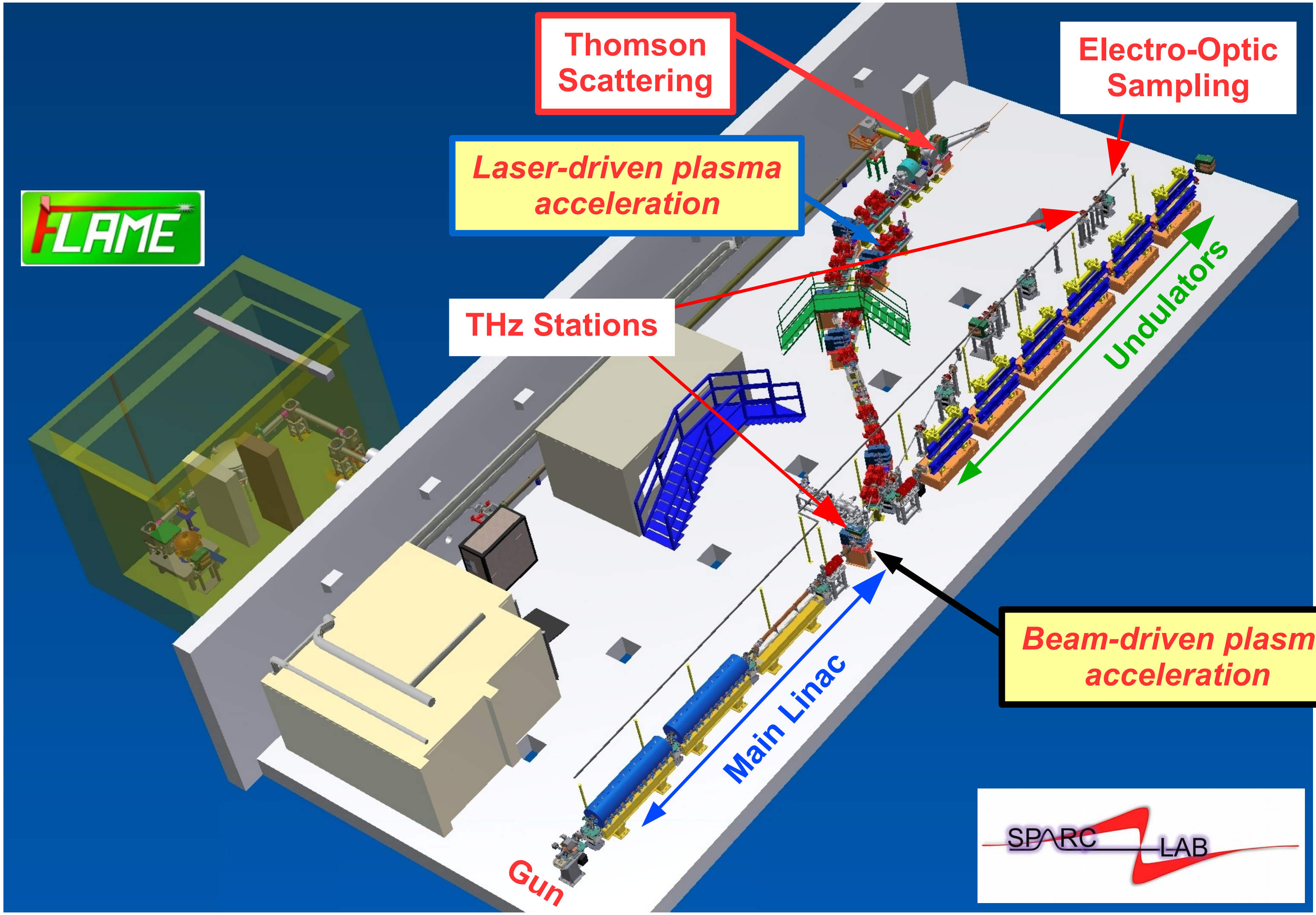
4th EuCARD-2 Annual Meeting

Recent results from SPARC_LAB facility

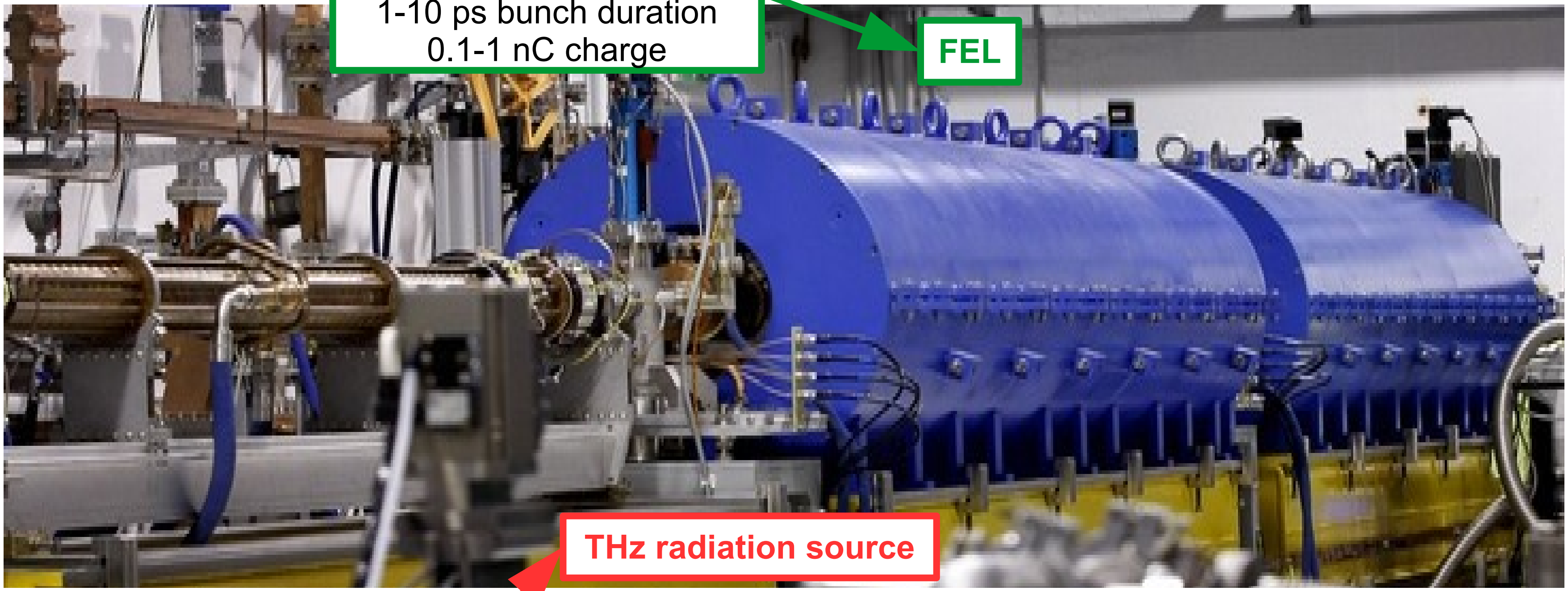
Riccardo Pompili
LNF-INFN
on behalf of the SPARC_LAB collaboration

SPARC_LAB test-facility



Ferrario, M., et al. "SPARC_LAB present and future." NIMB 309 (2013): 183-188.

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**

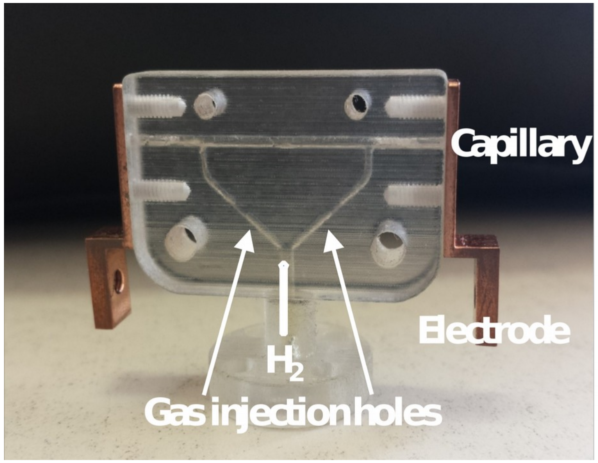
High-current operation (VB)
80-120 MeV beam energy
20 fs - 1 ps bunch duration
10-600 pC charge

