The goal of the external injection experiment at SPARC-LAB is to demonstrate the possibility to accelerate a high brightness electron beam, produced by a conventional accelerator, by exploiting the wakefields generated in an underdense plasma by a high power laser pulse, without degrading too much its emittance and energy spread. Simulations foresee an output beam with a charge up to 25 pC, an energy of up to 1 GeV, an energy spread within 1% around the peak current and an emittance of a few mm-mrad.
Simulations of LWFA

Simulations are performed using the code QFLUID2 which has the following features:

1) fluid approximation of the plasma;
2) quasi-static approximation;
3) cylindrical symmetry;
4) laser envelope evolution is self-consistent.

The accelerated bunch dynamics is resolved in a PIC-like fashion. QFLUID2 has been benchmarked with the 3D PIC code ALADYN.

EARLY SIMULATIONS: THE DREAM BEAM

The first simulations were performed assuming the laser guided by means of a transverse tapering of the plasma density. Since no power leakage due to capillary walls was present, the acceleration could take place over lengths in excess of 10 cm. The input bunch was a reasonable scaling of a beam produced by S2E simulations from photocathode to linal exit (w/o dogleg).

Emean=2.01 G eV
ΔE/E=0.8% rms
ε_n=0.6 mm.mrad

To new simulations results

MAIN INPUT PARAMETERS

e-Bunch: 13pC, 150MeV, 0.6 mm.mrad, 3.0μm rms trav. size, 2.4μm rms long. size
（About 1kA peak current）
Laser: 7J in 35fs, w0=32.5 um, w0_inj=135 um, guided over 30 ZR.
Plasma: tapered transv. density profile btw 0.6 10^{17} cm^{-3} and 0.8 10^{17} cm^{-3} for laser guiding.
Long. decreasing density tapering to cope with dephasing. Acceleration length of about 15cm.

The method is not viable when the laser is guided by a capillary since the focus position MUST be at the capillary entrance in order to maximize power coupling [1]. The solution is to taper the longitudinal plasma density such as to create a matching ramp. Its is likely that the same device can prevent most of the emittance dilution due to chromatism [2].

To main page

Beam matching

To solve the matching problem it is possible to inject the e-beam inside the plasma while the laser pulse is not yet completely focused. The increasing focussing forces compress the bunch adiabatically down to the optimal transverse size.

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**Simulations of LWFAimulation tool**

Simulations are performed using the code QFLUID2 which has the following features:

1. Fluid approximation of the plasma;
2. Quasi-static approximation;
3. Cylindrical symmetry;
4. Laser envelope evolution is self-consistent.

The accelerated bunch dynamics is resolved in a PIC-like fashion. QFLUID2 has been benchmarked with the 3D PIC code ALADYN.

**NEW SIMULATIONS: INTERMEDIATE STEPS**

As the experimental setting became clearer it was decided that the bunch used in the present simulations comes from a high charge beam accelerated in the linac and subsequently
shortened by velocity bunching, magnetic compression and by means of an RF deflector + collimator. Such bunches are a little bit longer than desired (about 5 um instead of 2 um). We can consider them as intermediate, easier steps toward the fully optimized beam that will be produced with a low charge-low length from the photocathode and furtherly shortened by velocity bunching, magnetic compression and by means of an RF deflector + collimator. Such bunches are a

**Beam matching**

In these simulations the beam matching has been performed "by hand", meaning that the transverse size was reduced to the right matched value (about 0.5 the true value) keeping the emittance constant. Moreover the beam is not matched at the plasma exit and this is clear from the emittance increase downstream LWFA.

In the experimental setting we foresee to perform the two matchings by tailoring the longitudinal plasma density at the capillary extremities, maybe using some kind of capillary shaping. Studies are underway to assess whether this kind of solution is viable.

**MAIN INPUT PARAMETERS** are as displayed in the “E-BEAM PRODUCTION” section. (there)

**References**


**Beam transport downstream plasma acceleration**

The beam is focussed by a triplet and dispersed by a dipole to a spectrometer about 5 m away

**Emittance dilution due to chromatism**

![Image](image-url)

**More on shorter bunches, matching and diagnostics**

Electron beam production and transport

<table>
<thead>
<tr>
<th>Bunch charge (pC)</th>
<th>Energy (MeV)</th>
<th>Bunch length (μm)</th>
<th>Norm. RMS Emittance (mm)</th>
<th>Energy Spread (%)</th>
<th>σ beam @ Interact (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 - 25</td>
<td>100 - 150</td>
<td>&lt; 0.5</td>
<td>&lt; 0.5</td>
<td>5 - 10</td>
<td></td>
</tr>
</tbody>
</table>

Beam parameters ranges at plasma injection

First CASE: RF deflector + Collimator

IN

OUT

Q ≈ 12 pC
σz ≈ 23 μ

This bunch is too long to be successfully accelerated in a plasma wave.

