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Laser-based plasma stabilization effect on a particle PWFA beam

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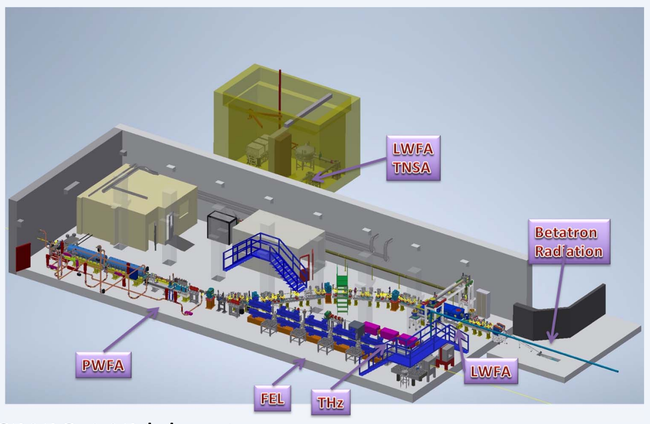
ABSTRACT

Efforts towards the next generation of compact accelerators based on plasma wakefield acceleration (PWFA) are aimed at enabling their application in various fields, including basic research, medicine, and industrial uses. To achieve this goal, significant focus is directed towards controlling the plasma creation process, ensuring the development of a time-jitter free channel, and maintaining stability, particularly in terms of uniformity and reproducibility. At SPARC_LAB, we are developing a beam driven PWFA, where an electron bunch drive the wakefield in the plasma and a second bunch, at ps delay from the first, is accelerated by the plasma. In this contribution, we present the results of an experimental campaign using a gas-filled discharge-capillary where the plasma and its generation are stabilized by triggering its ignition with an external laser pulse. The results show an efficient stabilization of the energy of the plasma accelerated beam.

SPARC_LAB facility

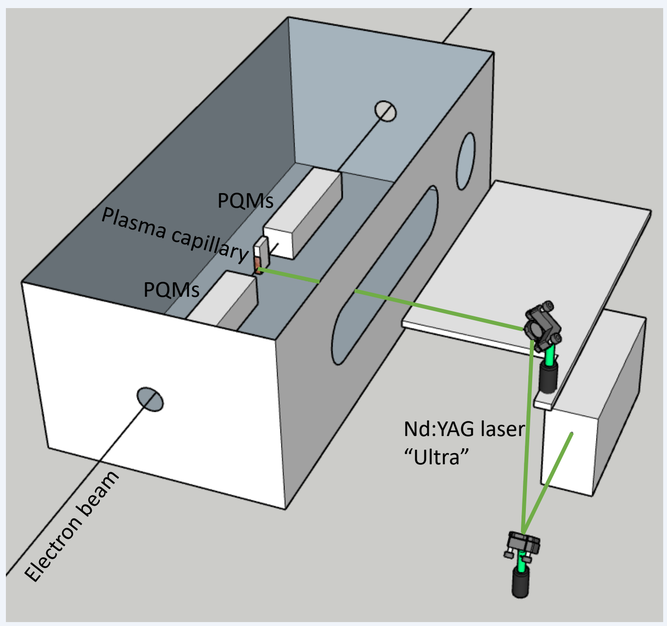


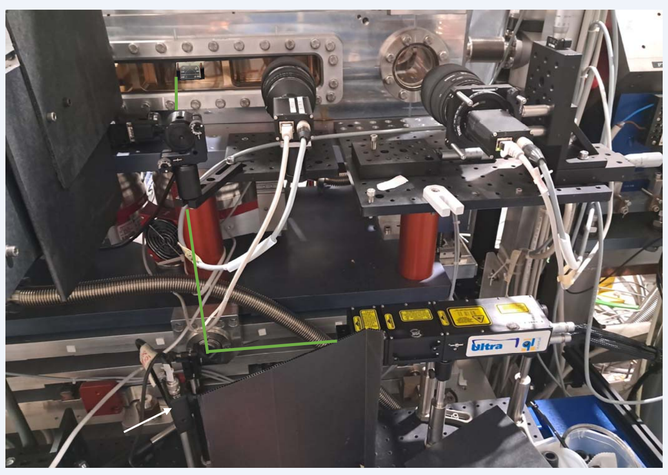
SPARC_LAB laboratory:

- High brightness photoinjector (~ 100 MeV with compressed beams) with multibunch operation[1]
- PWFA acceleration stage [2]
- Free Electron Laser beamline, linac or plasma driven [3,4]
- High power laser for plasma experiments [5]
- Other experimental radiation sources (THz [6], x-rays using Compton [7] or betatron [8])

