High-Brightness Laser-Plasma-Based Injectors [LOI-182]

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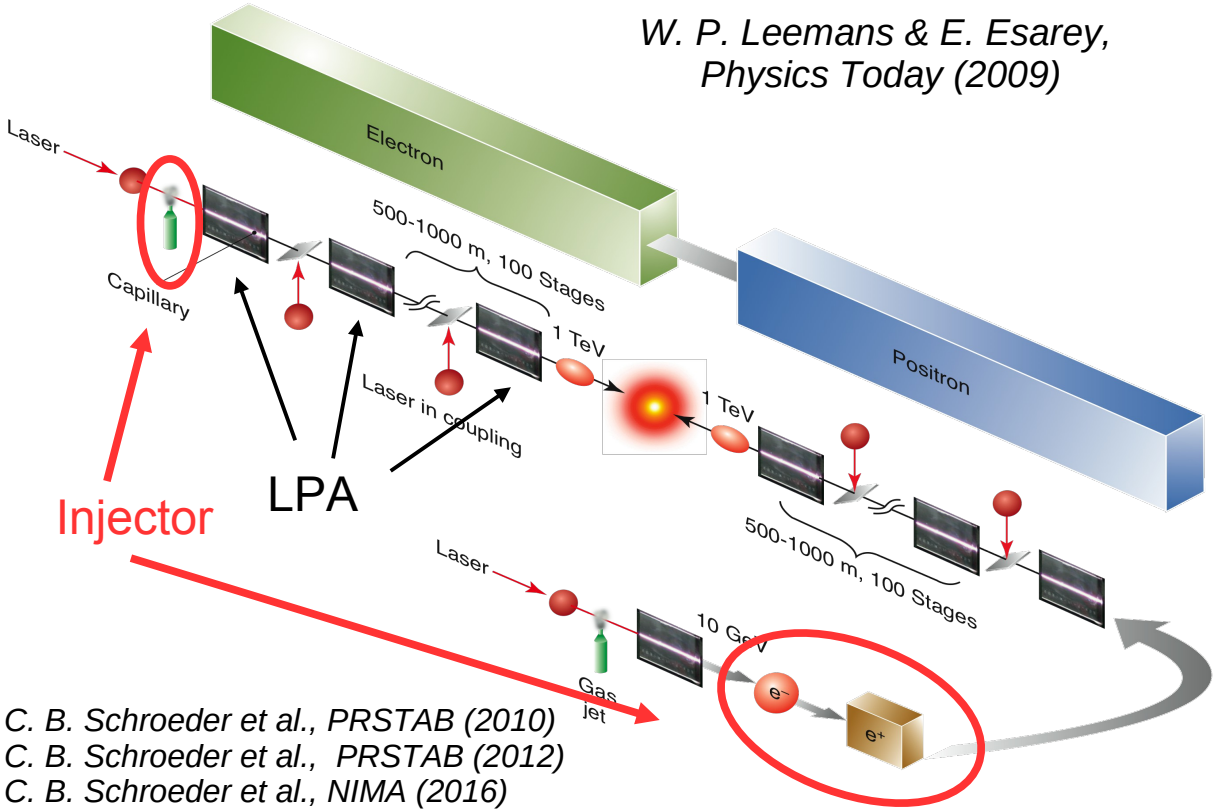
R&D devoted to implementation of high-quality, laser-plasma-based injectors for HEP applications highlighted in the 2016 Advanced Accelerator Development Strategy Report



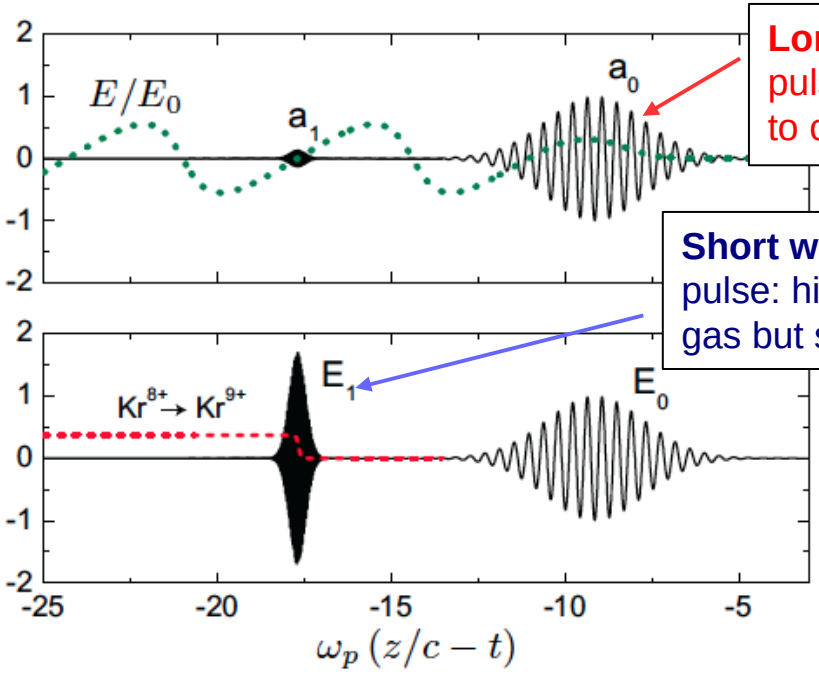
W. P. Leemans & E. Esarey, Physics Today (2009)

