Recent results from SPARC_LAB

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on behalf of the SPARC_LAB collaboration
SPARC_LAB test-facility

High brightness photo-injector

Low-current operation
- 30-170 MeV beam energy
- 1-10 ps bunch duration
- 0.1-1 nC charge

Thomson source
FEL

High-current operation (VB)
- 80-120 MeV beam energy
- 20 fs - 1 ps bunch duration
- 10-600 pC charge

THz radiation source
FEL (single spike + seeding)
Multi-bunch trains
LWFA (external injection)

Narrowband THz
FEL (2 colors)
PWFA (w/ resonant scheme)

Plasma-based acceleration

- Several plasma-based schemes will be tested
  - **PWFA resonant scheme** → 1-2 GV/m expected
    - $n_e \sim 10^{16}$ cm$^{-3}$, 1 mm diameter capillary, Hydrogen
  - **LWFA, external injection** → 5-10 GV/m expected
    - $n_e \sim 10^{17}$ cm$^{-3}$, 100 μm diameter capillary, Hydrogen

- **Goal:** high quality accelerated beams
  - Maintain the high brightness of injected beams
Plasma interaction chamber

Beam injection
- Longitudinal diagnostics (EOS)
- Transverse diagnostics (Ce:YAG screen)
- PMQ (NdFeB, $B_r > 1.3$ T) → 520 T/m

Hydrogen inlet
- 50-100 mbar from source
- 10 mbar in capillary

Turbo pumps
- 3x400 l/sec

Beam extraction
- PMQ, 520 T/m

Acceleration + diagnostics
- 3 cm length capillary
- 1 mm hole diameter
- $n_0$ measure by Stark broadening

SPARC linac
- 2 S-band TW sections (3 m)
- Last S-band section replaced with a C-band one (1.3 m)

Vacuum tests on the experimental chamber

Beam diagnostics
- Transverse diagnostics (Ce:YAG screen)
- THz station (CTR/CDR)

Thanks to V. Lollo
Vacuum level during plasma runs

Plasma chamber

RF gun (11 m away)

Gas flow @ 1 Hz

RF C-band section (1 m away)
PMQ installation

- Three PMQs installed, movable in z
- 2 movable channels (2 piezo motors)

520 T/m PMQs made by KYMA
- PMQ1 (close to capillary) is fixed
- 1st actuator moves PMQ2 and PMQ3 with respect to PMQ1
- 2nd actuator moves PMQ3 with respect to PMQ2 and PMQ1

- Minimum distance between quads is 3-4mm
- Maximum distance is >10mm
- Several springs are used to help against magnetic attraction
- The XYZ offsets and the phi-angle of the system are manually adjusted
Preliminary results

Without PMQs

With PMQs

67 um

54 um

18 um

14 um
Plasma characterization in capillary

Plasma density measurement from $\text{H}_\beta$ Stark broadening

The plasma density is controlled through the delay after the discharge

$$n_e = n_{e0} \exp(-\alpha t)$$

$$\alpha \approx 1.45 \mu s^{-1}$$
Active plasma lens

- Focusing field produced by electric discharge in a plasma-filled capillary
  - *Focusing field produced, according to Ampere's law, by the discharge current*

  \[ B_\phi(r) = \frac{1}{2} \int_0^r \mu_0 J(r') dr' \]

  - Weak chromaticity
    - \( K_{\text{focusing}} \) scales as \( 1/\gamma \)
  - Radial focusing
    - *Unlike quads it focuses in the two planes simultaneously*
  - Compactness
    - *Higher integrated field than permanent quadrupole magnets (PMQ)*
  - Not sensitive to beam distribution
    - *This is the case of passive (over/under-dense) plasma lenses*

Experimental layout

- Bunch
- Capillary
- Plasma
- Discharge circuit

Vacuum impedance

E. Chiadroni talk
Thursday 8.30

- Bunch
- Plasma
- Discharge circuit

OTR target

- 50 pC
- 1 ps
- 130 um
- 120 MeV
- 1 mm mrad

Vacuum impedance

- $n_e = 10^{17} \text{ cm}^{-3}$
- $V = 20 \text{ kV}$
- $I = 100 \text{ A}$
- $R_0 = 500 \text{ um}$
- $L = 3 \text{ cm}$
- Sapphire/Plastic
Active plasma lensing effect

Discharge ON (43A, 40 ns delay)

Discharge current profile
Electro-Optical Sampling

- Laser crosses the crystal with an angle (30°)
- Polarization modulation → transferred to intensity modulation by means of linear polarizer

\[ I_{det} = I_{laser} \sin^2 \Gamma \propto E_{THz}^2 \]
Multi-bunch trains with THz separation

ZnTe (400μm), single bunch 510 fs

GaP (100μm), comb beam (160 and 200 fs, 800 fs distance)

80 fs temporal resolution

Bunch compression and timing-jitter

- Ultra-short bunches with ultra-low jitter wrt laser pulses
  - Seeded FELs
  - External injection in laser-driven plasmas

- Photo-cathode laser

- VB compression

- Timing linked to PC laser → launch time-arrival time correlation \( \sim 1 \)

- Timing linked to compressor (RF) → launch time-arrival time correlation \( \sim 0 \)

- \( \sim 60 \text{ fs laser-bunch timing-jitter} \)

- LPS (Space-charge ON)
- LPS (Space-charge OFF)

- Bunch chirp
- Jitter chirp

- Launch time vs arrival time

- Relative energy offset (%) vs Time (fs)

- Arrival Time (ps) vs Launch Time (ps)
Jitter reduction by hybrid compression

Hybrid compression: bunch shortening by VB, relative ATJ reduction by magnetic compression

Conclusions

- SPARC_LAB is currently preparing the beam-driven plasma acceleration experiment. First tests are foreseen in next months.

- In 2016 we have investigated the focusing properties of a 3 cm-long active plasma lens, “probed” by an high-brightness electron beam

- We fully characterize the bunch 6D phase space for the first time
  - Results indicate that the longitudinal phase space (energy and duration) are not affected by the plasma lens
  - Strong nonlinearities are introduced on the transverse phase space (emittance) due to the nonlinear focusing field produced by the HV discharge

- For the external injection laser-driven acceleration we have demonstrated the possibility to ensure ultra-low timing-jitters between the laser pulse and the ultra-short bunch
  - It represents one of the most challenging issues in such experiments
  - An ultra-low timing jitter <20 fs has been experimentally achieved
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Thank you for your attention!