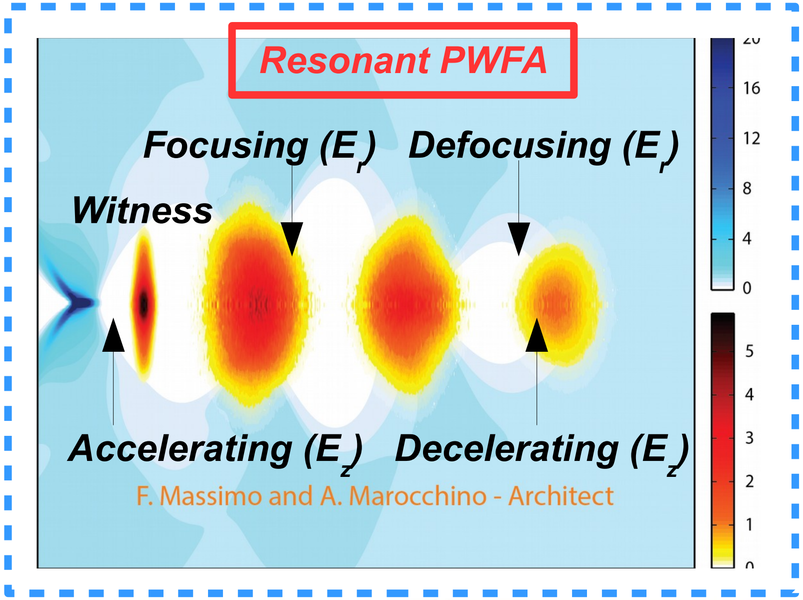
→ **THz radiation source**
→ **FEL (single spike + seeding)**
→ **Multi-bunch trains**
  → **Narrowband THz**
  → **FEL (2 colors)**
  → **PWFA (w/ resonant scheme)**
→ **LWFA (external injection)**

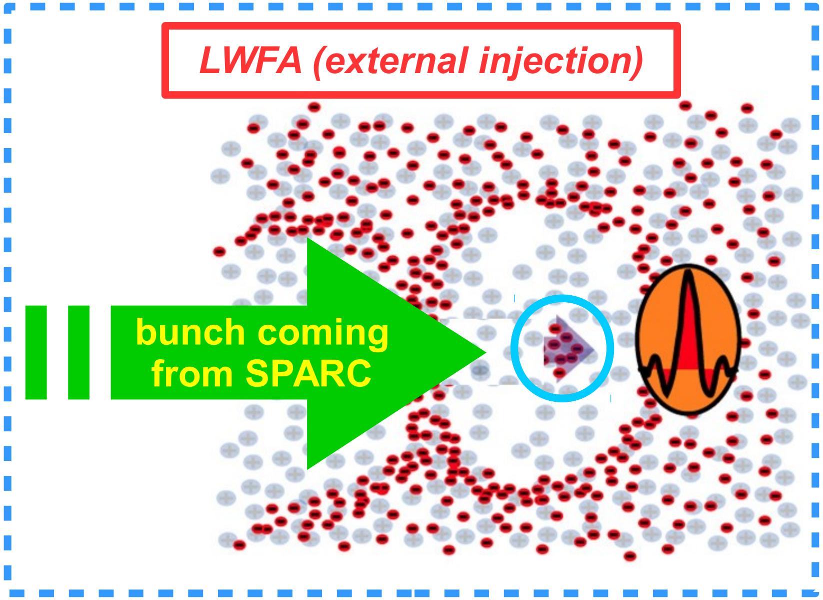
Serafini L., Ferrario M. "Velocity bunching in photo-injectors." AIP conference proceedings. 2001.
Anderson, S. G., et al. "Velocity bunching of high-brightness electron beams." PRSTAB 8.1 (2005): 014401.

Plasma-based acceleration

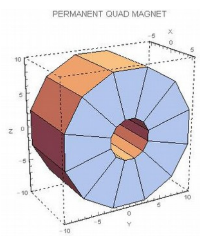
- Several plasma-based schemes will be tested
  - ***PWFA** resonant scheme → **1-2 GV/m** expected*
    - ***n_e~10^{16} cm^{-3}, 1 mm diameter capillary, Hydrogen***
  - ***LWFA**, external injection → **5-10 GV/m** expected*
    - ***n_e~10^{17} cm^{-3}, 100 μm diameter capillary, Hydrogen***
- Goal: **high quality** accelerated beams
  - *Maintain the high brightness of injected beams*







Plasma interaction chamber



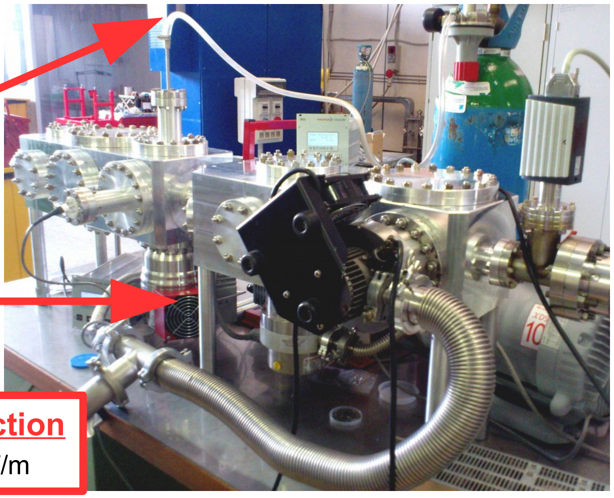
Beam injection
- Longitudinal diagnostics (EOS)
- Transverse diagnostics (Ce:YAG screen)
- PMQ (NdFeB, B_r>1.3 T) → 520 T/m

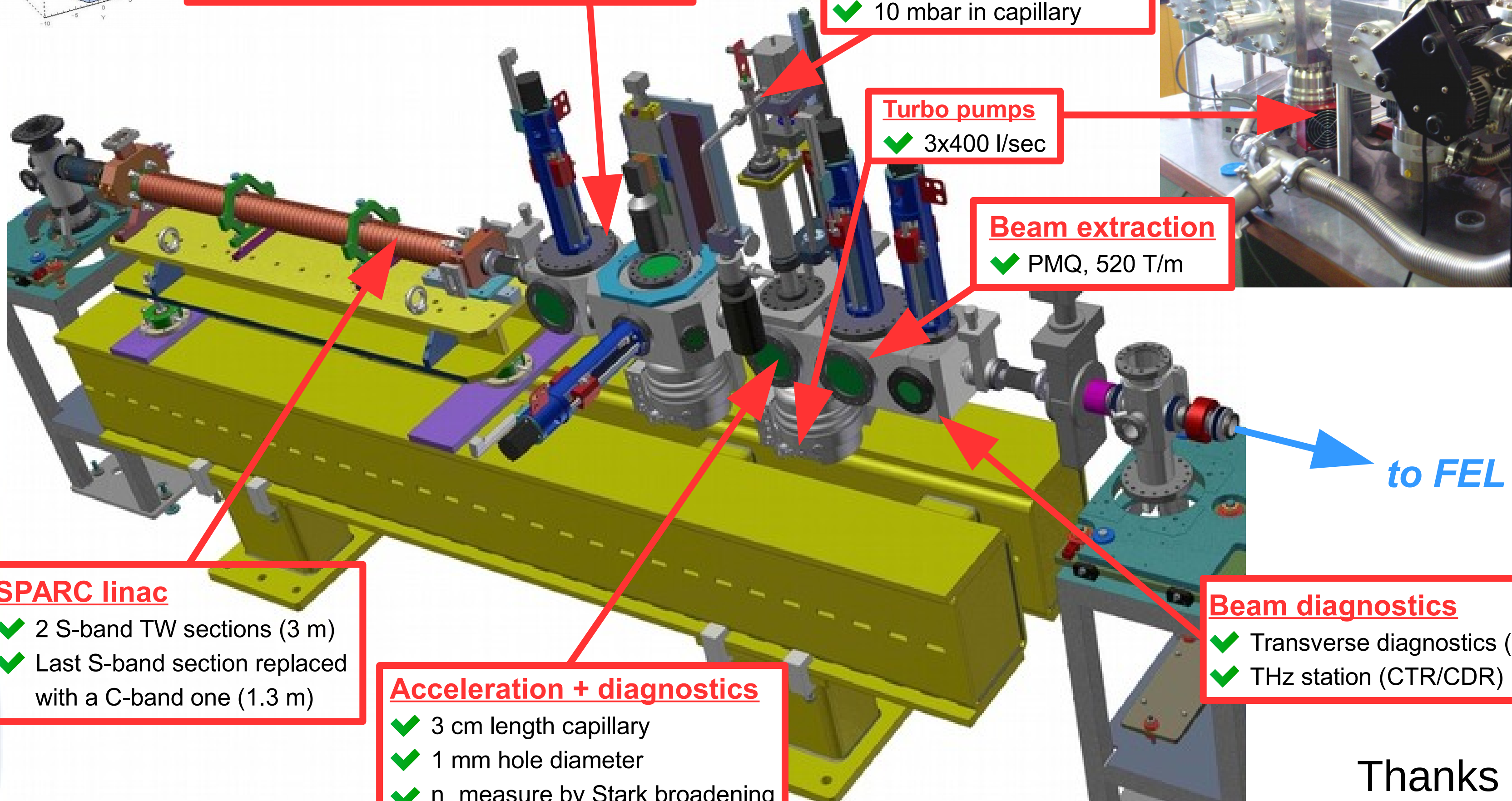
Hydrogen inlet
- 50-100 mbar from source
- 10 mbar in capillary

