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Stable and High-Quality Laser Wakefield Positron Acceleration Scheme

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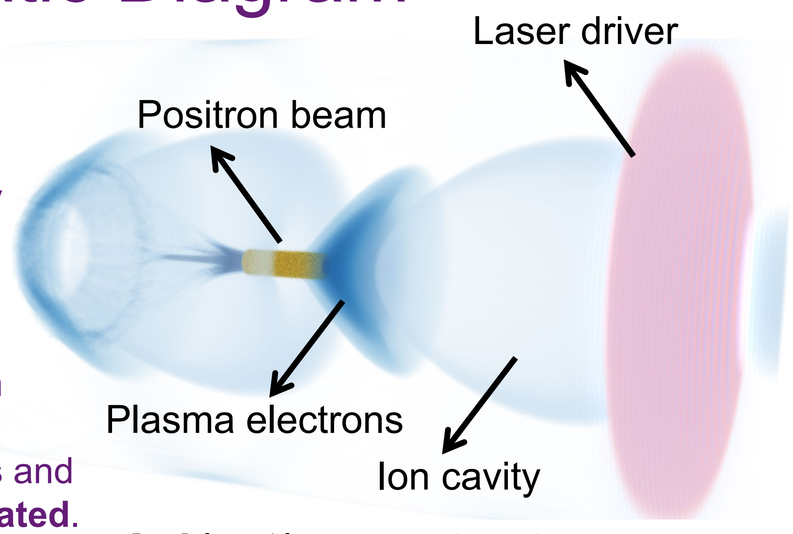
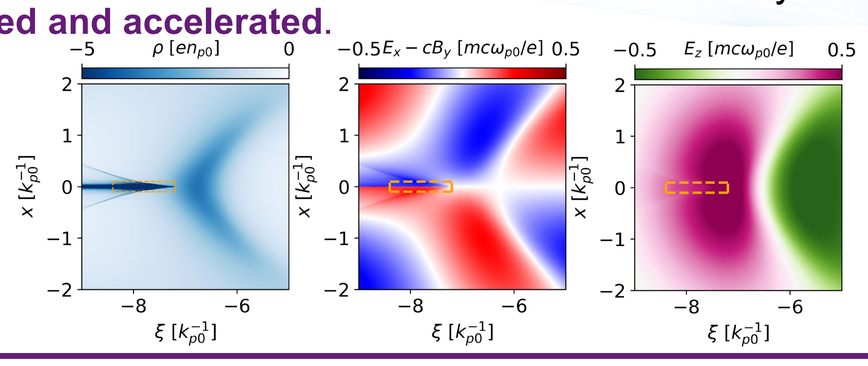
Motivation

- Precision measurement of the Higgs Boson and physics beyond Standard Model with **high energy electron-positron collider** is of the most important issues for particle physics.
- **LWFA** provides ultra high accelerating gradient. However, achieving **high-quality positron acceleration** via LWFA remains an open question.

Schematic Diagram

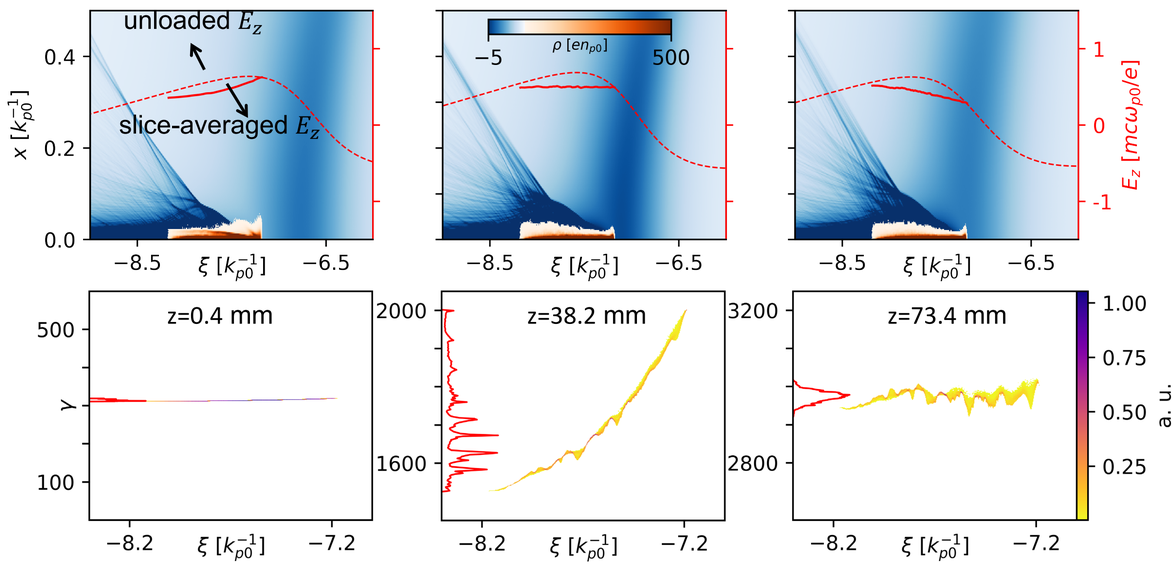
- A **channel-guided** and **relatively short** laser excites a stable partially evacuated wake.
- A **high-density** e⁺ beam placed behind the first bucket attracts electrons and is **focused and accelerated**.