C. B. Schroeder et al., PRSTAB (2010)
C. B. Schroeder et al., PRSTAB (2012)
C. B. Schroeder et al., NIMA (2016)
C. B. Schroeder et al., LOI-216

- Future TeV-class, plasma-based colliders require beams with unprecedented quality:
  $N_b > 10^9$, $\varepsilon < 100$ nm, $\sigma_\gamma/\gamma < 1\%$
  → beams of interest also for a plasma-based XFEL
- Laser-plasma-based source of electrons (and positrons) is desirable
  → compactness
  → synchronization
- (Uncontrolled) self-injection unlikely to produce beams with simultaneously ALL required parameters
  → sensitivity to laser and plasma parameters
  → limited tunability (inj. & acceleration are coupled)

- Controlled injection methods have been proposed (colliding pulse inj., ionization-induced inj. w/ one or many pulses, density gradient inj., etc.)
  → decouple injection process from acceleration yields **tunability** and **improved** beam quality
  → some schemes already implemented but additional R&D/optimization is required for all the schemes

Two-color laser ionization injection



Long wavelength pump pulse: large pond. force to create large wakef ėld

Short wavelength injection pulse: high f ėld to ionize high-Z gas but small pond. force

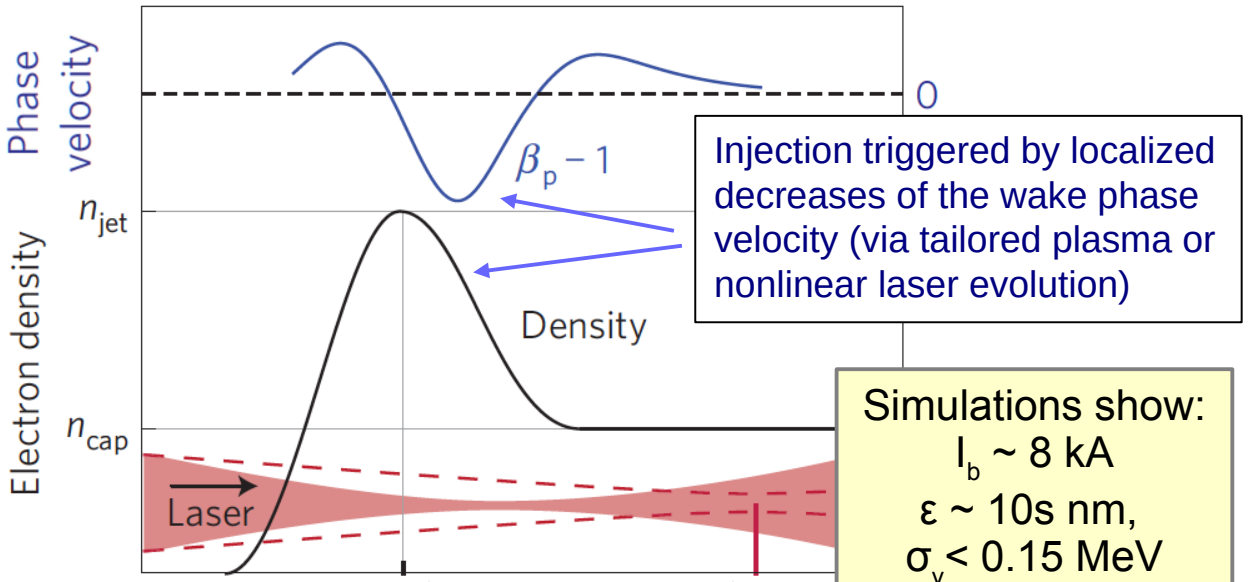
Simulations show:
Q_b ~ 100 pC
ε ~ 10s nm,
σ_γ/γ ~ 1%

→ ε, Q_b, σ_γ can be controlled via a_i, w_i, + length of high-Z gas

→ full potential realized with long wavelength drive lasers (e.g., CO_2 or Tm:YLF), but demonstration with Ti:Sa possible

[L. Yu et al., PRL 2014, C.B. Schroeder, PRAB 20154]

Density gradient injection



Injection triggered by localized decreases of the wake phase velocity (via tailored plasma or nonlinear laser evolution)

Simulations show:
I_b ~ 8 kA
ε ~ 10s nm,
σ_γ < 0.15 MeV

→ σ_γ small due to position/energy correlation

→ small ε owing to small $p_\perp$ of trapped particles

→ experimentally demonstrated: stability and tunability

[C.G.R. Geddes et al., PRL 2008, A.J. Gonsalves Nat. Phys 2011, K.K. Swanson PRAB 2017, X.L. Xu, PRAB 2017]

- **Summary**:

→ techniques to improve beam quality have been proposed (two-color and density gradient among most promising), vigorous R&D/optimization of these concepts should be carried out;

→ if small emittance can be maintained during acceleration cooling of e-beam might not be necessary (however, plasma-based cooling techniques have been proposed [Bulanov, LOI-134]);

→ plasma-based generation of high-quality positron beams more challenging, significant R&D required [Bulanov, LOI-134].