Turbo pumps
- 3x400 l/sec

Beam extraction
- PMQ, 520 T/m

Vacuum tests on the experimental chamber





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

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

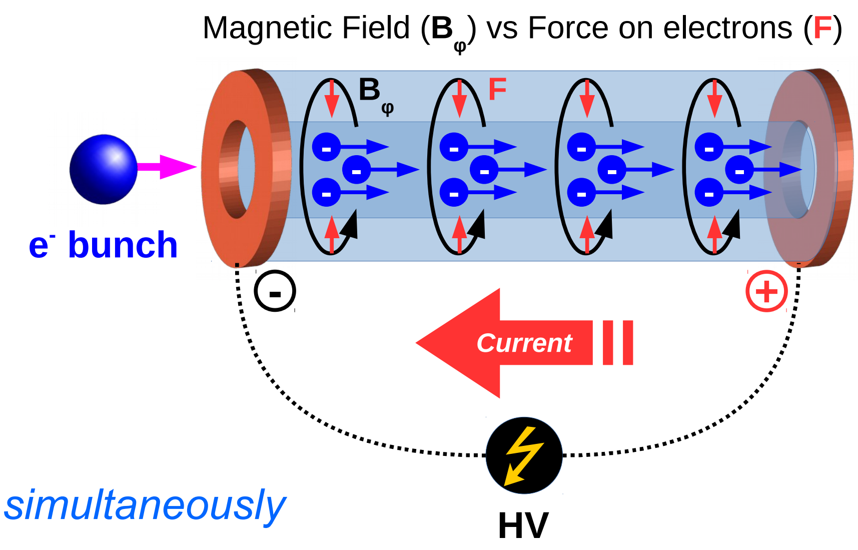
Beam diagnostics
- Transverse diagnostics (Ce:YAG screen)
- THz station (CTR/CDR)

Thanks to V. Lollo

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*

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

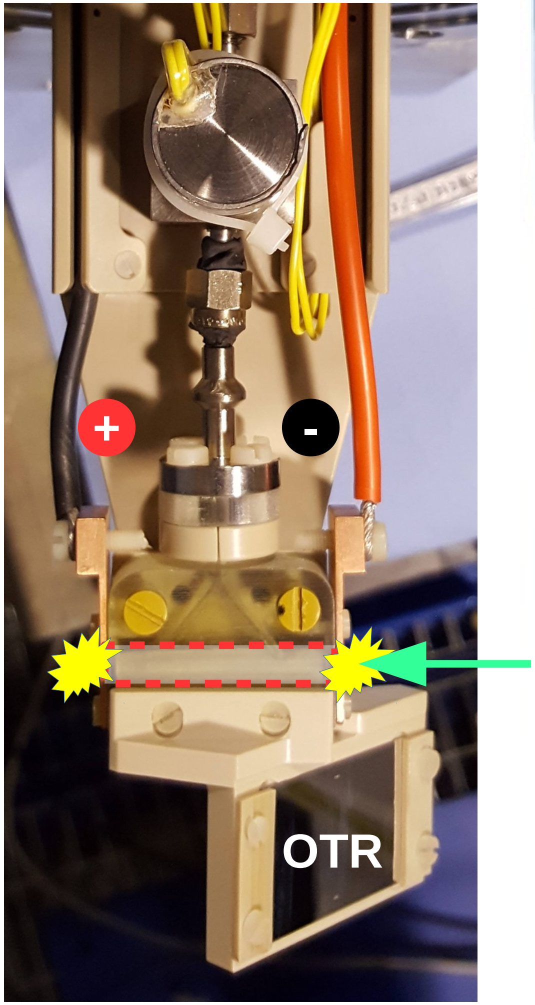


- ✓ Weak chromaticity
  - *$K_{focusing}$ scales as 1/γ*
- ✓ Radial focusing
  - *Unlike quads it focuses in the two planes simultaneously*
- ✓ Compactness
  - *Higher integrated field than permanent quadrupole magnets (PMQ)*
- ✓ Not sensitive to beam distribution
  - *This is the case of passive (over/under-dense)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

Van Tilborg, J., et al. "Active plasma lensing for relativistic laser-plasma-accelerated electron beams." Physical review letters 115.18 (2015): 184802.
Pompili, R., et al. "Experimental characterization of active plasma lensing for electron beams." Applied Physics Letters 110.10 (2017): 104101.

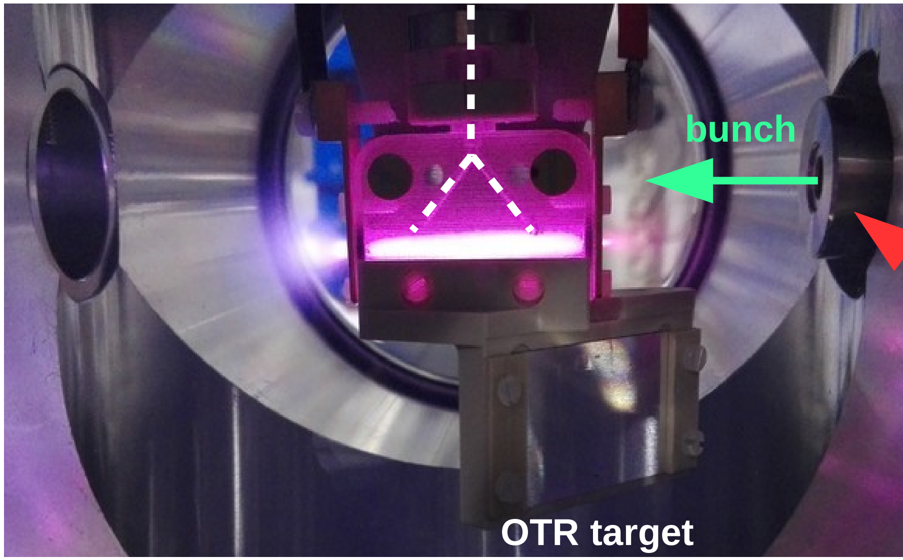
Discharge-capillary setup

- First tests on active plasma lensing have been carried out in April 2016
  - *3 cm-long capillary made by sapphire*
  - *1mm hole diameter*
  - *2 symmetric inlets for gas flow at ¼ and ¾ of capillary*
  - *A plastic housing (3D printed) is used to fix the capillary to a PEEK (vacuum compatible) support*
  - *An OTR screen is installed below in correspondence of the capillary entrance to measure the beam spot size*

