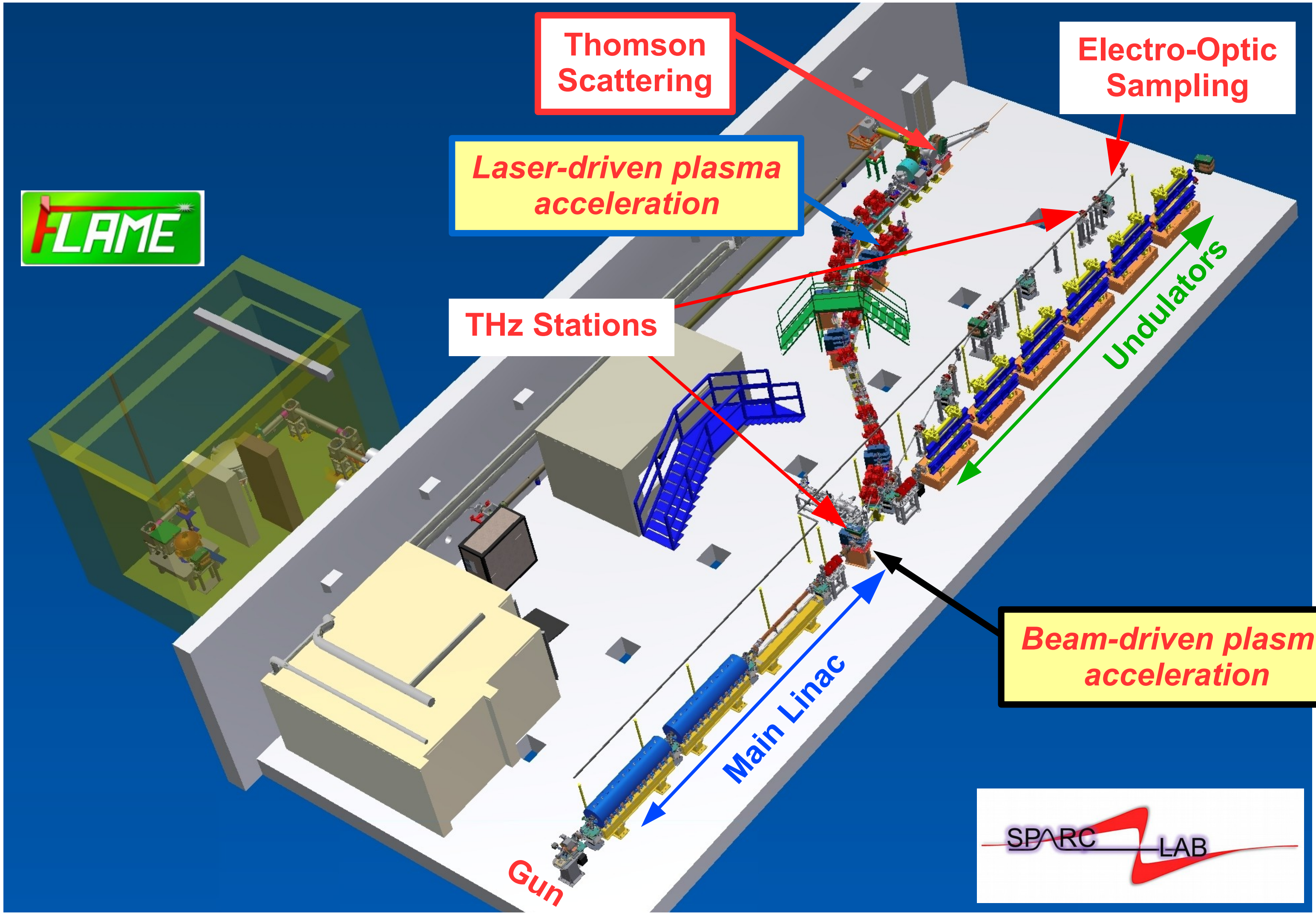
Recent results from SPARC_LAB

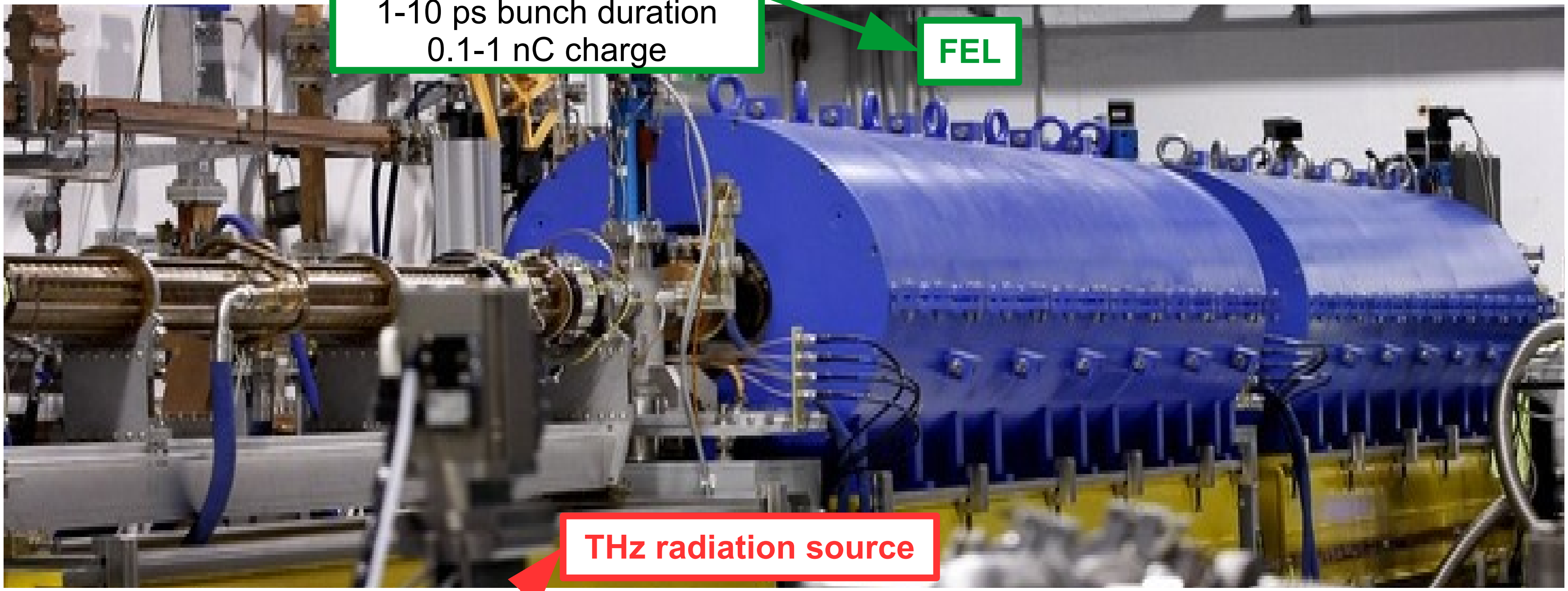
Riccardo Pompili
LNF-INFN
on behalf of the SPARC_LAB collaboration

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

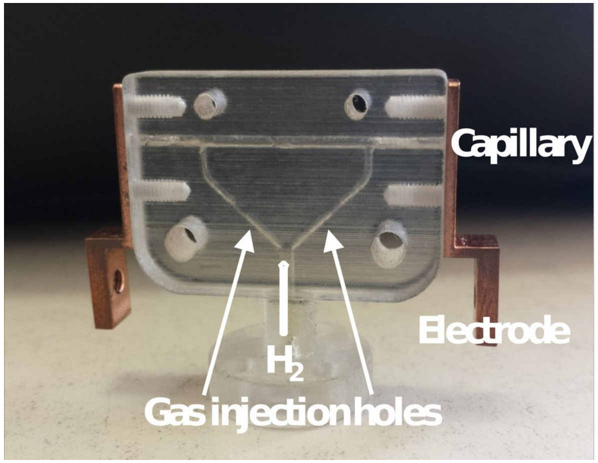
High-current operation (VB)
80-120 MeV beam energy
20 fs - 1 ps bunch duration
10-600 pC charge

