Time-Resolved Studies of Beam-Loading Variations in a Plasma-Wakefield Accelerator at FLASHForward

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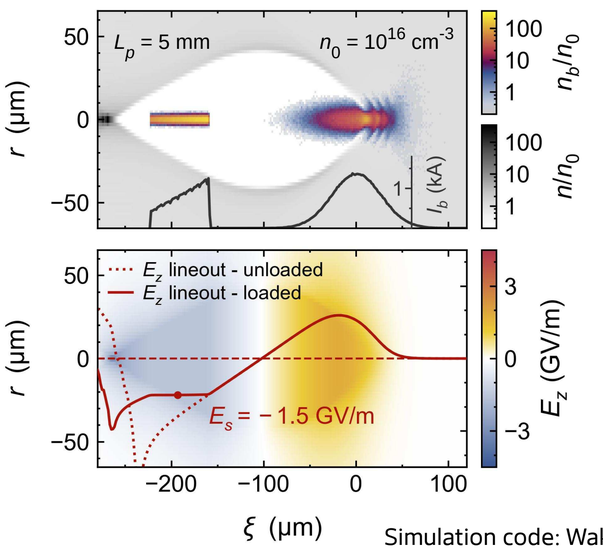
1. PWFA: beam loading in the blowout regime

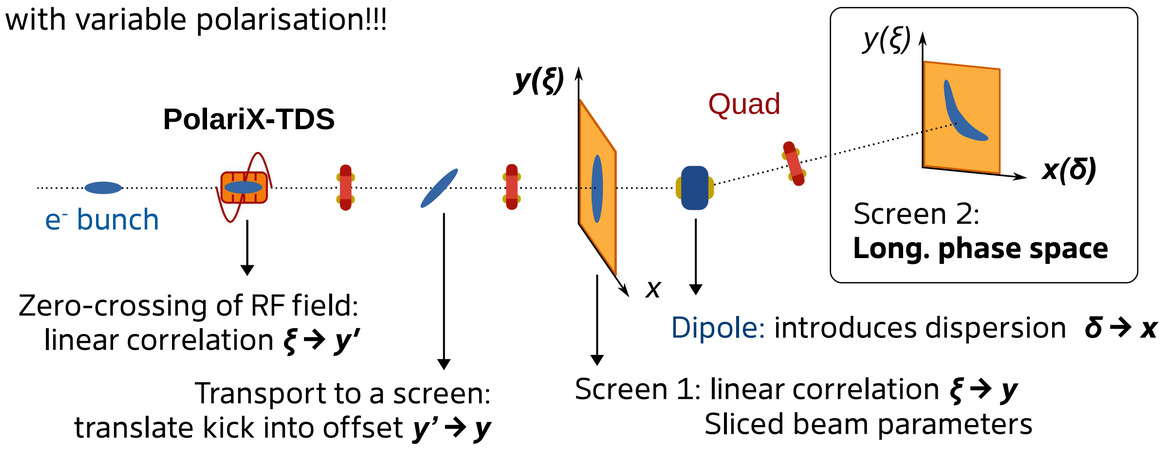


Simulation code: Wake-T [2]

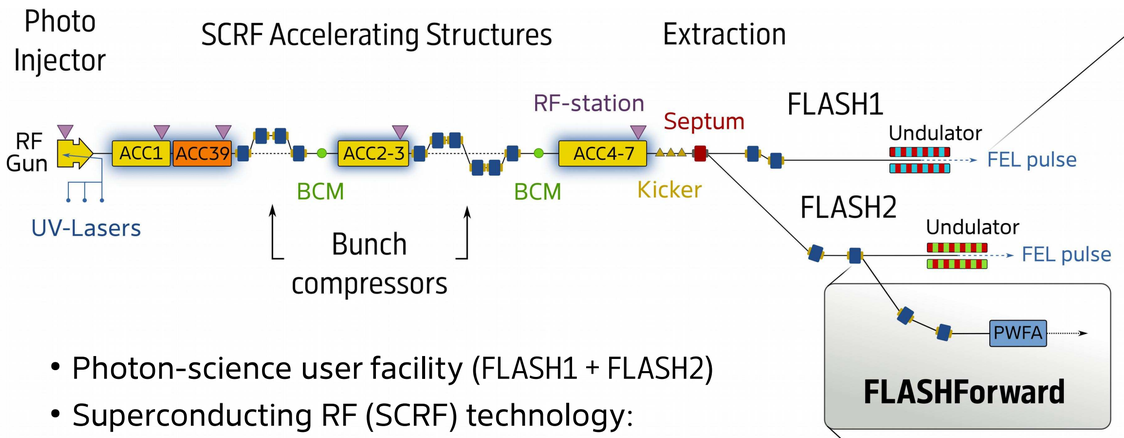
- High-energy particle-accelerators (e.g. FELs, linear colliders) require:
  → small emittance – $\varepsilon_{x,y}$
  → small energy spread – σ_δ
- Blowout regime ($n_b / n_0 >> 1$)
  → ion-column → linear focusing ✓
- BUT: control over longitudinal phase space required
  → beam loading (optimal for trapezoidal current profile [1]) ✓

2. Transverse deflection RF-structure (PolariX-TDS)

- Regular time-resolved diagnostic at Free-Electron Lasers (FEL)
- Novel PolariX-TDS [3, 4]: f_{RF} ≈ 12 GHz; V ≈ 10 MV; R_t ≈ 3 fs; with variable polarisation!!!