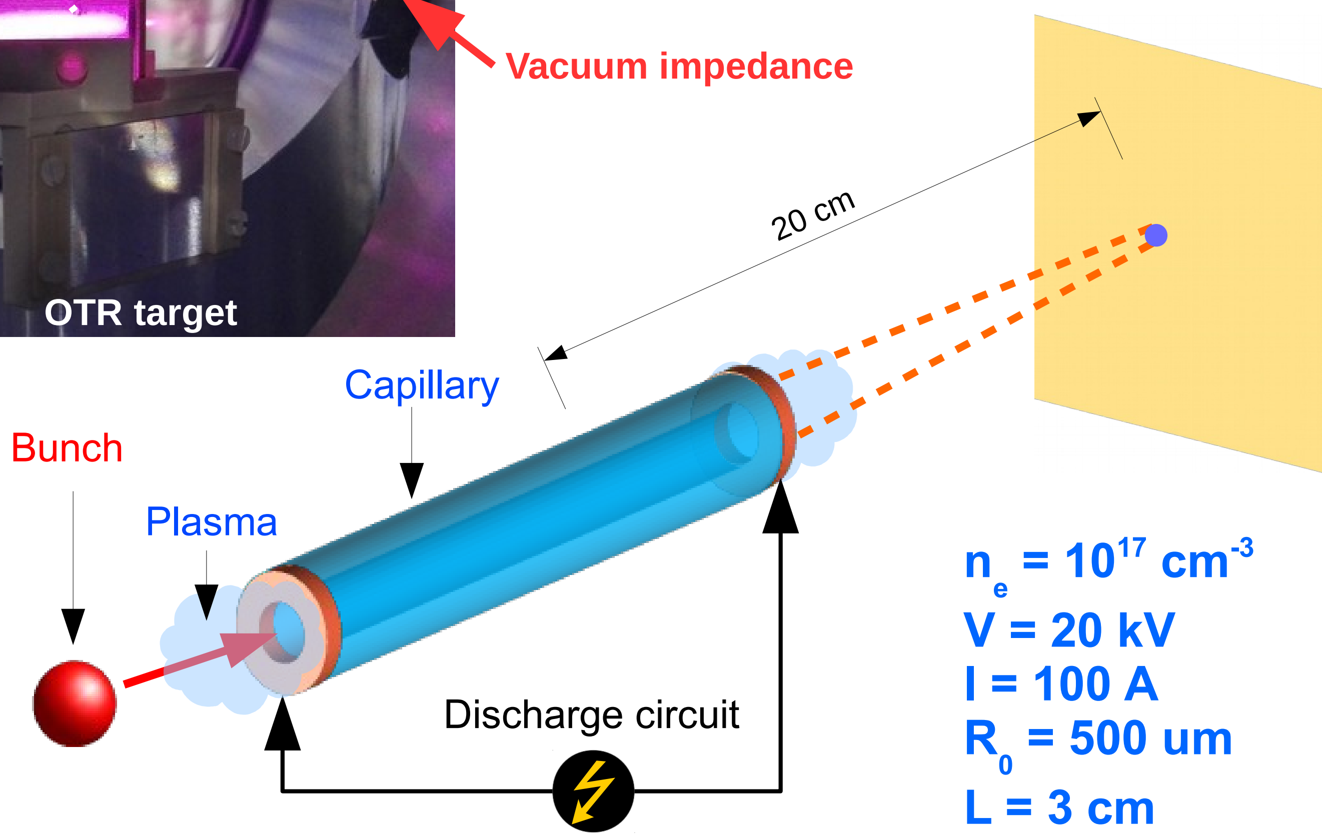


- The H_2 generation and injection system consists of
  - *Electrolytic generator (1L of water → 1.4 m^3 Hydrogen)*
  - *Pressure reduction system (300 mbar → 10 mbar in capillary)*
  - *Electro-valve triggered by the HV discharge with tunable aperture (3 ms) and delay time (10 us before discharge)*

