Energy Compression and Stabilization of Laser-Plasma Accelerators

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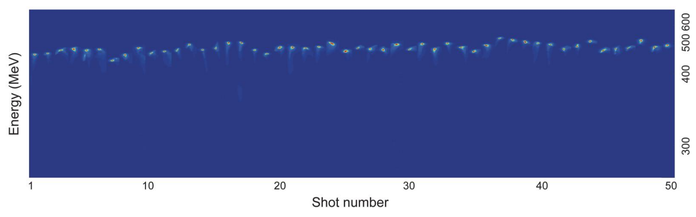
Laser-plasma accelerators suffer from large energy spread and jitter

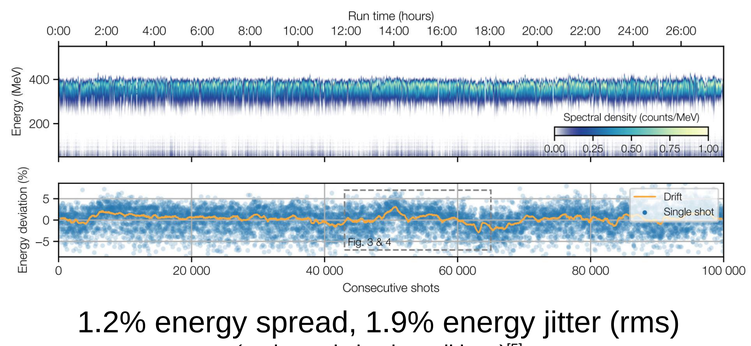
- **Compact**, cm-scale sources of electron beams with up to **GeV** energy, **kA** current and **fs** duration[1,2].
- Currently limited in applications due to **large energy spread and jitter** in the few-percent range.
- **Major challenge**: demonstrate energy spread and energy jitter **≲0.1% rms** for applications such as free-electron lasers (FELs) or storage ring injectors.

FEL demonstration at SIOM[3]



0.2-1.2% energy spread, ≲3% energy jitter (rms).

LUX facility at DESY[4]



1.2% energy spread, 1.9% energy jitter (rms)
(under optimized conditions)[5]