Stabilizing laser setup

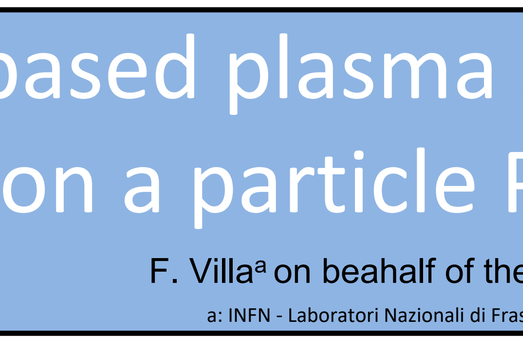
- The laser is impinging on the anode electrode at near grazing angle
- Laser parameters: duration 4 ns, energy $< 100\ \mu$J, wavelength: 532 nm
- A photodiode, beside the lower mirror, monitor the time of arrival of the laser pulse respect to the discharge and the electron beam





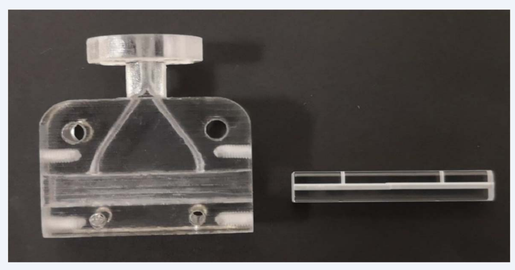
PWFA

Plasma WakeField Acceleration: beam-driven acceleration of a "witness" bunch (W) using plasma as a medium to transfer energy from "driver" bunch (D)

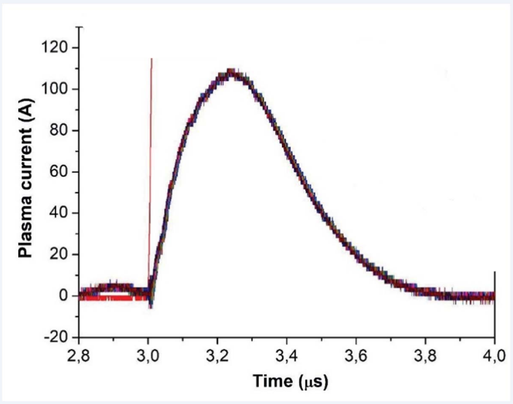


Typical PIC simulation of the PWFA process [3]

Plasma stage setup



Capillary used in the experiment: 3D printed inlets, sapphire capillary 3 cm length, 1 mm diameter, filling gas: nitrogen

