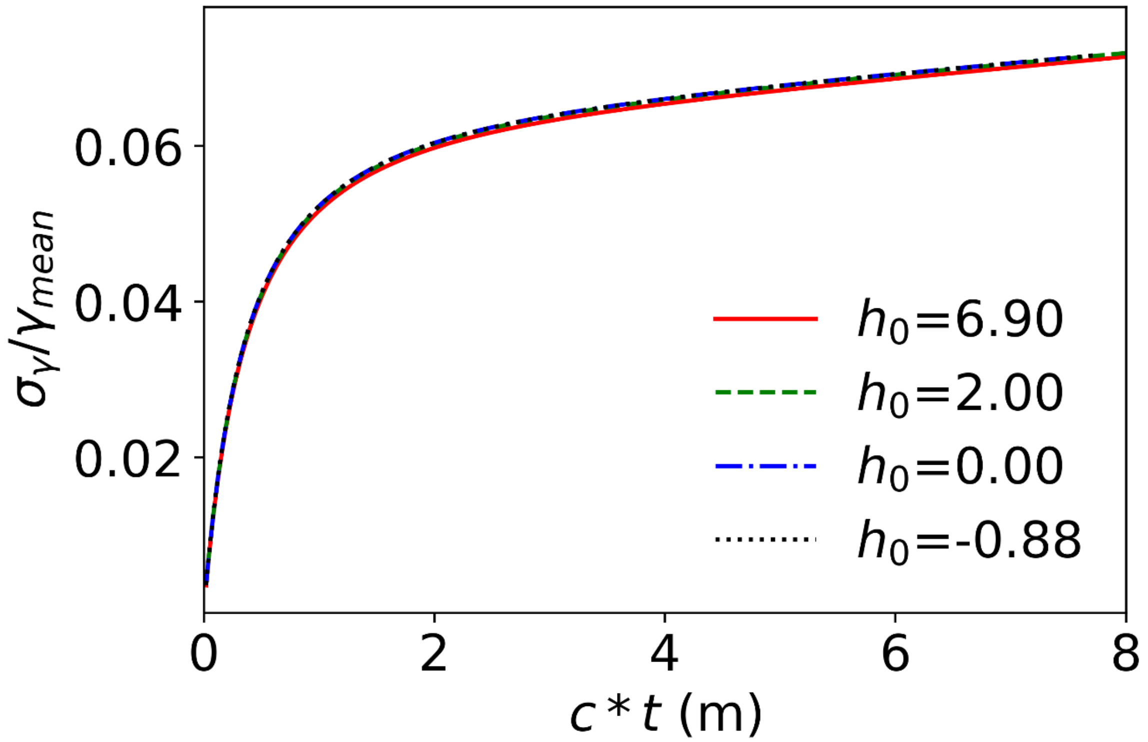


Figure 6: Relative energy spread of the witness beam w.r.t. propagation distance.

- Energy spread is mainly a longitudinal effect.

Conclusion

- The initial kurtosis of a non-Gaussian transverse beam profile can have significant impact on the beam’s acceleration quality for applications, e.g brightness.
- Beam metrics being investigated in this proceeding will stay on or approach a nearly stabilized value soon after the growth in the first half meter propagation.
- A beam profile with matched radius and large initial kurtosis will show higher brightness after acceleration

Thanks for your attention!