New solution: development of a plasma-based energy compressor

Energy spread correction

Chicane
Bunch decompression

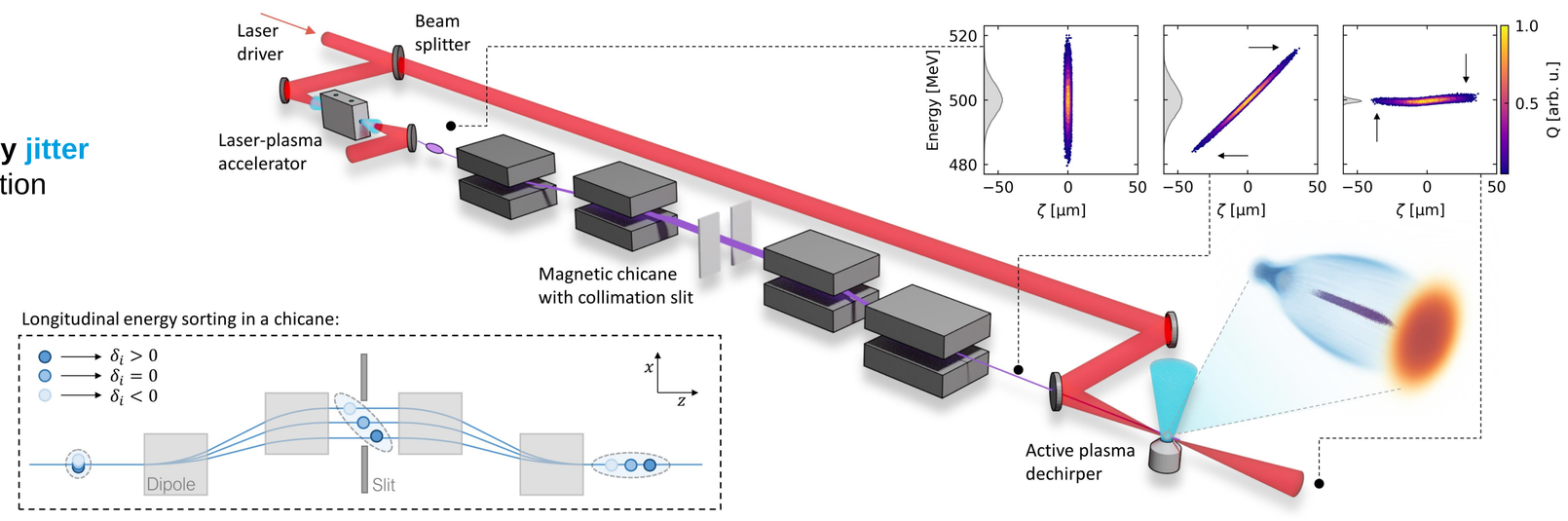
+

Active plasma dechirper (APD)
Linear longitudinal fields

+

Synchronized drivers
LPA and APD laser drivers are intrinsically synchronized

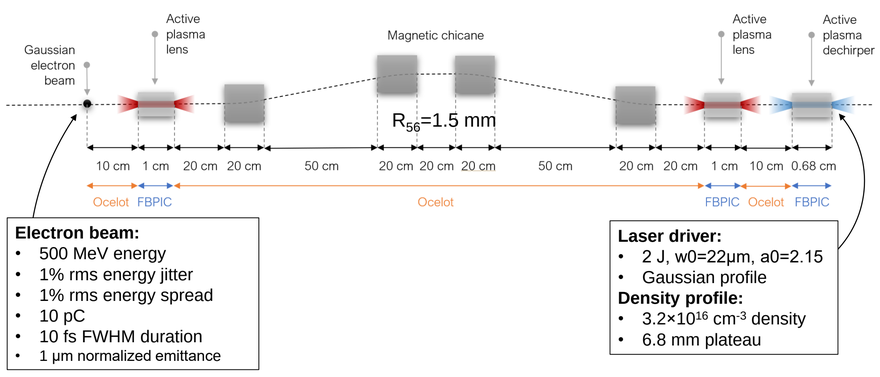
Energy jitter correction



Simulations demonstrate outstanding performance

Under idealized conditions

Initial **Gaussian** electron beam with imprinted energy jitter



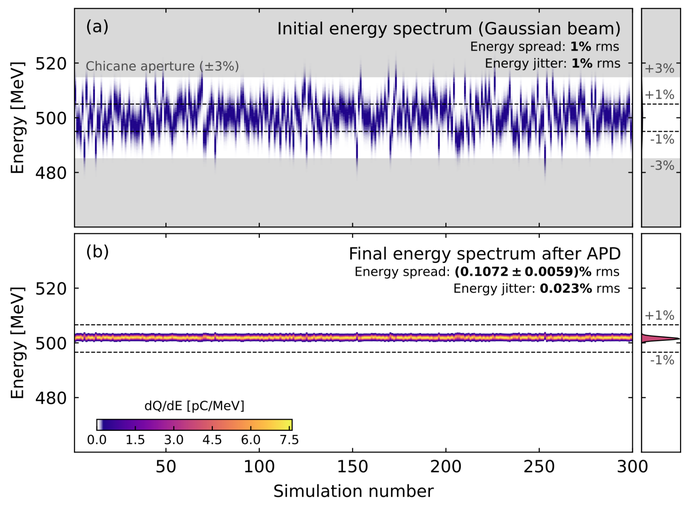
Electron beam:
- 500 MeV energy
- 1% rms energy jitter
- 1% rms energy spread
- 10 pC
- 10 fs FWHM duration
- 1 μm normalized emittance

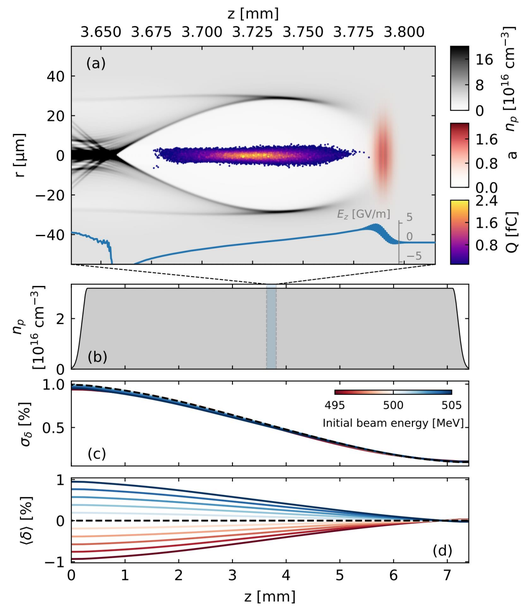
Laser driver:
- 2 J, w0=22μm, a0=2.15
- Gaussian profile