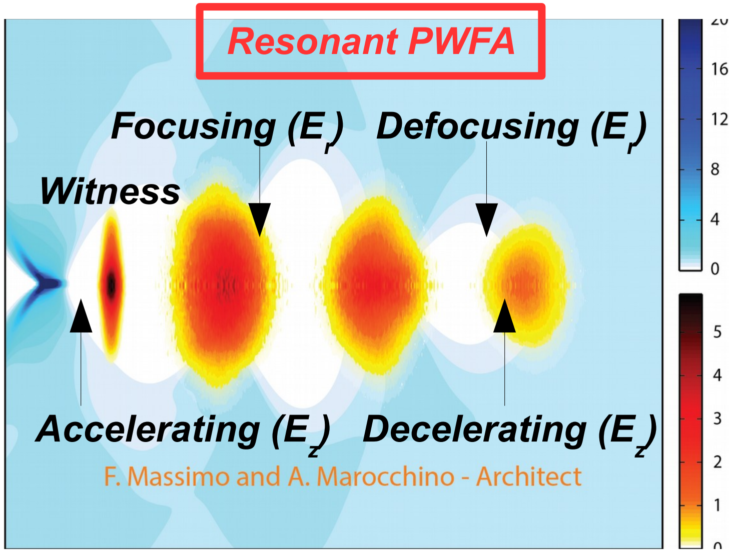
→ THz radiation source
→ FEL (single spike + seeding)
→ Multi-bunch trains
  → Narrowband THz
  → FEL (2 colors)
  → PWFA (w/ resonant scheme)
→ LWFA (external injection)

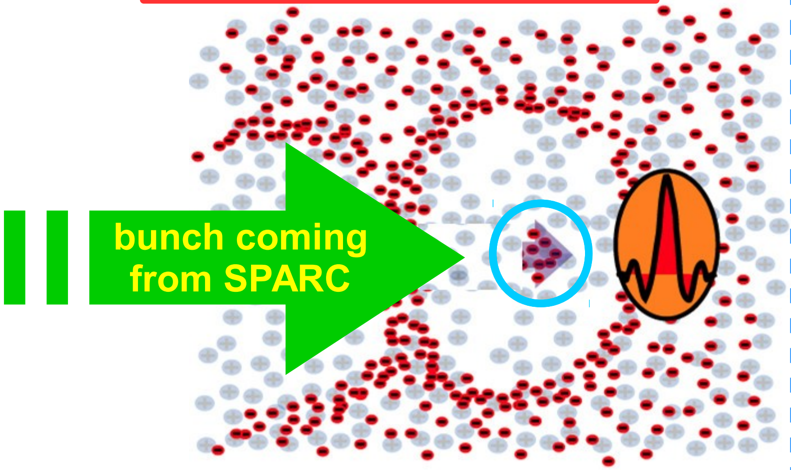
Serafini L., Ferrario M. "Velocity bunching in photo-injectors." AIP conference proceedings. 2001.
Anderson, S. G., et al. "Velocity bunching of high-brightness electron beams." PRSTAB 8.1 (2005): 014401.

Plasma-based acceleration

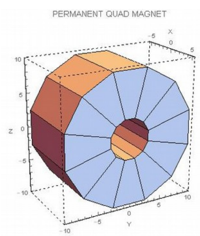
- Several plasma-based schemes will be tested
  - *PWFA resonant scheme → 1-2 GV/m expected*
    - *n_e~10^{16} cm^{-3}, 1 mm diameter capillary, Hydrogen*
  - *LWFA, external injection → 5-10 GV/m expected*
    - *n_e~10^{17} cm^{-3}, 100 μm diameter capillary, Hydrogen*
- Goal: **high quality** accelerated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





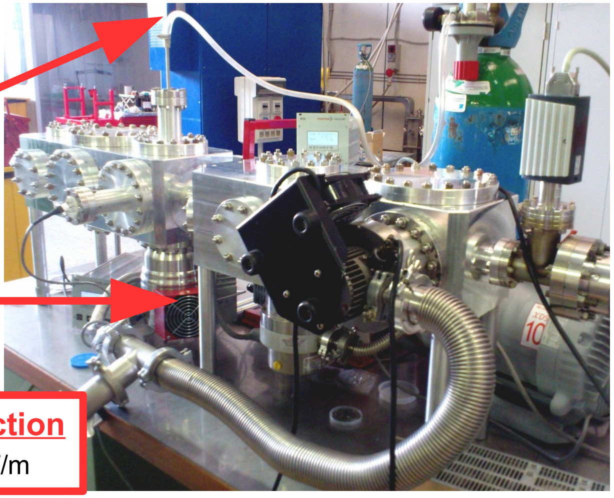


Plasma interaction chamber



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

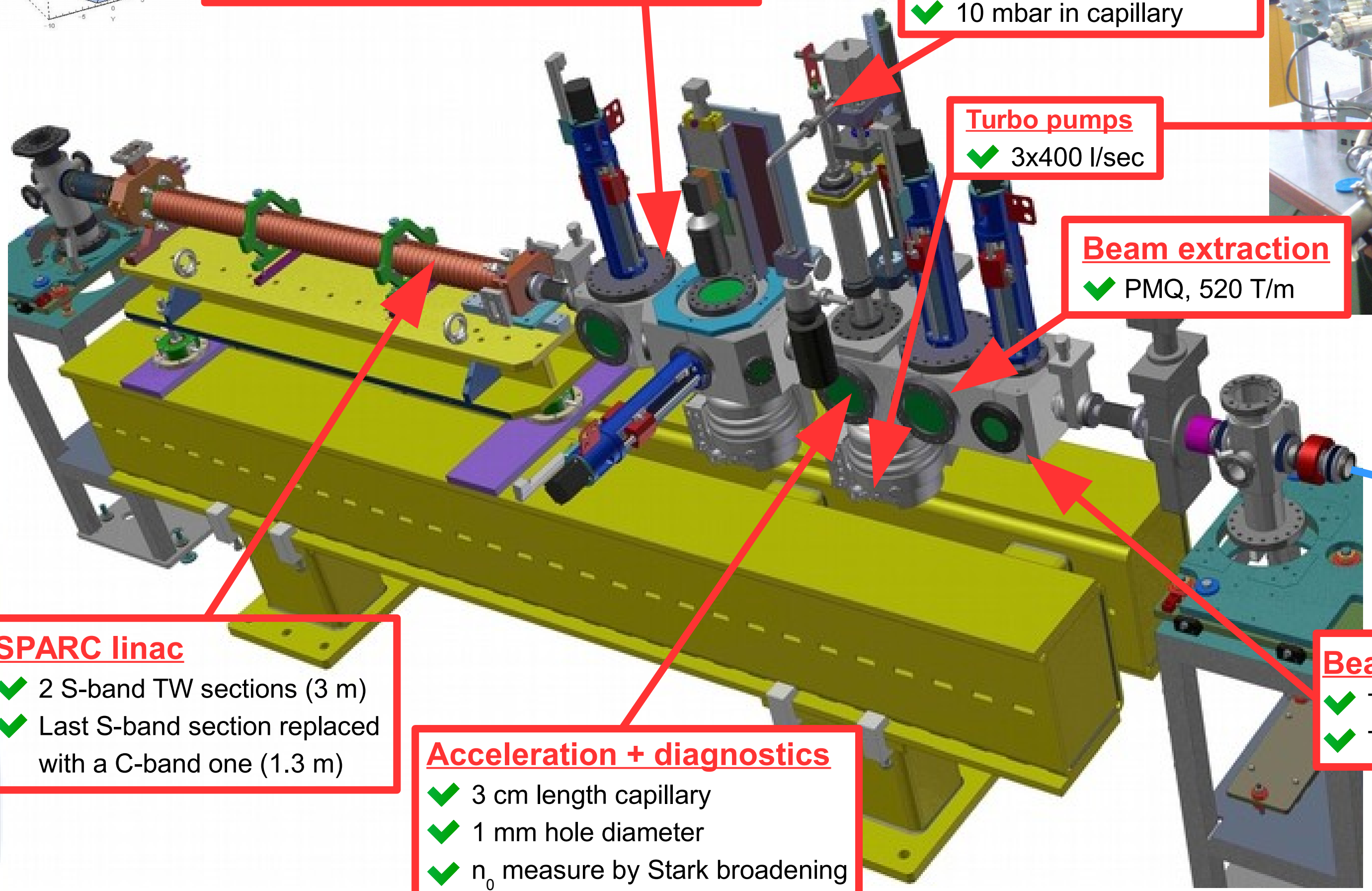
Vacuum tests on the experimental chamber