Experimental layout



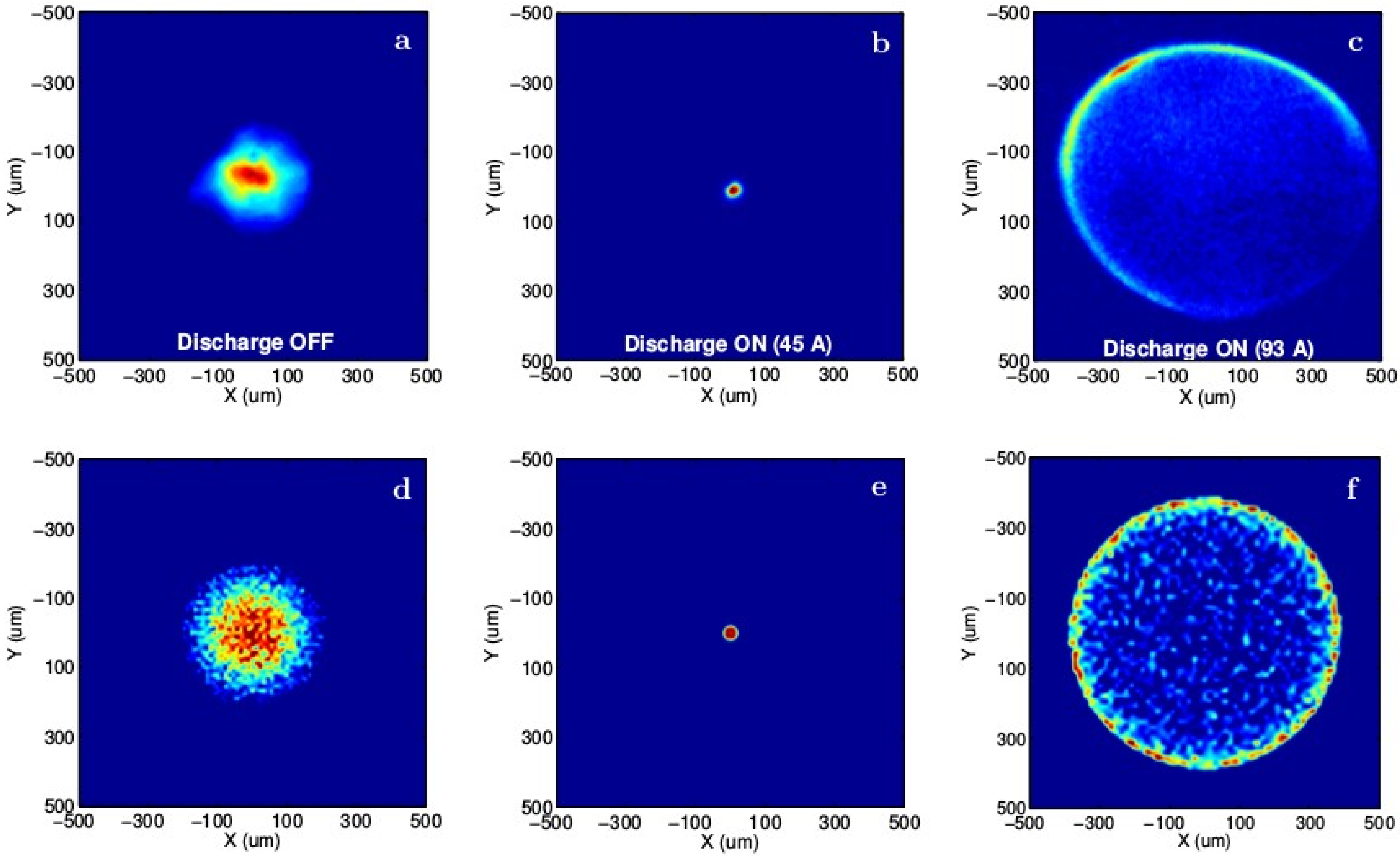
Vacuum impedance



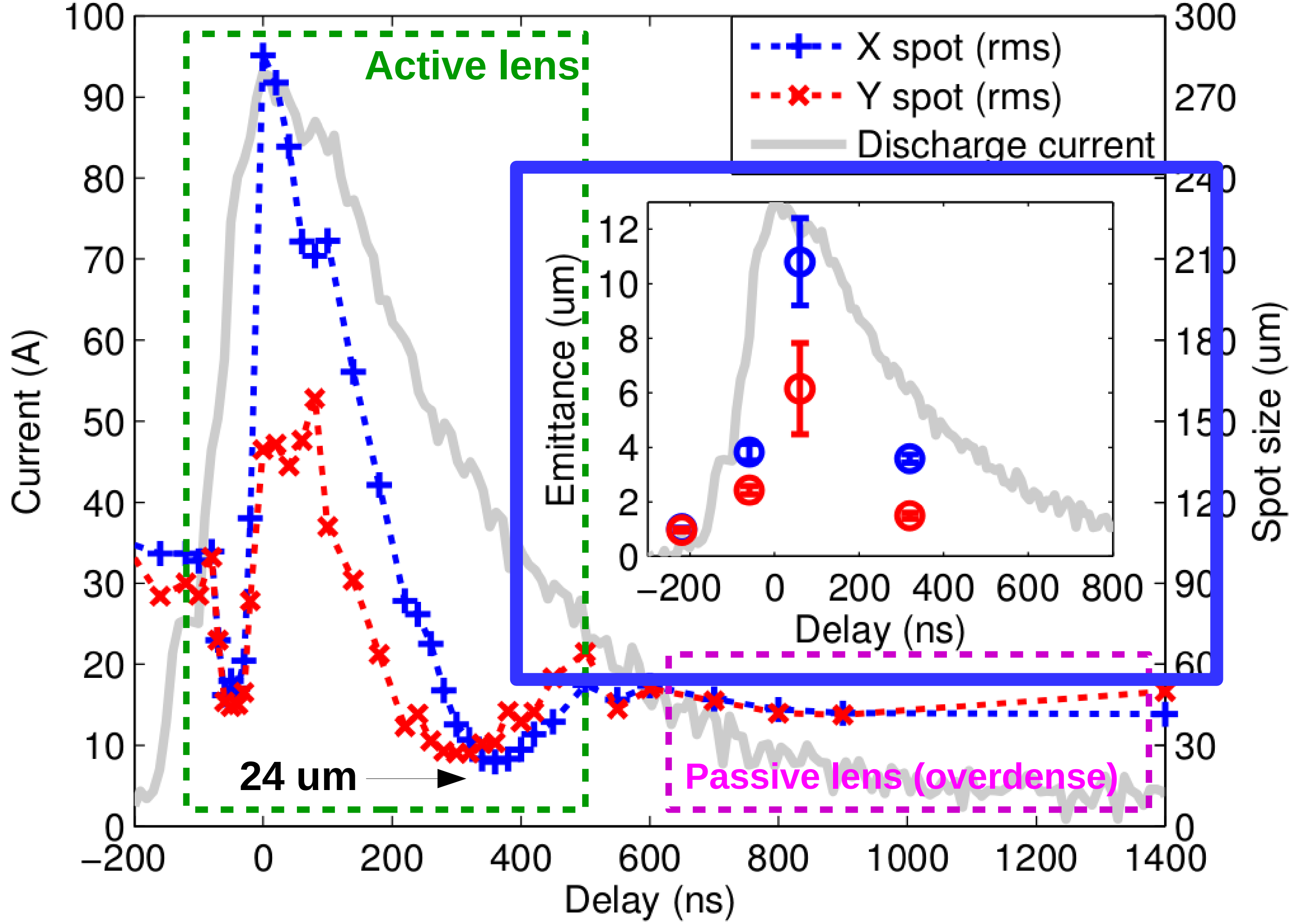
50 pC
1 ps
130 um
120 MeV
1 mm mrad

$n_e = 10^{17}$ cm^{-3}
V = 20 kV
I = 100 A
R_0 = 500 um
L = 3 cm
Sapphire

Active plasma lensing effect

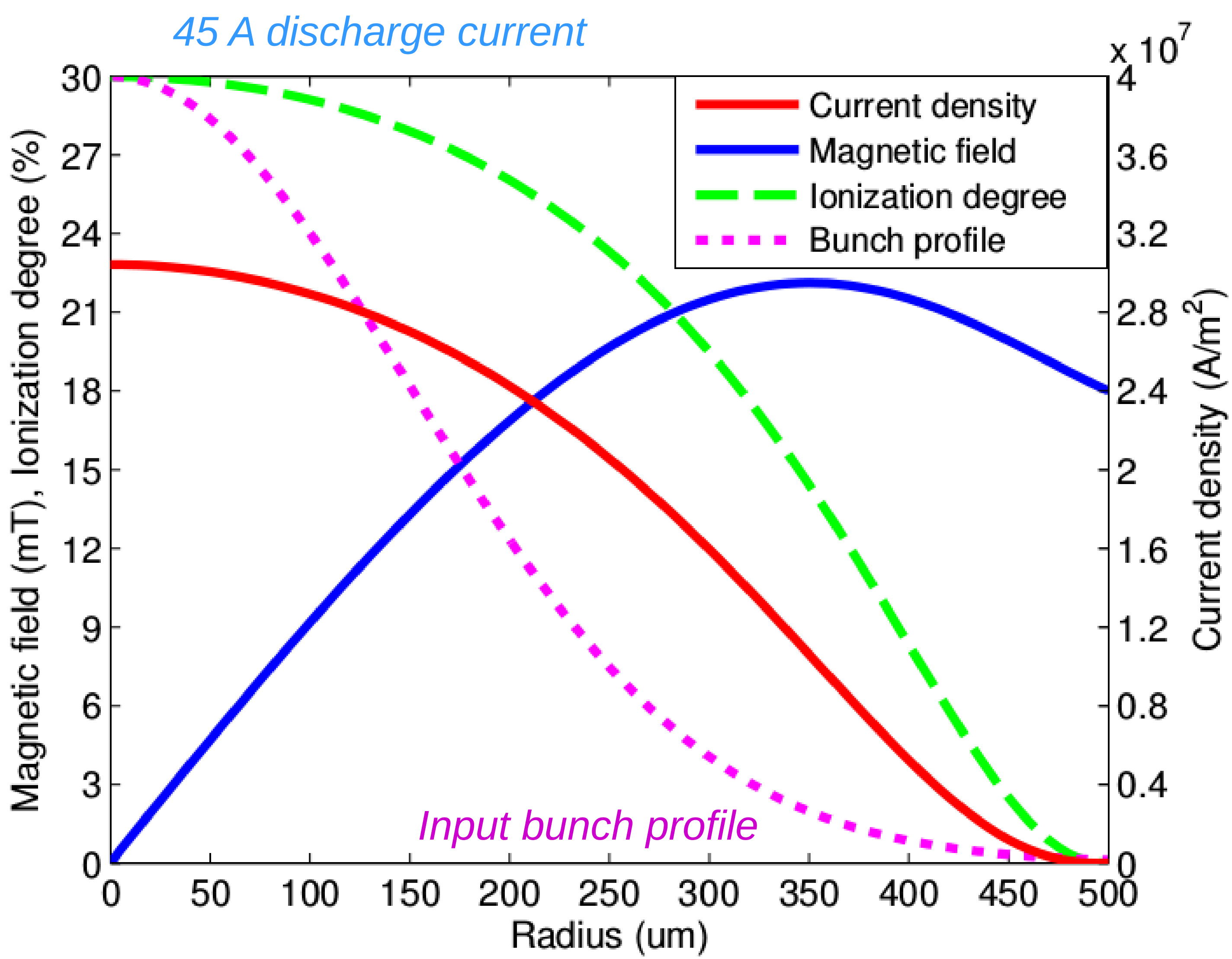


Envelope scan with 3cm capillary

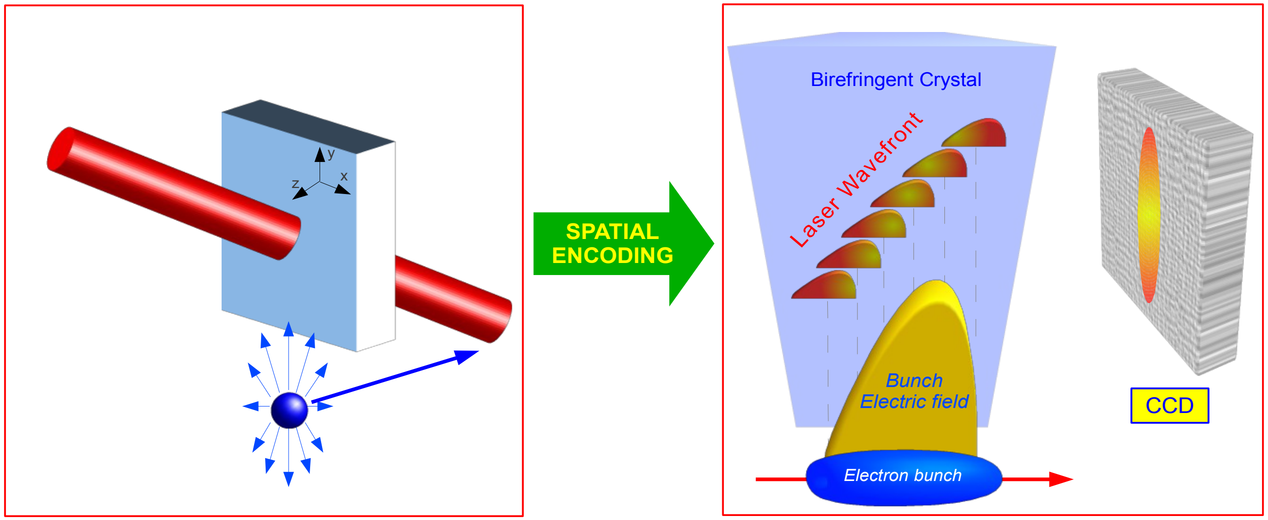


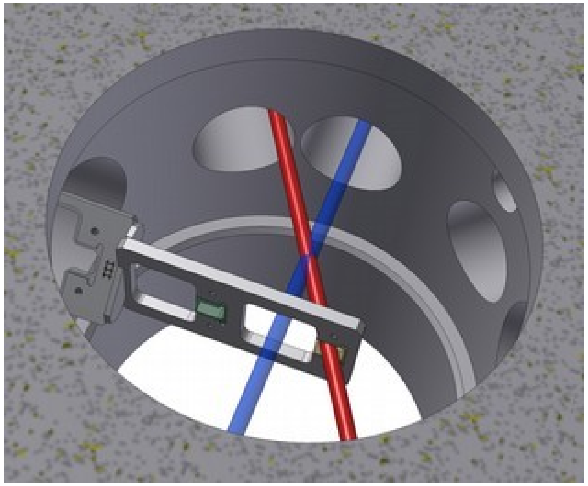
Pompili, R., et al. "Experimental characterization of active plasma lensing for electron beams." Applied Physics Letters 110.10 (2017): 104101.