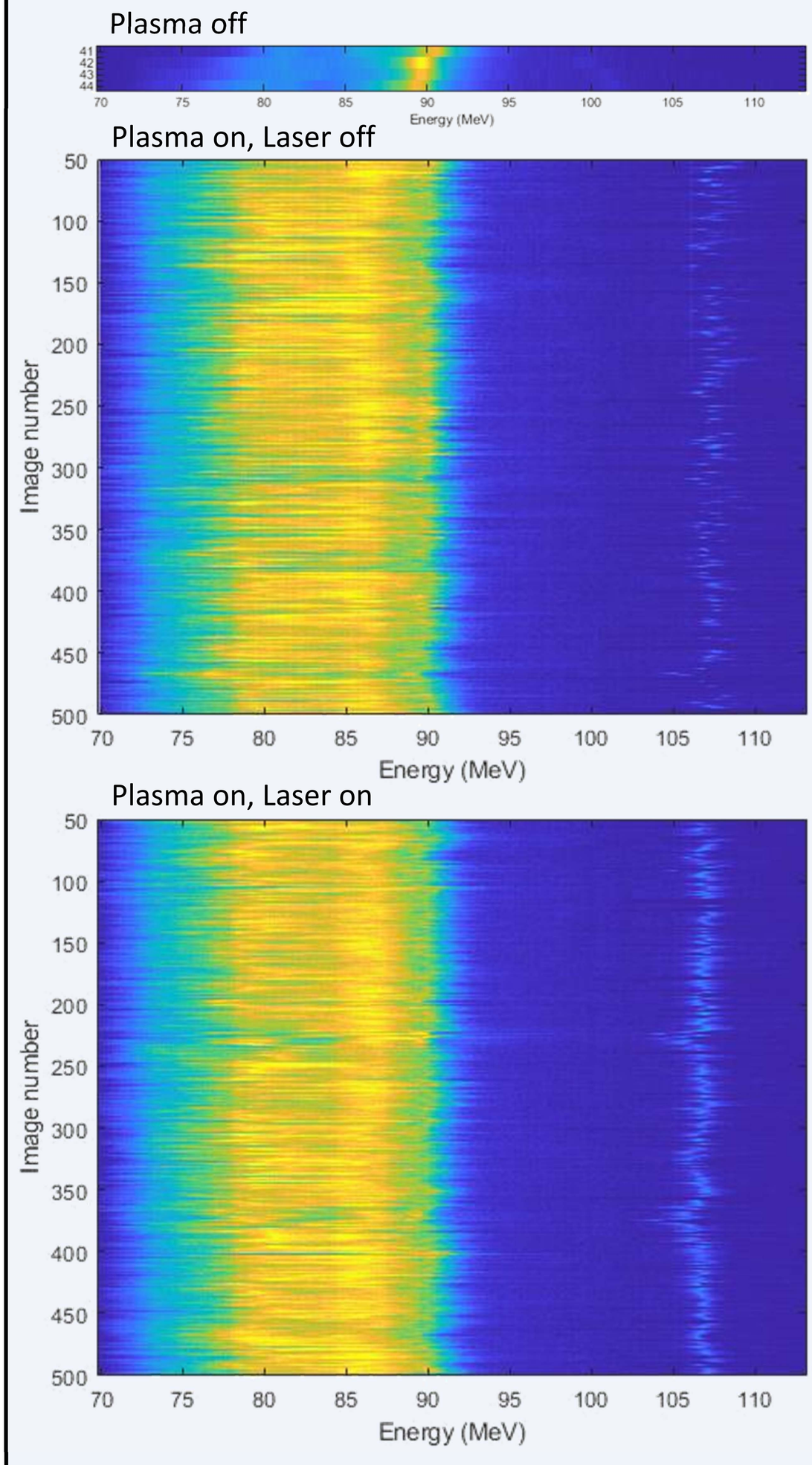


Typical discharge duration (black) inside the capillary and the stabilizing laser (red). [9]

- PWFA optimal plasma density ($10^{15} cm^{-3}$) is reach after 5.4 μs from the discharge rise.
- Shot-to-shot stability of the discharge (at 6 kV working value): [10]
  - 220 ns without the laser
  - 4 ns with the stabilizing laser
- Corresponding fluctuation in plasma density:
  - 18% without laser
  - 6% with stabilizing laser
- It is possible to work with the machine at 10Hz using nitrogen

Energy gain and stabilization effect on PWFA

Measurements at low resolution-large acceptance electron spectrometer after PWFA



- ~17 MeV gain (~550 MV/m) due to PWFA
- Without stabilizing laser: about 40% of the shots has none to very low charge (same level as the noise), witness energy jitter: 1.2 MeV
- With stabilizing laser: about 2% low charged/empty shots (some shot are affected by fluctuation in the machine values), witness energy jitter: 0.6 MeV

Bibliography

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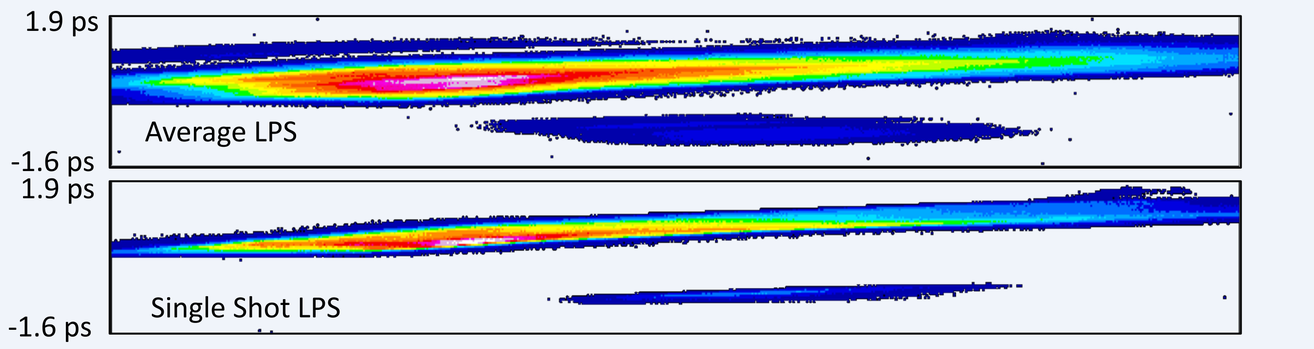
More information on SPARC_LAB website:
https://sparclab.lnf.infn.it/

Electron beam parameters before the PWFA acceleration



Longitudinal phase space of the electron beams before the plasma interaction

- Driver-witness separation: 1.3±0.1 ps, <0.5 MeV (centroids)
- Charge: 500±20 pC driver, 49±2 pC witness