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

Turbo pumps
- ✔ 3x400 l/sec

Beam extraction
- ✔ PMQ, 520 T/m



to Free Electron Laser

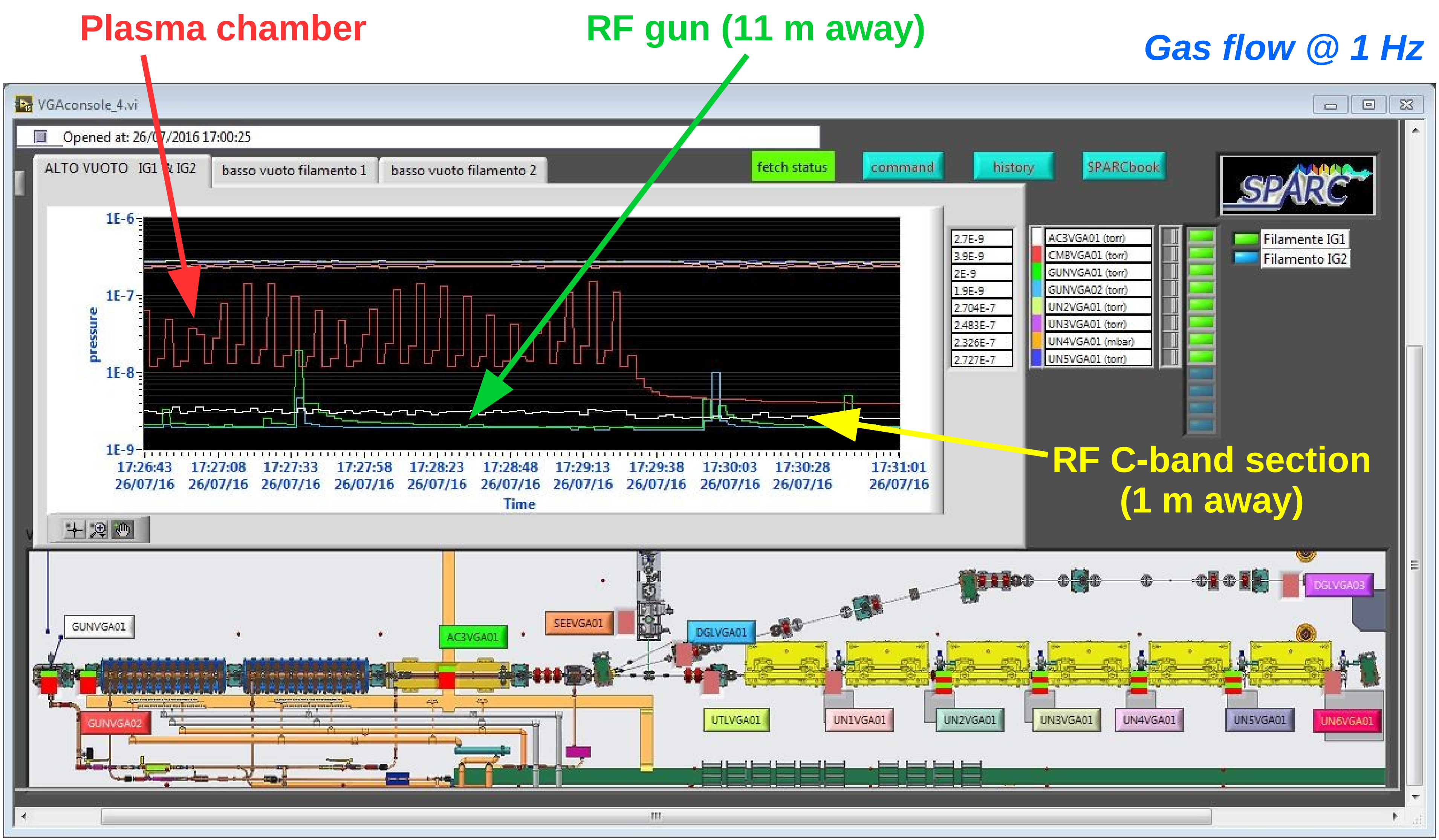
SPARC linac
- ✔ 2 S-band TW sections (3 m)
- ✔ Last S-band section replaced with a C-band one (1.3 m)