Density profile:
- 3.2×10^{16} cm^{-3} density
- 6.8 mm plateau

Energy spread
1 % ⟶ 0.11 %

Energy jitter
1 % ⟶ 0.023 %

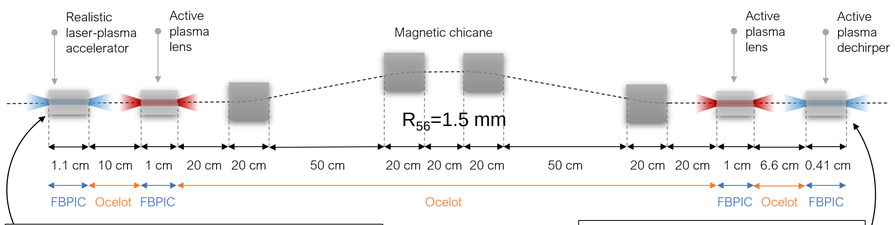




Beam evolution in the APD.

Under highly realistic conditions

Full **start-to-end simulations** with **realistic LPA** and **jitters**



Laser driver:
- 2.68 J, w0=21μm, a0=2.21, 34 fs
- Flattened Gaussian profile
- 1 % energy jitter
- 100 μm focal plane jitter
- 1% pulse duration jitter

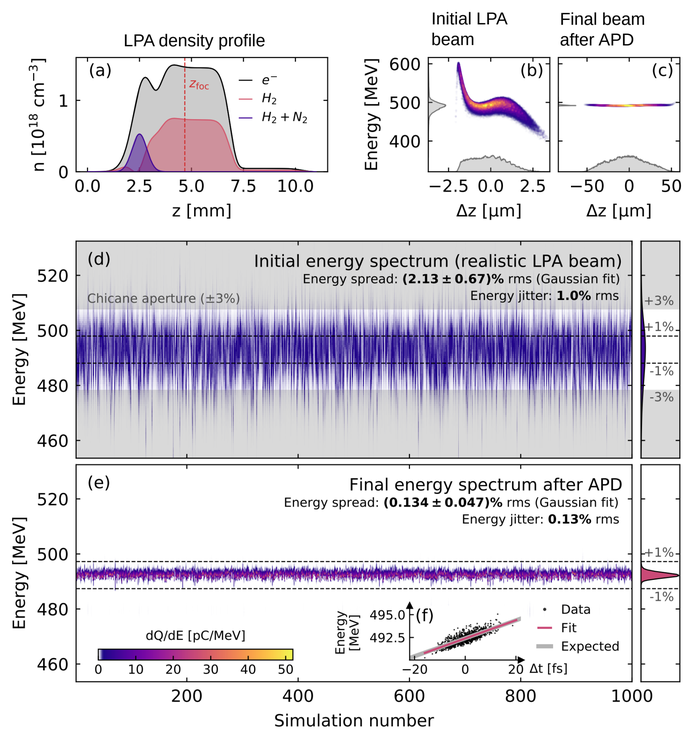
Electron beam:
- (494.3±4.9) MeV
- (2.13±0.67) % rms energy spread
- (49.8±5.6) pC
- (8.96±0.57) fs FWHM duration
- (2.48±0.12) μm normalized emittance (x)
- (0.749±0.062) μm normalized emittance (y)
- 0.5 mrad pointing jitter

Laser driver:
- 2 J, w0=27.5μm, a0=1.48, 34 fs
- Flattened Gaussian profile
- 1 % energy jitter
- 100 μm focal plane jitter
- 1% pulse duration jitter
- 5 fs timing jitter w.r.t. LPA driver

Density profile:
- 4.1×10^{16} cm^{-3} density
- 5.4 mm plateau

Energy spread
2.13 % ⟶ 0.13 %

Energy jitter
1 % ⟶ 0.13 %



For more details, see publication:

A. Ferran Pousa et al., Phys. Rev. Lett. **129**, 094801 (2022)

References

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