Nonlinear focusing field



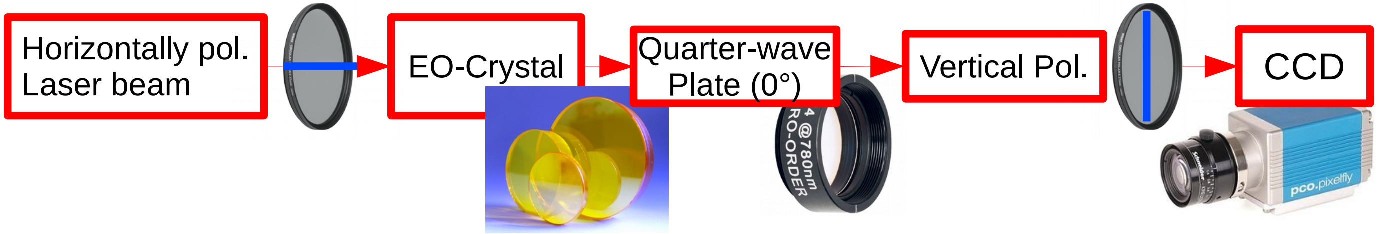
Electro-Optical Sampling



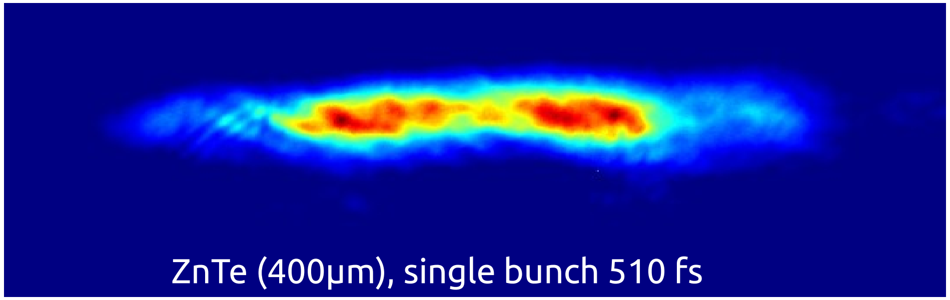


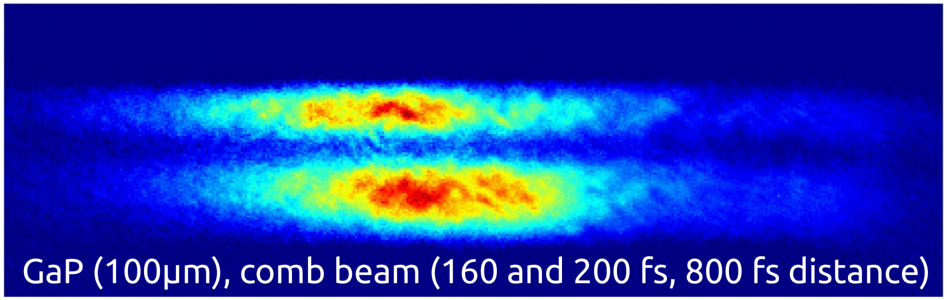
- **Laser crosses the crystal with an angle (30°)**
- **Polarization modulation → transferred to intensity modulation by means of linear polarizer**