Second CASE: as first case + velocity bunching

IN

OUT

Q ≈ 5 pC
σz ≈ 0.5 μ

This bunch can be easily injected inside the plasma wave and the expected accelerated beam seems promising.

Sketch of the collimator used in the simulations

20 μ gap

2 mm thickness

7.5 cm spacing

Display layout


A. Bacci, L. Serafini, INFN-MI, Milan, Italy.

A. Cianchi, Università di Tor Vergata, Rome, Italy.

A. Mostacci, Università di Roma “La Sapienza”, Rome, Italy.

INFN-LNF, Frascati, Italy.

INFN-MI, Milan, Italy.

Università di Tor Vergata, Rome, Italy.

Università di Milano, Milan, Italy.

A. Mostacci, Università di Roma “La Sapienza”, Rome, Italy.
The SPARC_LAB sub-ps synchronization of electrons and photons consists in locking all sub-systems to a very stable reference signal distributed over the machine. The maximum acceptable time jitter between electron and photon at interaction points is about 100 fs rms for Thomson scattering experiment and <50 fs for LPWFA with external injection. Thus, the main issues are two:

1) Distribute a reference signal with a high phase stability:
   - Electrical signal through coaxial cables
   - Optical signal through glass fibers

2) Lock each sub-system (MIRA photo-injector laser oscillator, FLAME laser oscillator and RF power distribution) to the reference. Figure 1 shows the case of an electrical distribution using coaxial cables. This solution is ready to be tested at SPARC_LAB since we have recently installed a thermal isolated cable bundle containing the coaxial cables (Figure 2). A dedicated cable has been placed for the future installation of fiber links. Thermal isolation has been chosen to grant a very low dependency of cables elongation with respect to the external temperature behavior. Optionally, an electrical phase feedback system could be implemented to compensate the residual temperature drift.

An electrical reference oscillator at 79.33 MHz (the main RF frequency) is used to lock the MIRA laser oscillator. The locking system is a standard electro-opto-mechanical PLL. The phase comparison is performed at 285.6 MHz to obtain a good resolution. One of the phase detector input is the signal coming from a frequency up-conversion of the electrical reference oscillator by means of a comb generator and a band-pass filter. The second input comes from a large bandwidth photodiod illuminated by the MIRA pulse train and band-pass filter at 285.6 MHz. The error signal is sent to a piezo-motor driver that regulates the length of the laser cavity to stabilize the pulse train frequency. The same method is used to synchronize the FLAME oscillator to the reference. Also the 79.33 MHz coming from the two laser oscillators should be compared and the phase difference should be used to drive a phase shifter to ensure the superposition of the laser pulses that happens every 12.6 ns (one period of the train repetition rate). This is mandatory if we want an efficient and repeatable electron-laser interaction.

A slow feedback is operating to compensate the waveguide network drift due to temperature changes. A fast loop is operating around the klystron to stabilize the phase into a single RF pulse compensating the klystron tuning drift. Recently we have upgraded the MIRA PLL designing a new phase detection and error amplifier system. A more precise synchronization has been achieved limiting the error signal in the frequencies up to some kHz from the carrier reference. The result is shown in Figure 3, where the two phase spectra of the reference and the MIRA spectrum are plotted together with the absolute time jitter obtained by integrating the curves from lower to higher frequency. The absolute jitter are low and the relative one can be estimated to be sub-20 fs. This is a great enhancement since the standard system purchased with the laser yielded a relative jitter of about 350 fs.

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1) Distribute a reference signal with high phase stability:
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2) Lock each sub-system (MIRA photo-injector laser oscillator, FLAME laser oscillator and RF power distribution) to the reference.

A future upgrade of the system is foreseen in the late 2012, when an optical reference oscillator and an optical distribution system will be installed and tested. This should yield a very high time arrival resolution (2 fs or better) and consequently high performance PLLs.

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CAPILLARY:
laser guiding and beam matching system

SHORT BUNCHES FROM PHOTO-CATHODE

DIAGNOSTIC STATION