3a. FLASH facility [5]

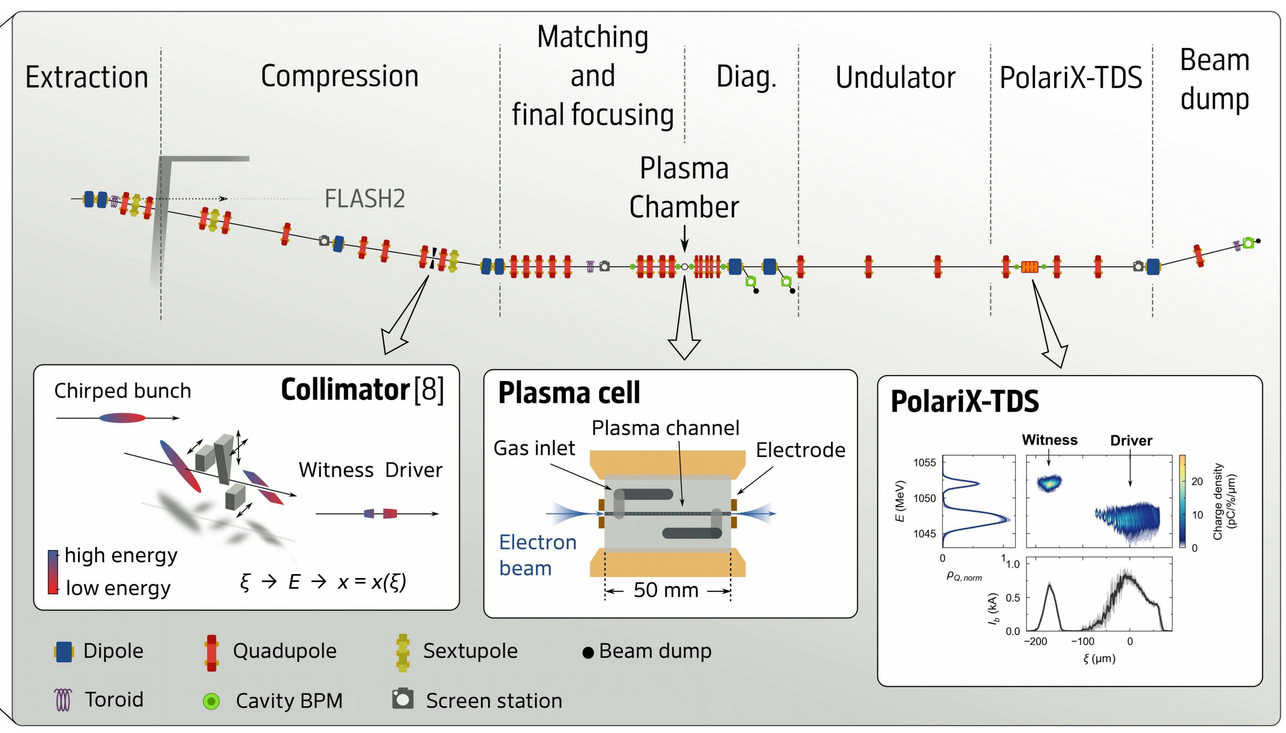


- Photon-science user facility (FLASH1 + FLASH2)
- Superconducting RF (SCRF) technology:
  → long bunch trains → RF-feedback stabilisation
- Precise tuning of longitudinal phase space
- FEL-quality electron beams at E ≤ 1.25 GeV

} Suitable for PWFA

- Bunch-compression monitors (BCM) [6]:
  → parasitic bunch length measurement – $\sigma_{\xi,\,BCM}$

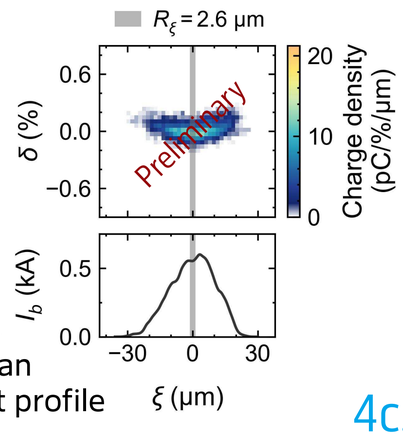
3b. FLASHForward facility [7]