$$I_{det} = I_{laser} \sin^2 \Gamma \propto E^2_{THz}$$

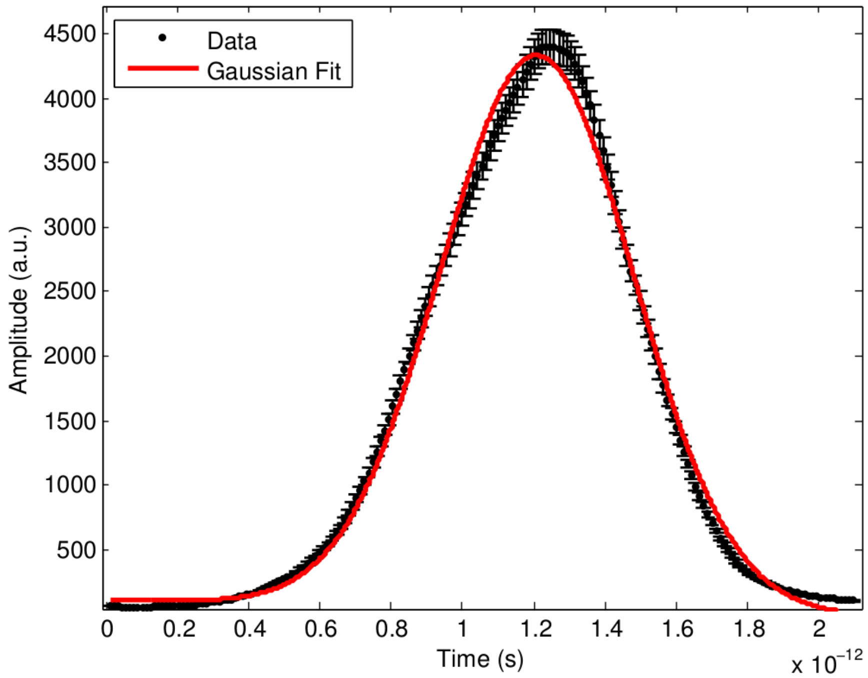


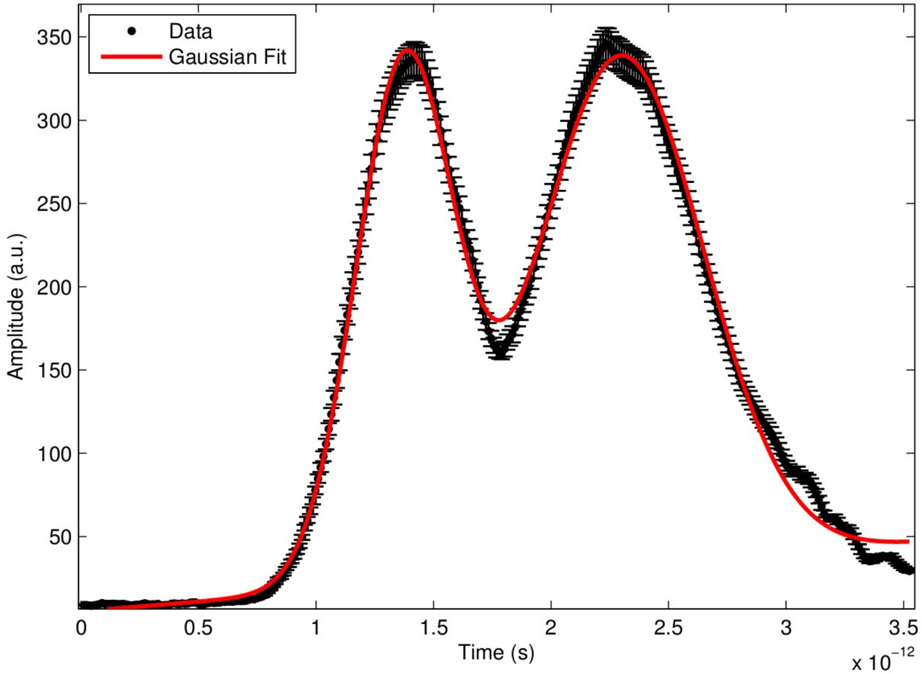
Multi-bunch trains with THz separation





80 fs temporal resolution

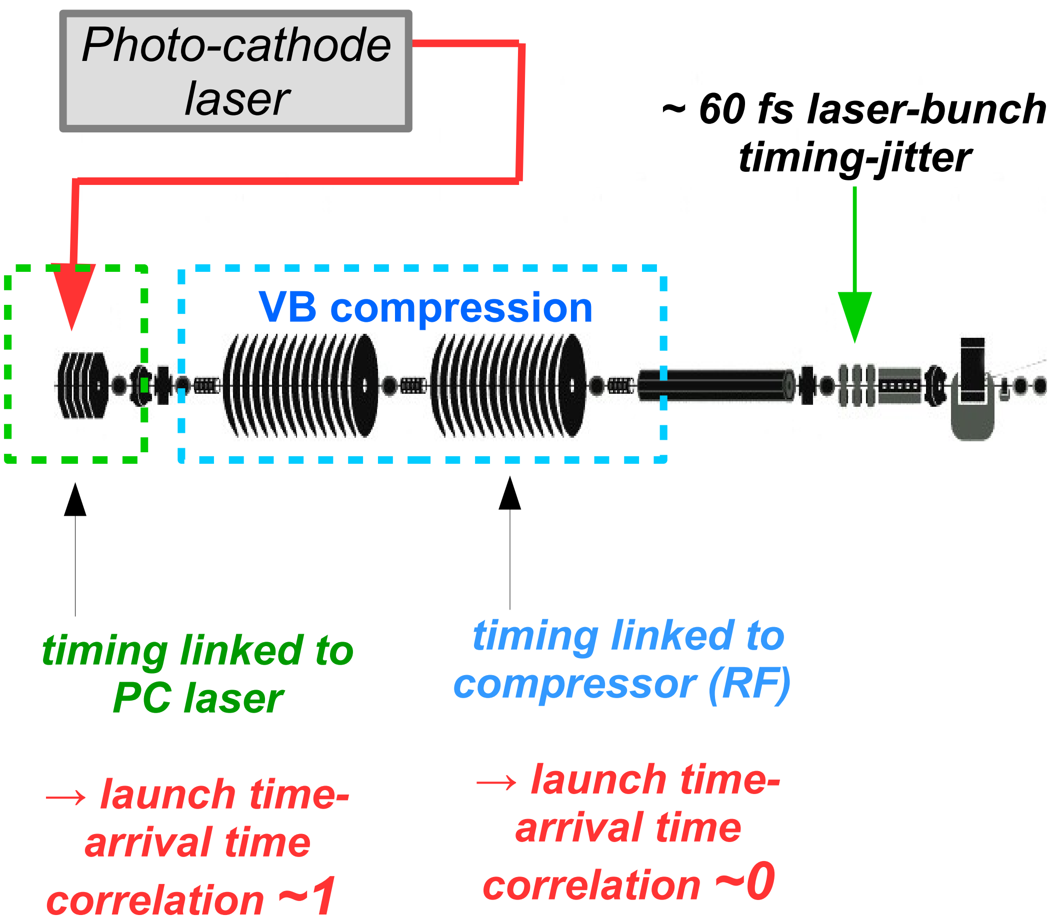


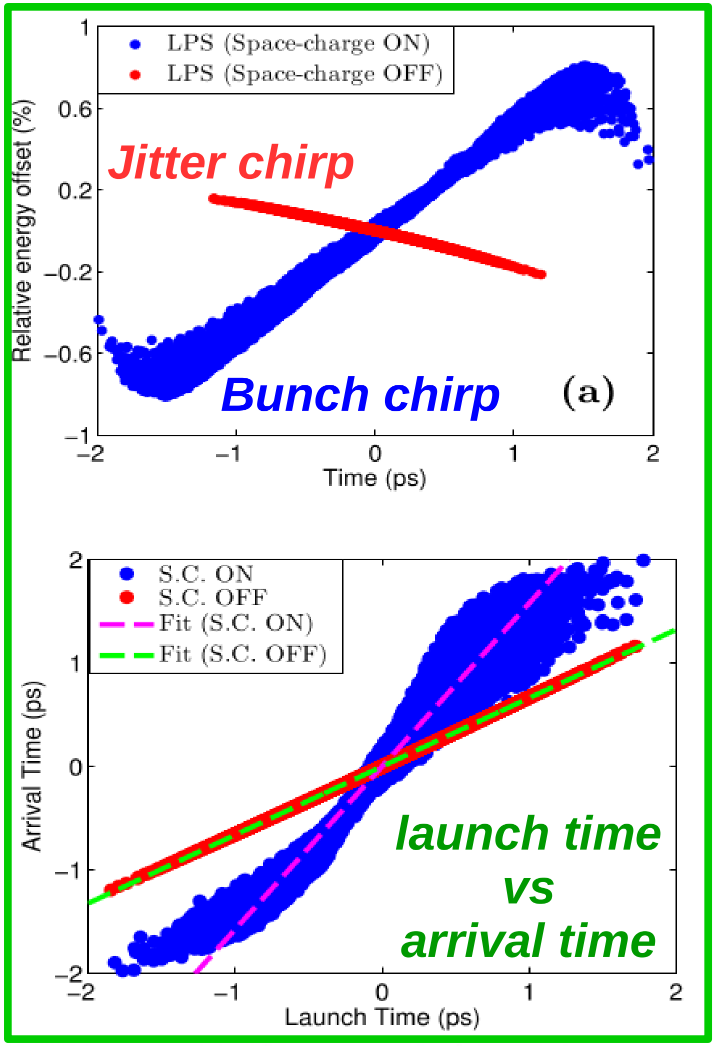


R. Pompili, et al., Nuclear Instruments and Methods in Physics Research Section A: Accelerators. 740, 216 (2014).

Bunch compression and timing-jitter

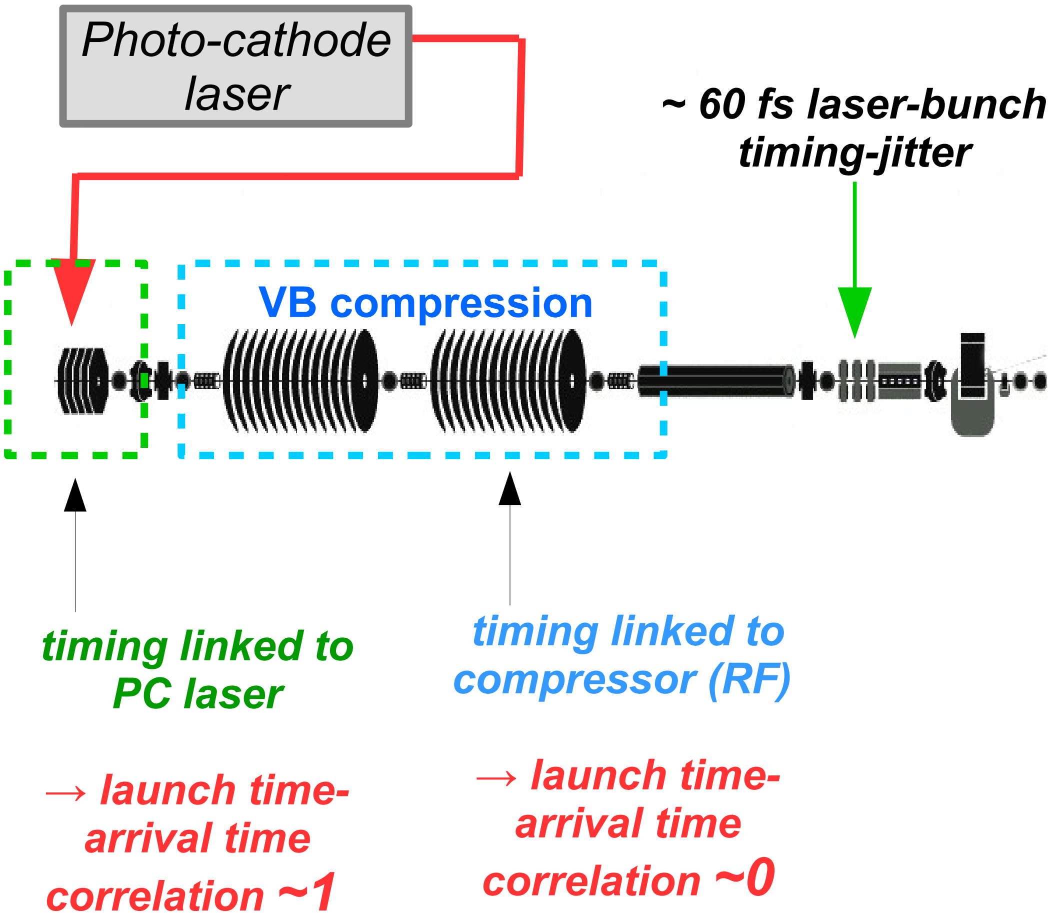
- Ultra-short bunches with ultra-low jitter wrt laser pulses
  - **Seeded FELs**
  - **External injection in laser-driven plasmas**