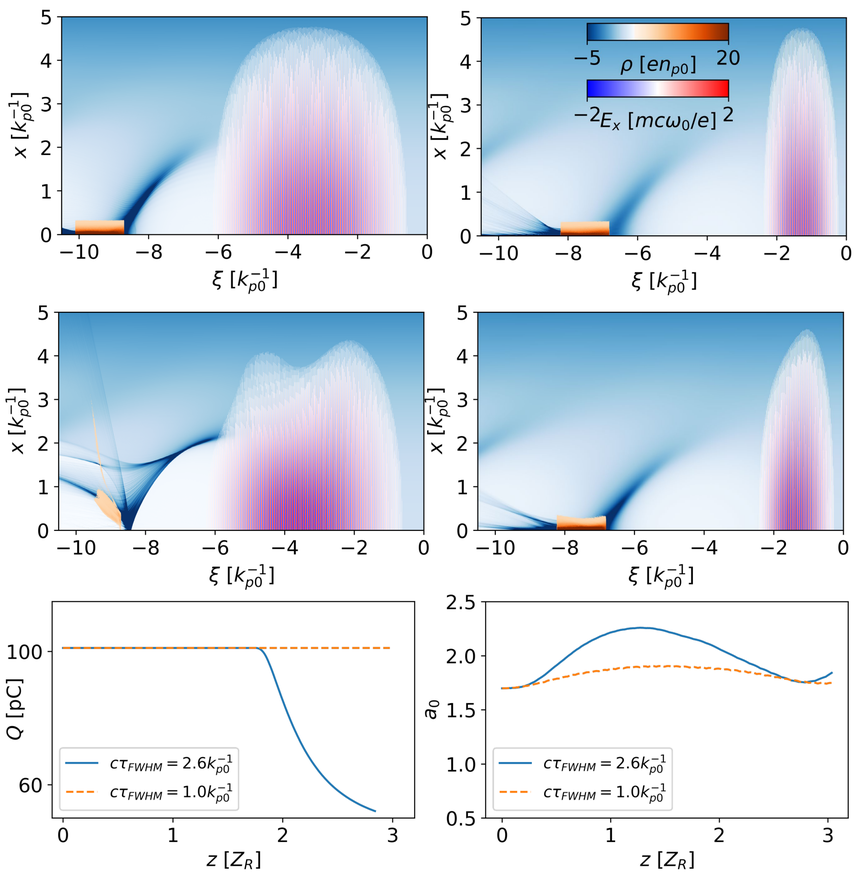
Dynamic Energy Dechirper

- Initially, the e⁺ beam head experiences a **higher** accelerating field than the tail, and **a negative chirp** is imparted to the beam.
- As the laser **slides backward (dephasing)** relative to the positrons, the loaded E_z gradually **flattens** along ξ, ending the chirp process.
- Thereafter, the beam head experiences a **lower** accelerating field than the tail, and it **"dechirps"** the existing energy chirp.
- By **tailoring** the e⁺ **current profile** and **loading phase**, the correlated energy spread induced by dephasing can be eliminated at desired acceleration distances.