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

Vacuum level during plasma runs

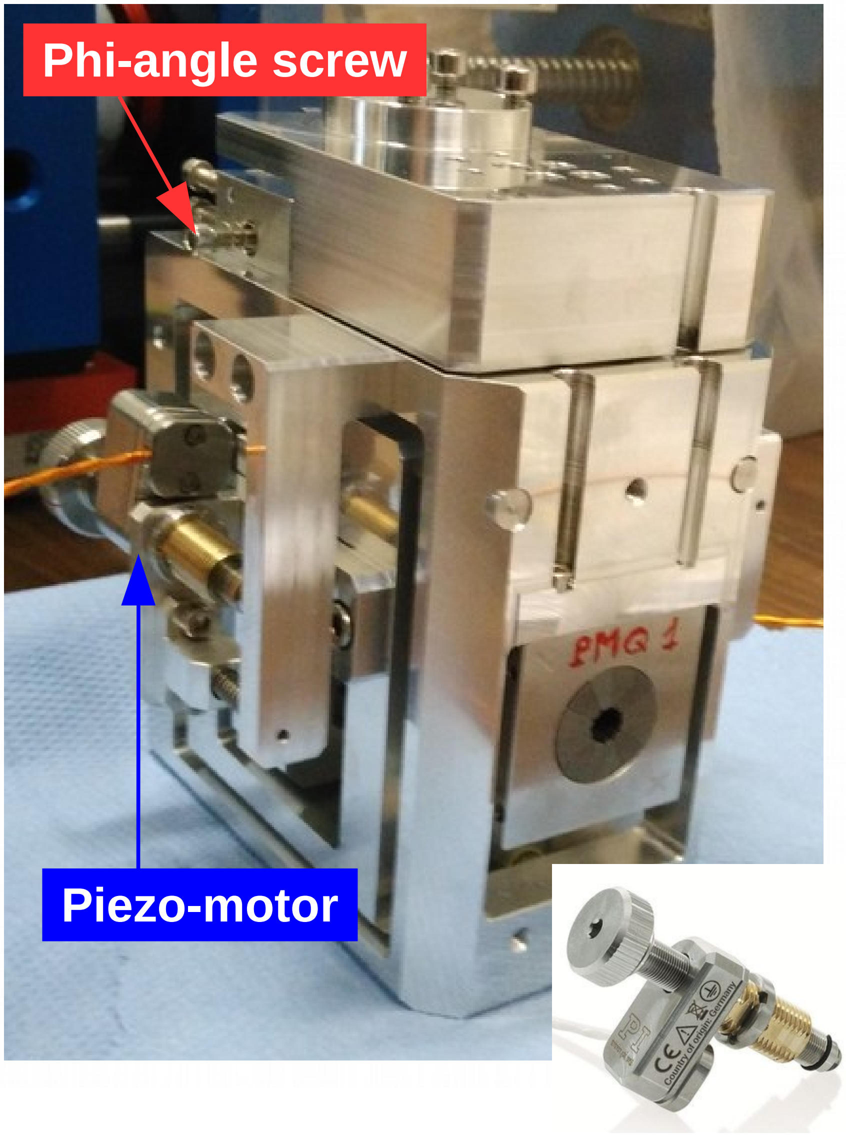


PMQ installation

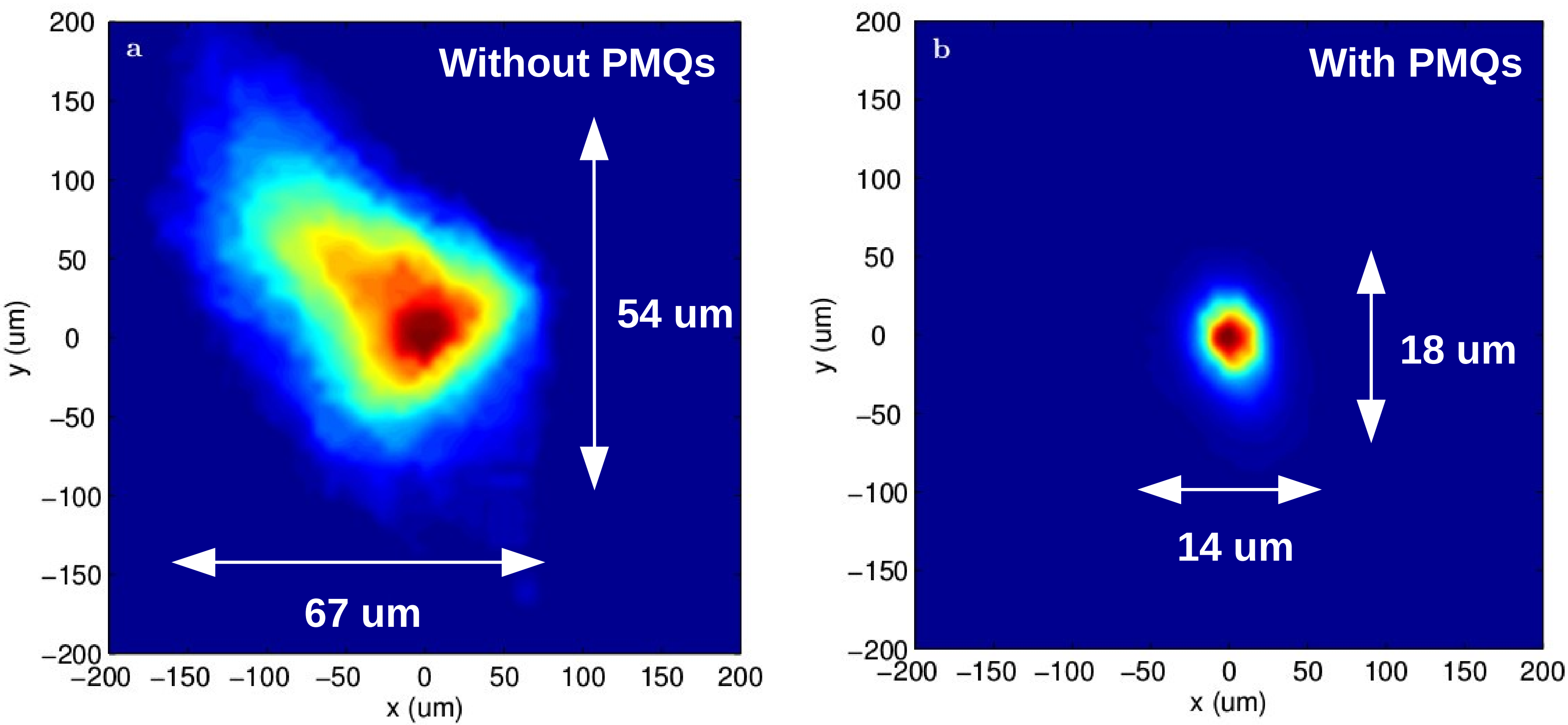
- Three PMQs installed, movable in z
- 2 movable channels (2 piezo motors)