4. Direct observation of beam-loading variations [9]

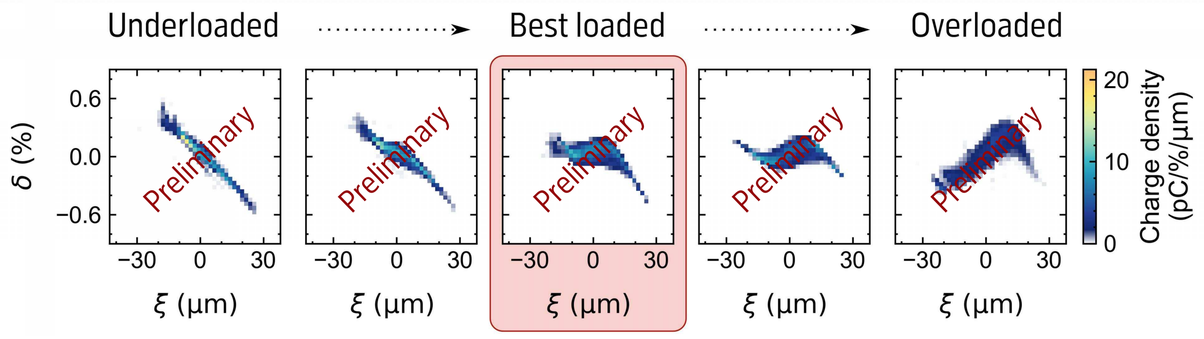
- Working-point optimisation:
  → **C. A. Lindstrøm, et al.**, PRL **126**(1), 2021
- Plasma parameters:
  → Ar gas
  → n_0 ≈ 10^{16} cm^{-3}
  → L ≈ 50 mm
- Incoming bunch:
  → E ≈ 1 GeV
  → Q ≈ 50 pC
- Accelerated bunch:
  → ΔE = 44 MeV
  → E_z ≈ 1 GV/m
  → sub-optimal beam loading
  → Q ≈ 41 pC

4a. Plasma OFF



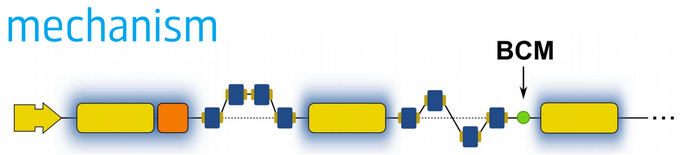
Gaussian current profile

4b. Plasma ON

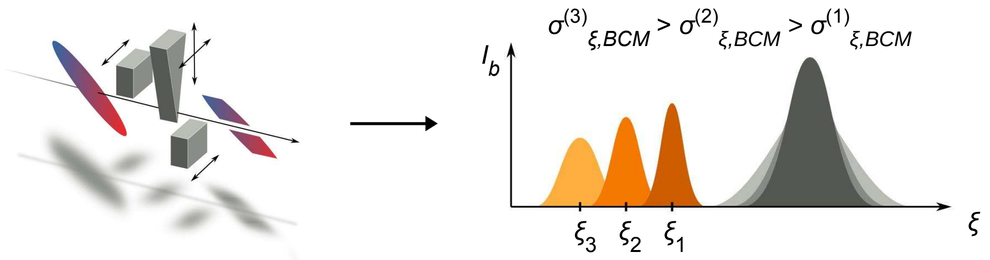


4c. Beam-loading variation mechanism

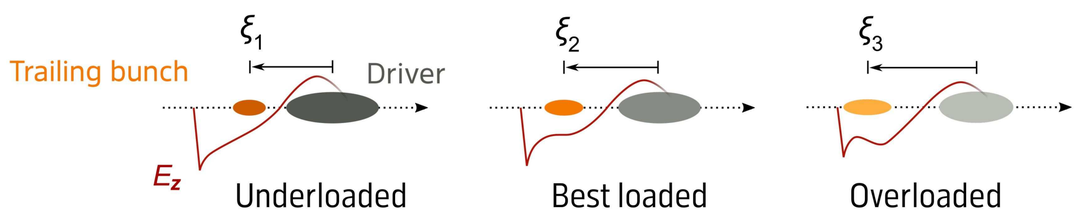
1) Compression jitter at the linac:



2) Change of scraping → modification of driver-witness current profile:



3) Variation of the amount of beam loading:



5. Conclusions & Outlook

- First direct observation of longitudinal phase space of electron bunches accelerated in a PWFA stage.
- The amount of beam loading shows a clear correlation with the amount of compression at the linac:
  → high sensitivity of PWFA acceleration to machine parameters
- These studies enable the experimental determination of machine tolerances to achieve the required stability in a PWFA stage.

References

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