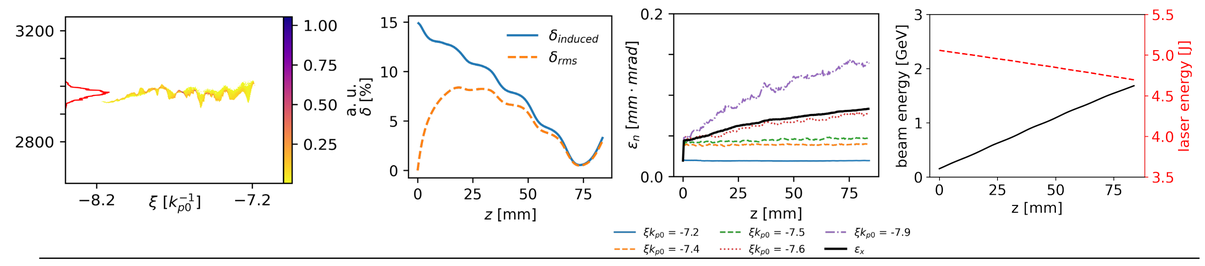
Suppress Laser Evolution

- e⁺ acceleration is **sensitive** to laser evolution.
- Laser parameters suitable for e⁻ acceleration may cause **charge loss** in e⁺ acceleration.
- **Shortening** the pulse length suppress the **self-focusing effect**, leading to near-perfect **channel-guided** laser propagation.



$$\eta_r(\xi,r) \simeq 1-\frac{k_{p0}^2}{2k_0^2}\rho(\xi,r)$$
$$\rho(\xi,r) = \rho_0(r) + \delta\rho(\xi,r)$$
$$\delta\rho(\xi,r) \propto a_0^2 \int_{\xi}^{0} d\xi' \sin\left[k_{p0}(\xi'-\xi)\right] exp\left(-\frac{4(\xi'-\xi)^2}{L^2}\right)$$

Toward collider-quality



Parameters	PIC results	Scaled values	CEPC booster [1]
n_{plasma} [cm⁻³]	1.74×10^{17}	1.98×10^{15}	--
E_{laser} [J]	5	4160	--
τ [fs]	42	400	--
E_{e^+} [GeV]	1.37	120	120
Q_{e^+} [nC]	0.03	0.28	0.7
ε_n [mm·mrad]	0.08	0.76	295
δ_{rms}	0.55%	0.55% (<0.1%*)	0.099%

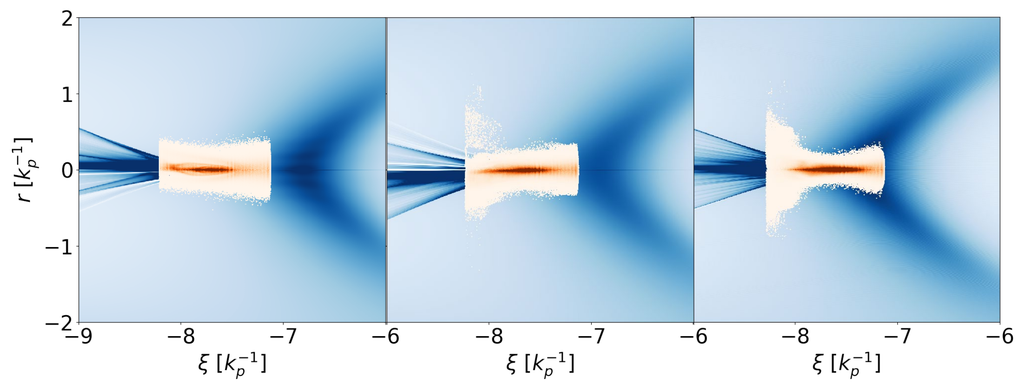
* with post-acceleration phase-space manipulations [2]-[3]

	$B_{6D} \equiv I^{**}_{avg}/\varepsilon_x\varepsilon_y\delta_{0.1\%}$ (A/m²/0.1%)
Scaled results	1.66×10^{14}
ILC [4]	1.0×10^{15}
FCC-ee [5]	0.96×10^{13}
CEPC [1]	1.0×10^{13}

** bunch length taken as $6\sigma_{z,rms}$

Inherent Stabilization

- Initial transverse misalignments of the e⁺ beam can trigger hosing, but subsequent **damping** is observed in PIC simulations.



Acknowledgements

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[4] T. Behnke, et al. arXiv: 1306.6329
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