- **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

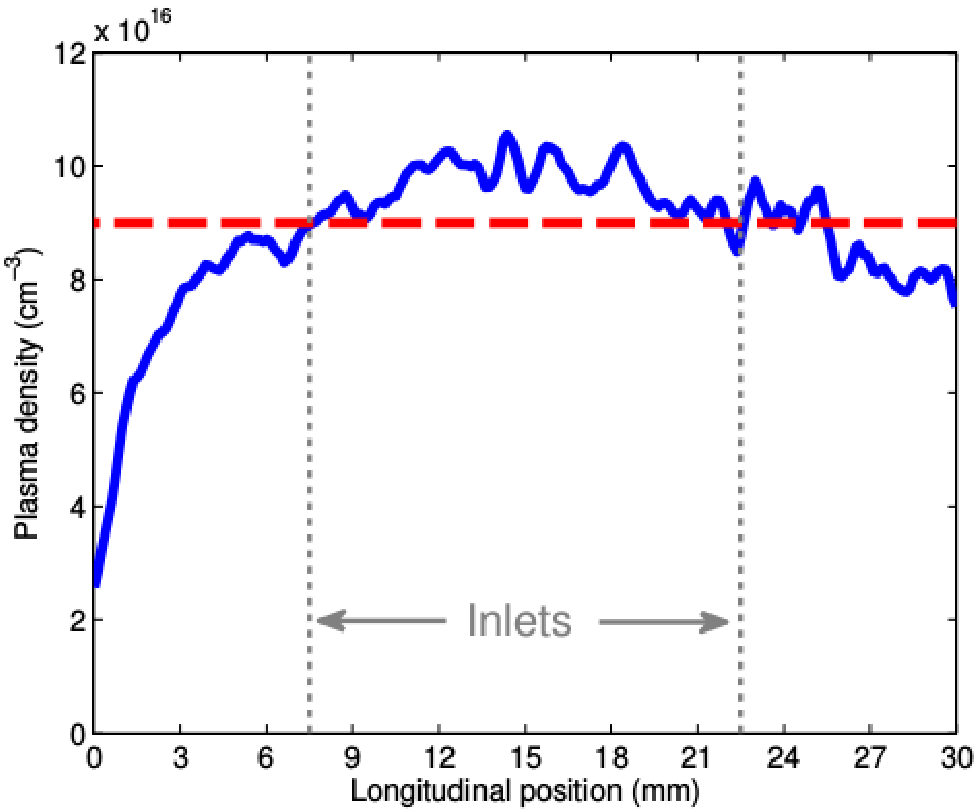


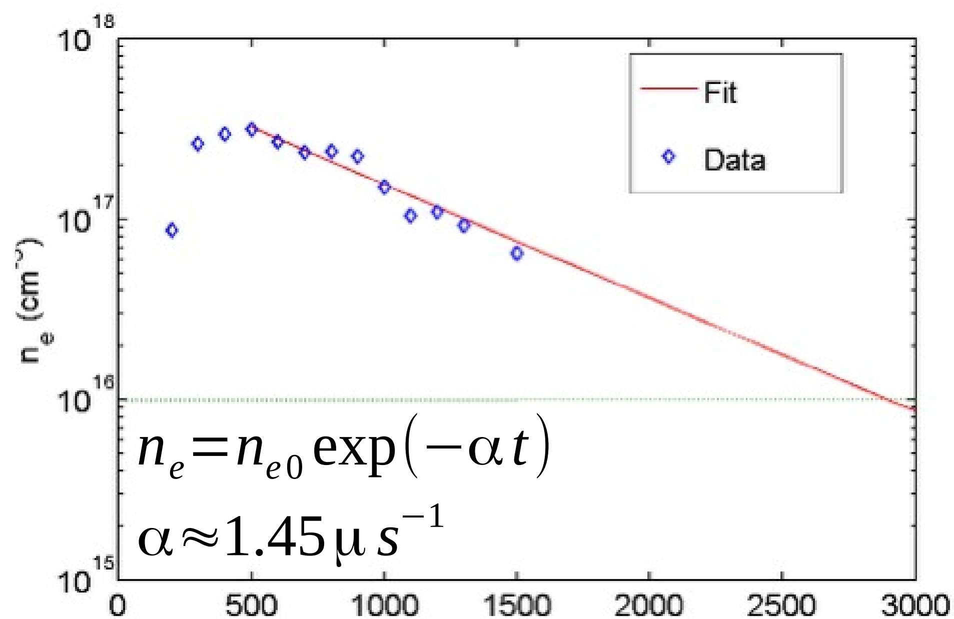
Preliminary results



Plasma characterization in capillary

Plasma density measurement from H_β Stark broadening





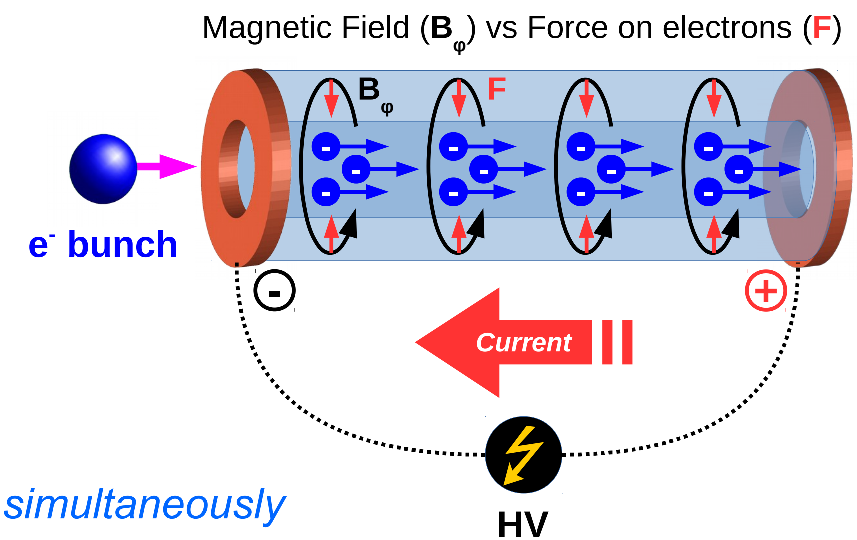
F. Filippi talk
WG5 – Tue 19.15

The plasma density is controlled through the delay after the discharge

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*

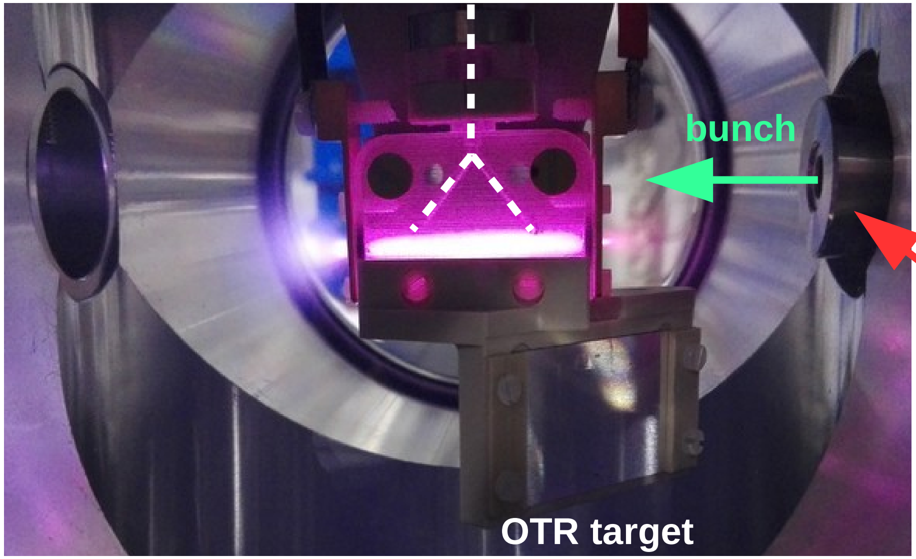
$$B_\phi(r)=\frac{1}{2}\int_0^r \mu_0 J(r')\,dr'$$



- Weak chromaticity
  - *$K_{focusing}$ scales as $1/\gamma$*
- 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*

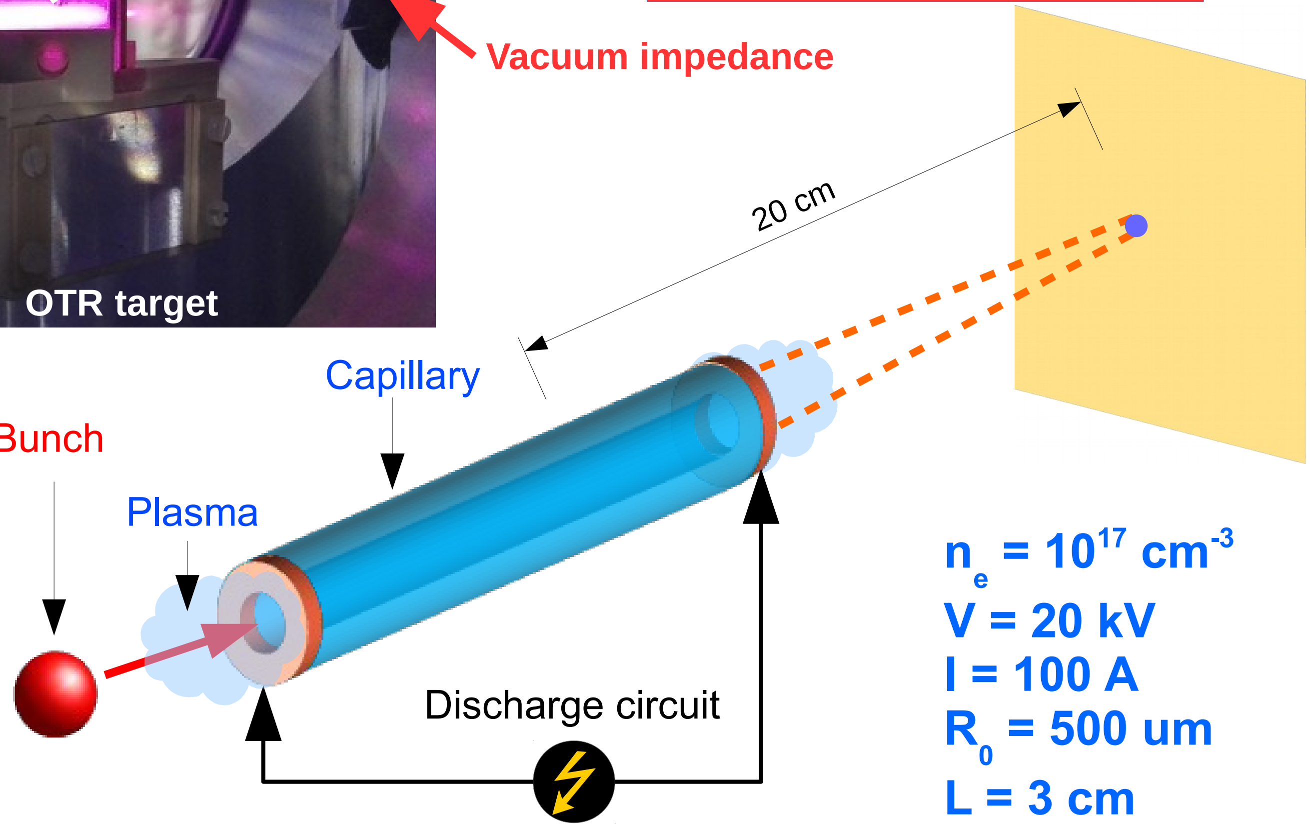
Van Tilborg, J., et al. "Active plasma lensing for relativistic laser-plasma-accelerated electron beams." Physical review letters 115.18 (2015): 184802.
Pompili, R., et al. "Experimental characterization of active plasma lensing for electron beams." Applied Physics Letters 110.10 (2017): 104101.