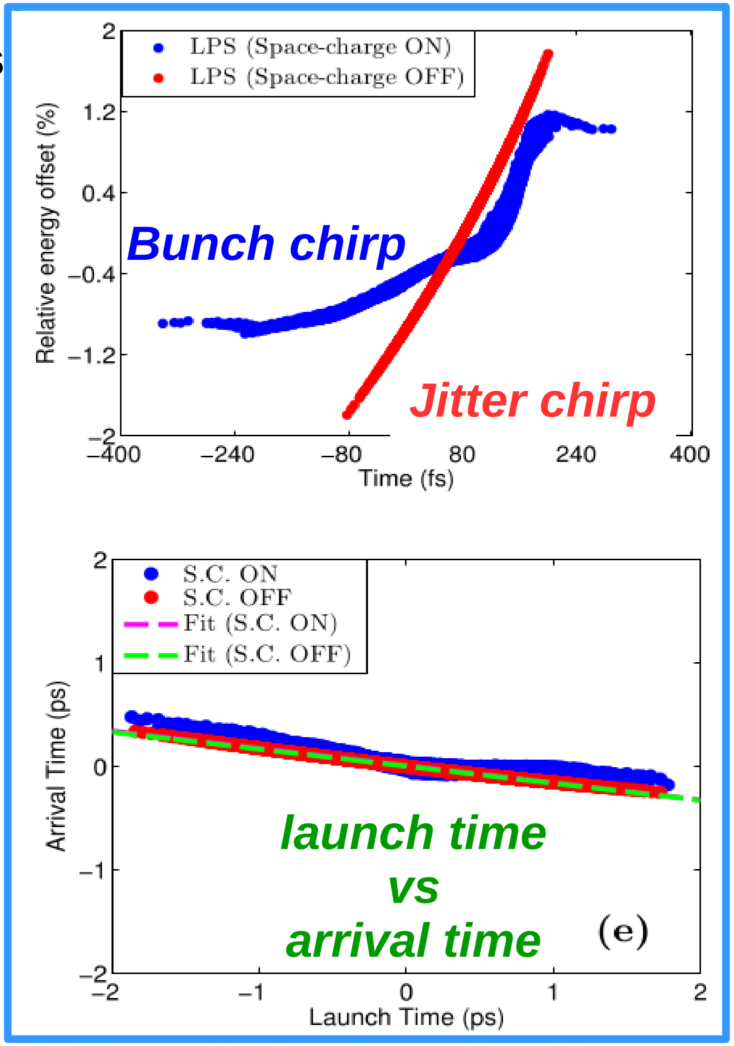




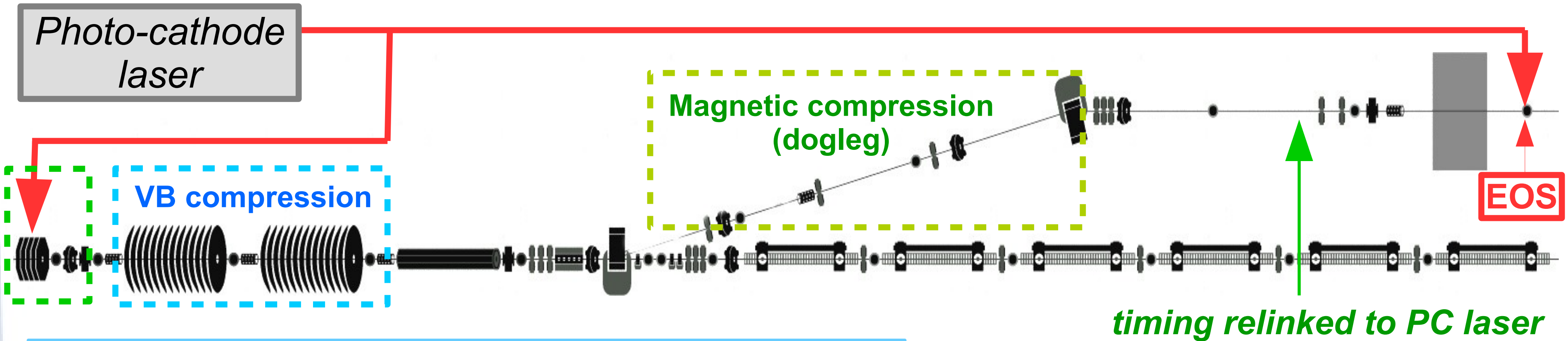
Bunch compression and timing-jitter

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



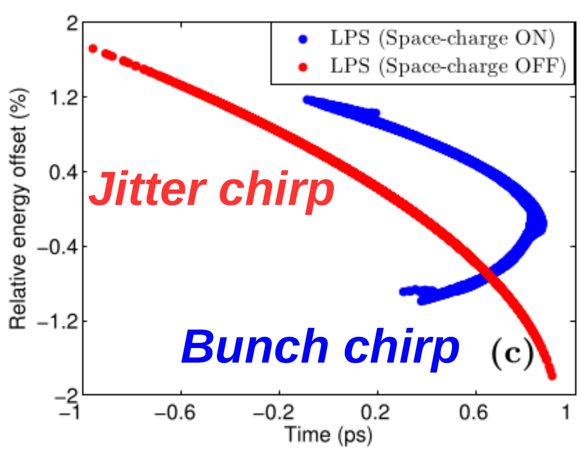


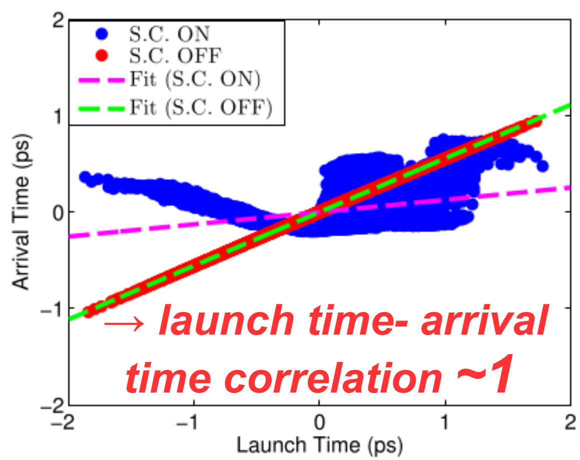
Jitter reduction by hybrid compression

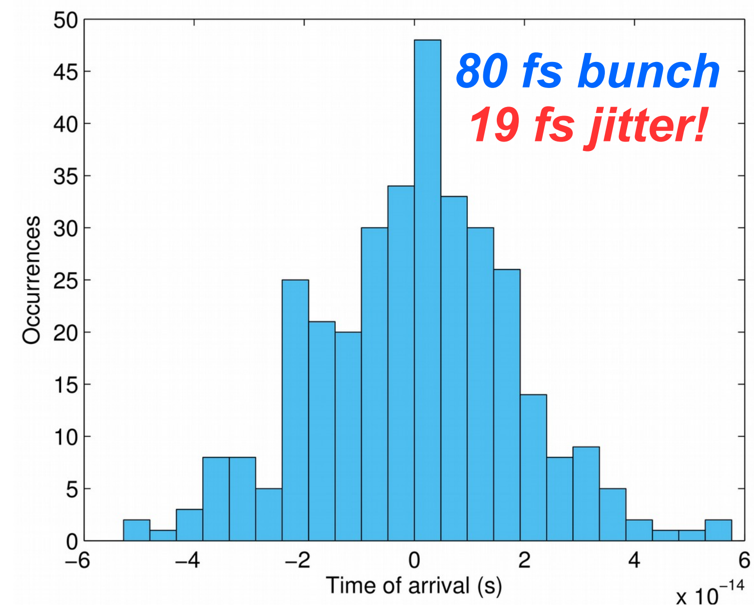


*__Hybrid compression__: bunch shortening by **VB**, relative ATJ reduction by **magnetic compression***

Pompili, R., et al. "Femtosecond timing-jitter between photo-cathode laser and ultra-short electron bunches by means of hybrid compression." New Journal of Physics 18.8 (2016): 083033.



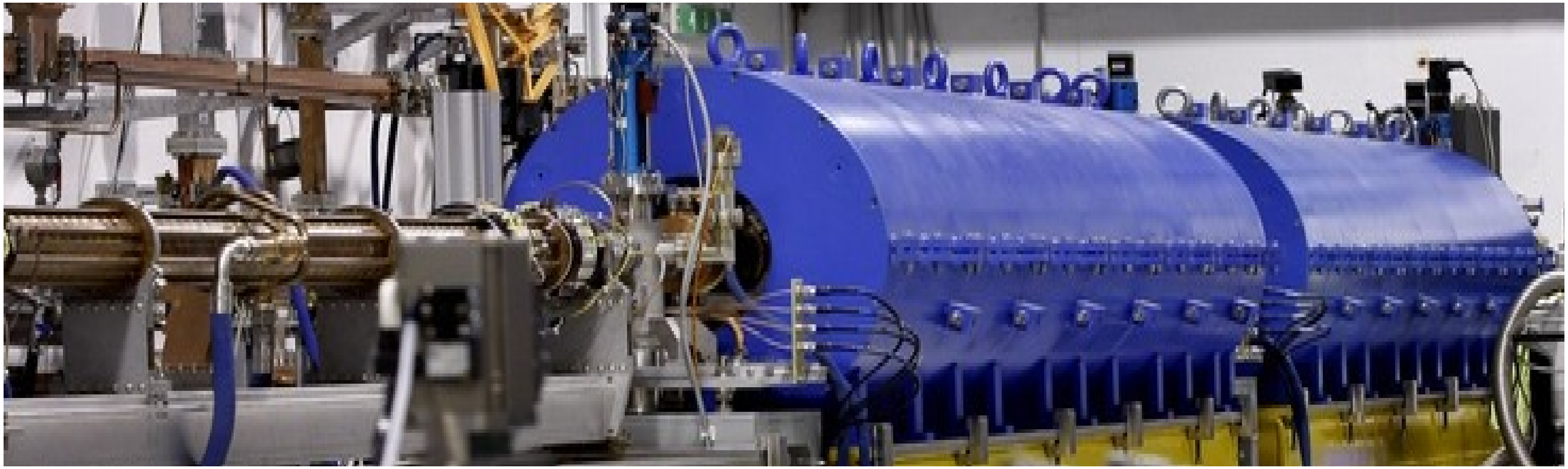




Conclusions

- 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 represented one of the most challenging issues in such experiments*
  - *An ultra-low timing jitter <20 fs has been experimentally achieved*

Acknowledgments



- M.P. Anania, M. Bellaveglia, A. Biagioni, E. Chiadroni, M. Croia, D. Di Giovenale, M. Ferrario, F. Filippi, V. Lollo, A. Marocchino, S. Pella, G. Di Pirro, S. Romeo, J. Scifo, V. Shpakov, C. Vaccarezza, F. Villa (INFN, Frascati)
- A. Cianchi (Tor Vergata University of Rome)
- A. Giribono, A. Mostacci (Sapienza University of Rome)
- A.R. Rossi (INFN, Milano)
- A. Zigler (Hebrew University of Jerusalem)

This work has been partially supported by the EU Commission in the Seventh Framework Program, Grant Agreement 312453-EuCARD-2 and the Italian Minister of Research in the framework of FIRB – Fondo per gli Investimenti della Ricerca di Base, Project n. RBFR12NK5K.

Thank you for your attention!