Experimental layout



Vacuum impedance

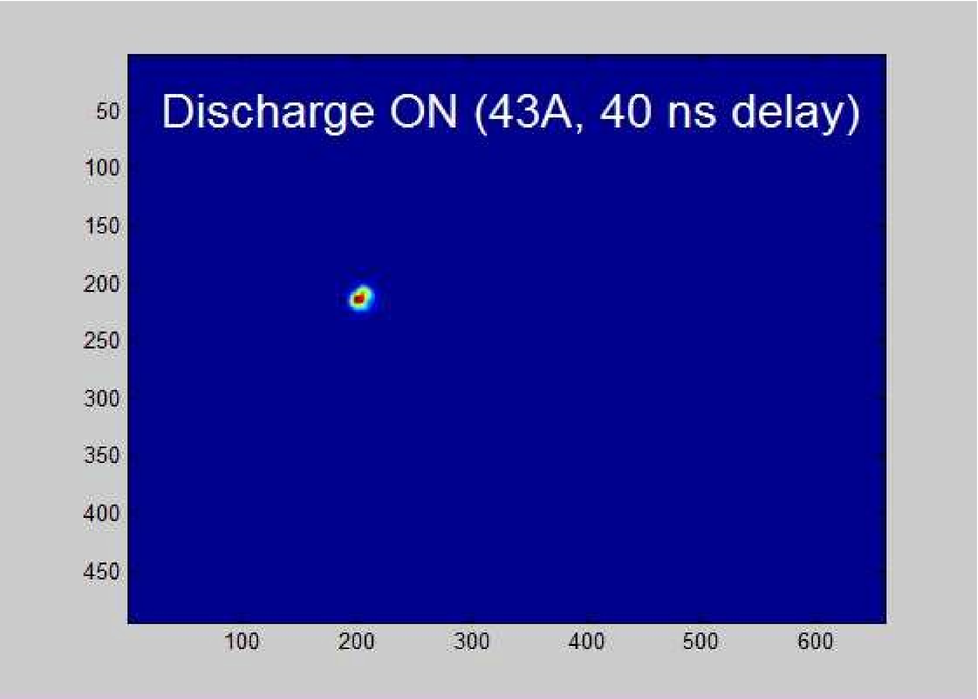
E. Chiadroni talk Thursday 8.30

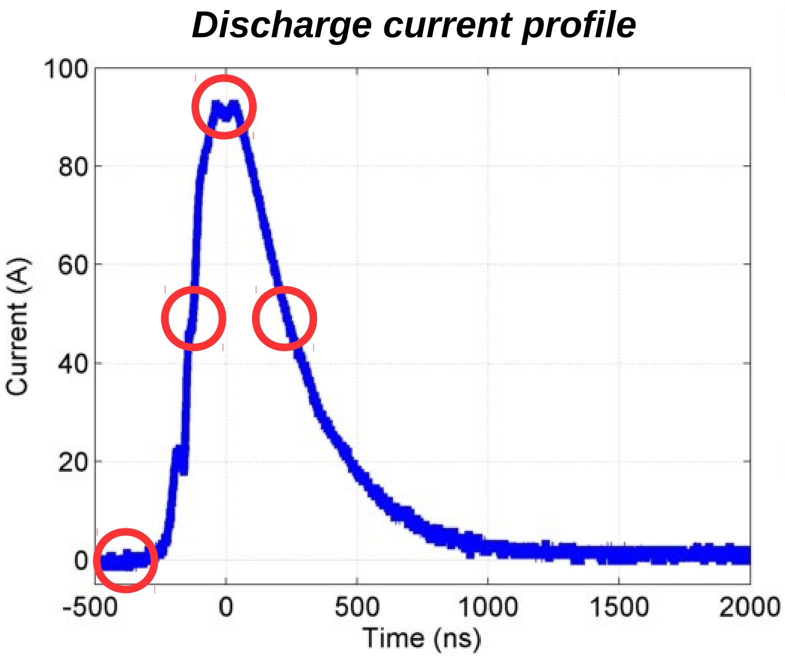


50 pC
1 ps
130 um
120 MeV
1 mm mrad

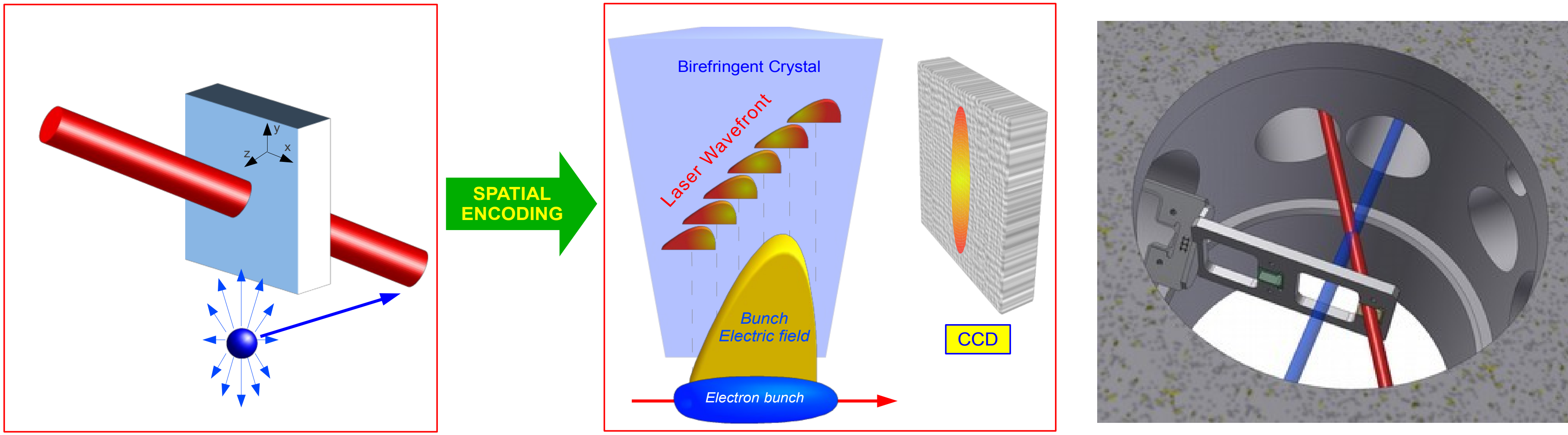
$n_e = 10^{17}$ cm^{-3}
V = 20 kV
I = 100 A
R_0 = 500 um
L = 3 cm
Sapphire/Plastic

Active plasma lensing effect



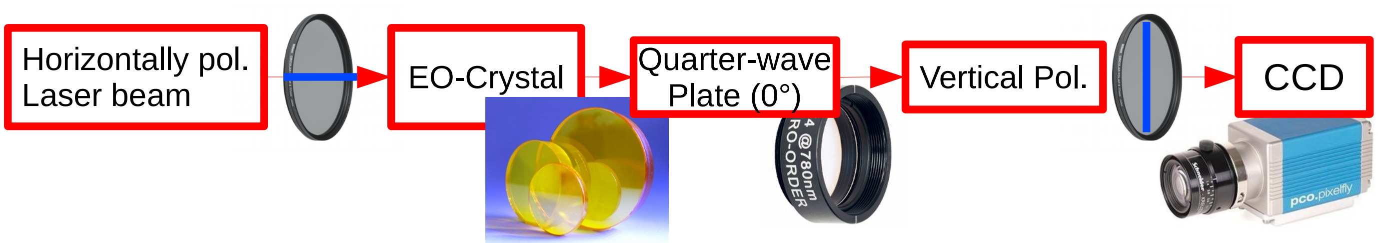


Electro-Optical Sampling

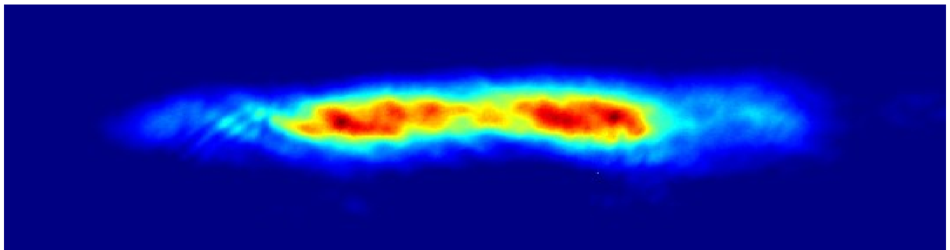


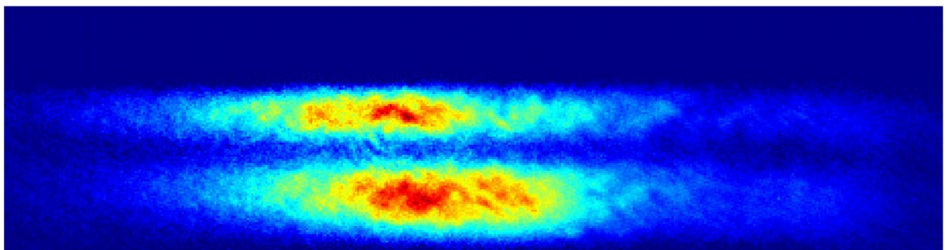
- **Laser crosses the crystal with an angle (30°)**
- **Polarization modulation → transferred to intensity modulation by means of linear polarizer**

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

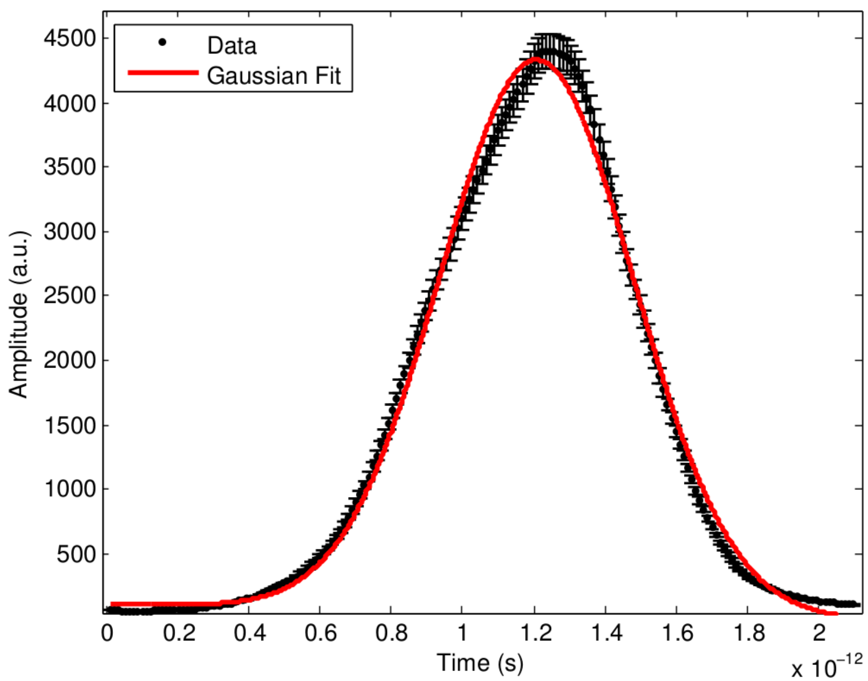


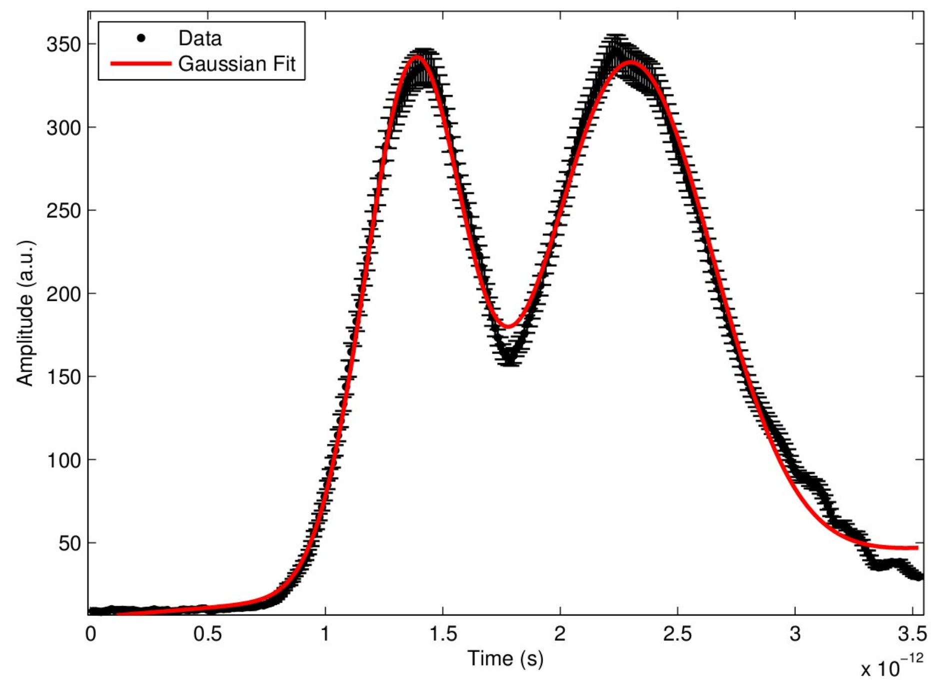
Multi-bunch trains with THz separation


ZnTe (400μm), single bunch 510 fs


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

80 fs temporal resolution

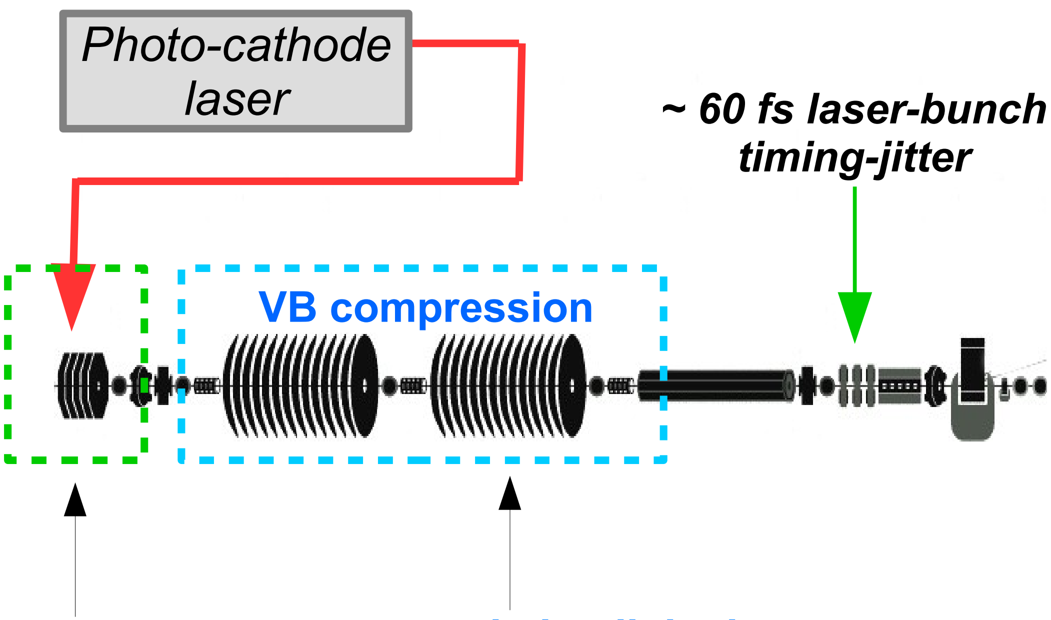




R. Pompili, et al., Nuclear Instruments and Methods in Physics Research Section A: Accelerators. 740, 216 (2014).

Bunch compression and timing-jitter

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

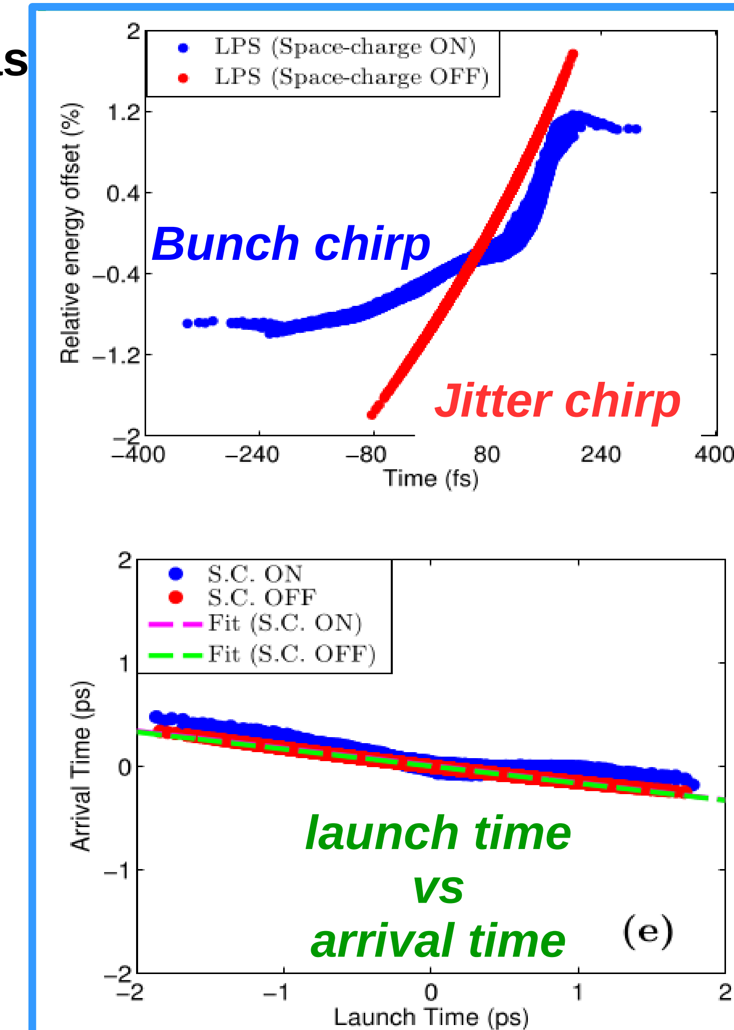


timing linked to PC laser

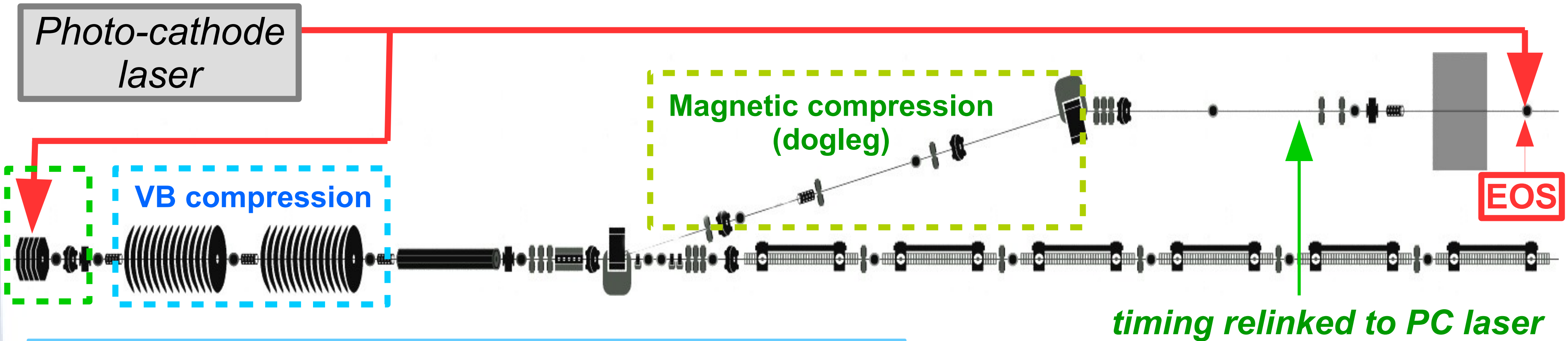
→ launch time-arrival time correlation ~1

timing linked to compressor (RF)

→ launch time-arrival time correlation ~0

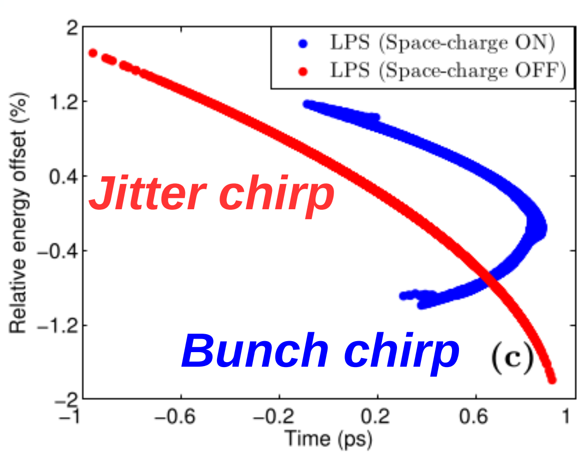


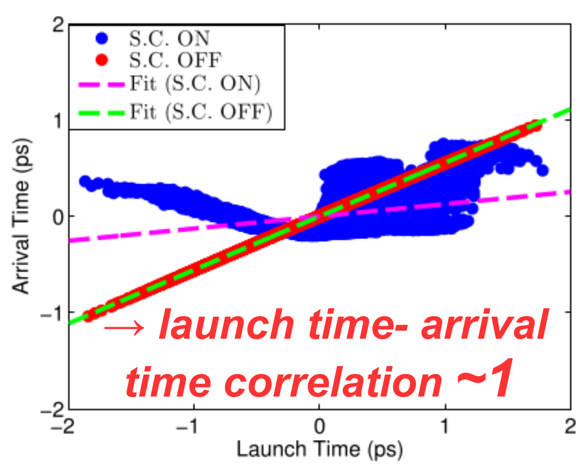
Jitter reduction by hybrid compression

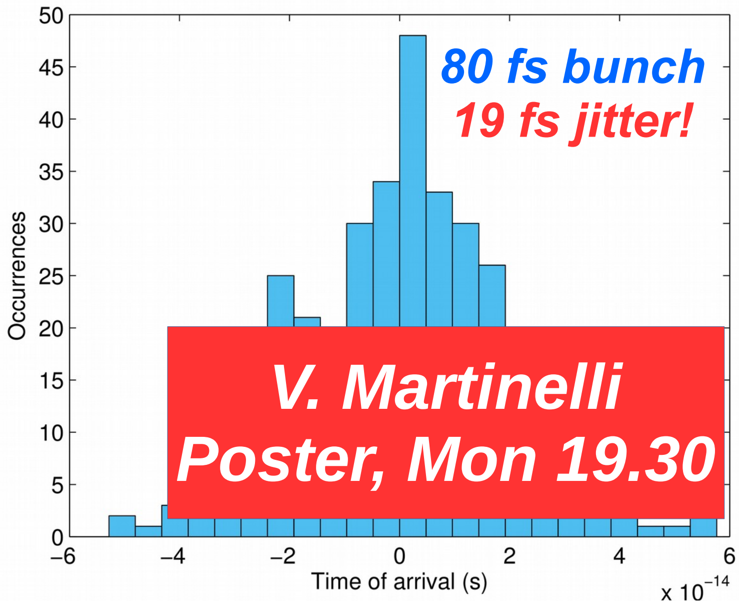


Hybrid compression**: bunch shortening by **VB**, relative ATJ reduction by **magnetic compression

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

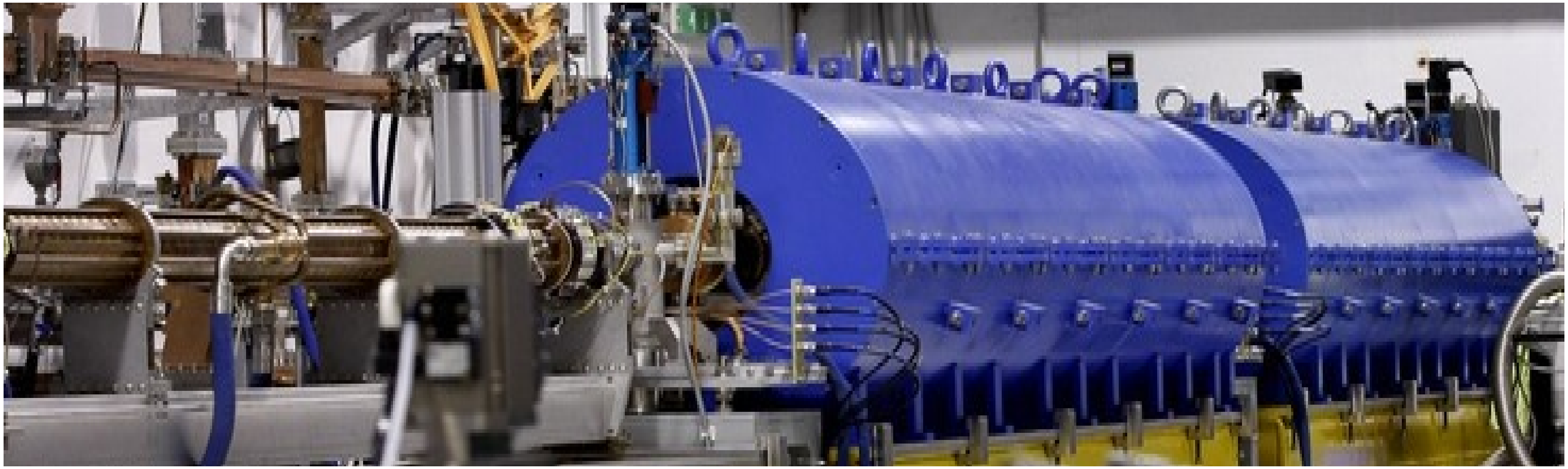
- SPARC_LAB is currently preparing the beam-driven plasma acceleration experiment. First tests are foreseen in next months.

- 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 represents 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)*
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- *J.B. Rosenzweig (UCLA, Los Angeles)*
- *A. Zigler (Hebrew University of Jerusalem)*

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Thank you for your attention!