July 31 - August 5

ADVANCED ACCELERATOR CONCEPTS

2016

Gaylord National Convention Center, National Harbor, MD

Beam-driven Plasma Wakefield Acceleration at SPARC_LAB

INFN Istituto Nazionale di Fisica Nucleare Laboratori Nazionali di Frascati

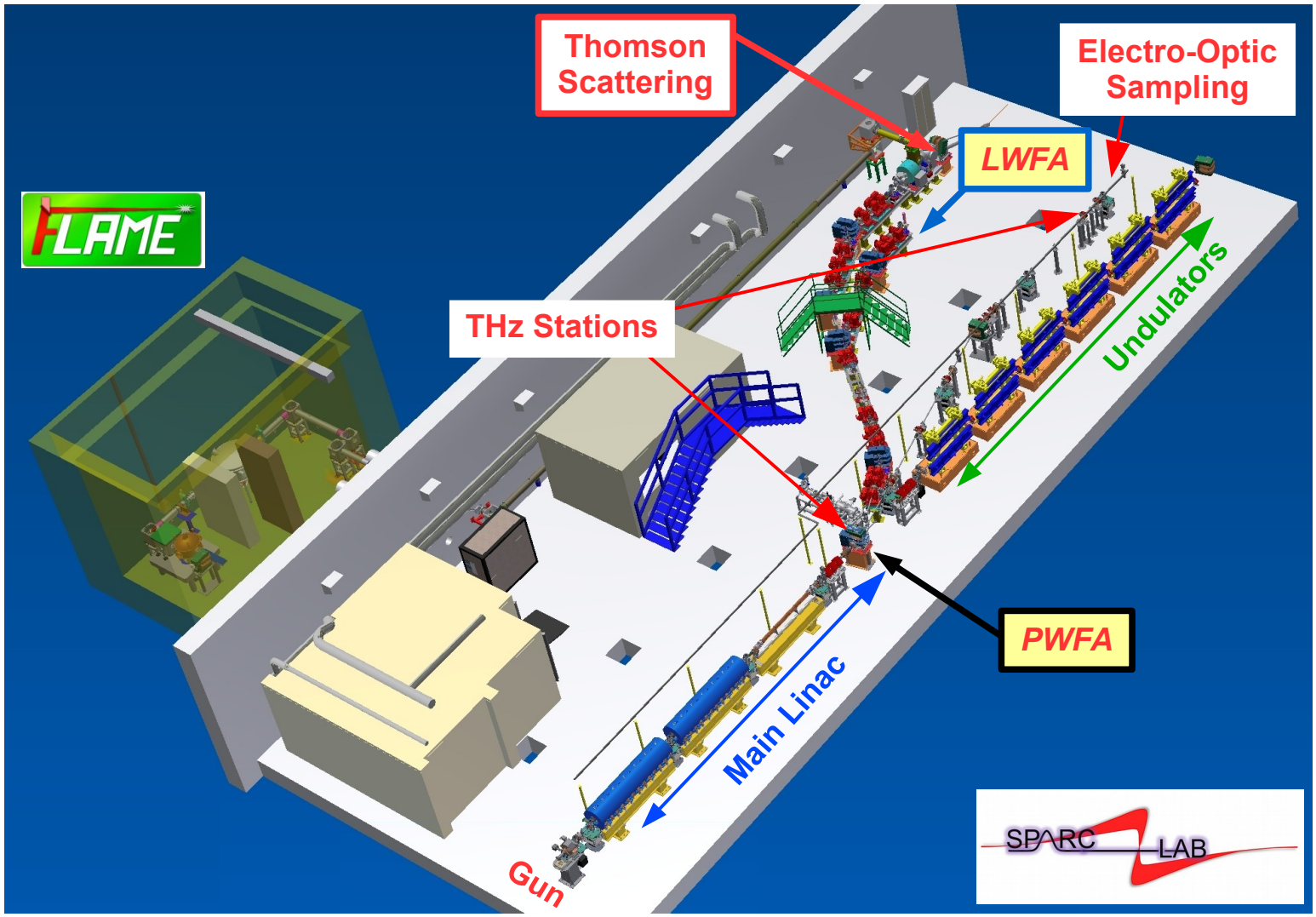
Riccardo Pompili

LNF-INFN

on behalf of the SPARC_LAB collaboration

SPARC LAB

SPARC_LAB test-facility

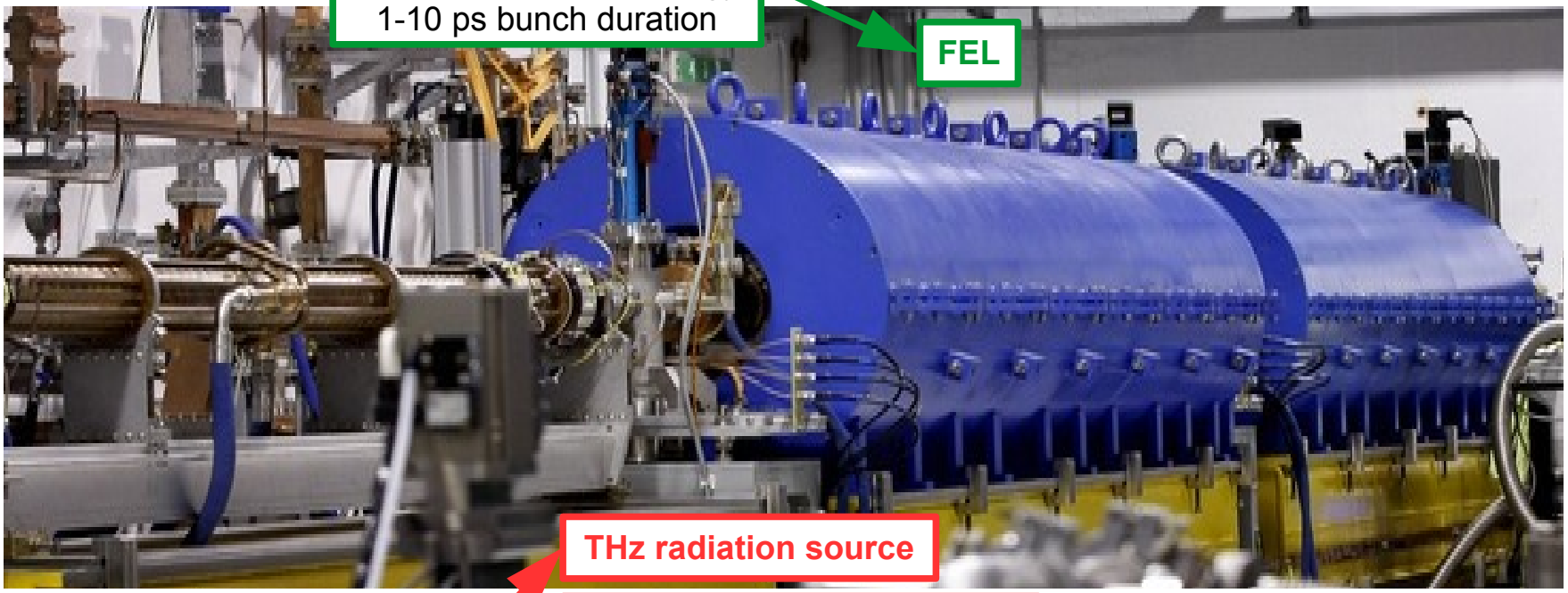


Ferrario, M., et al. "SPARC_LAB present and future." NIMB 309 (2013): 183-188.

High brightness photo-injector

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

- **Thomson source**
- **FEL**



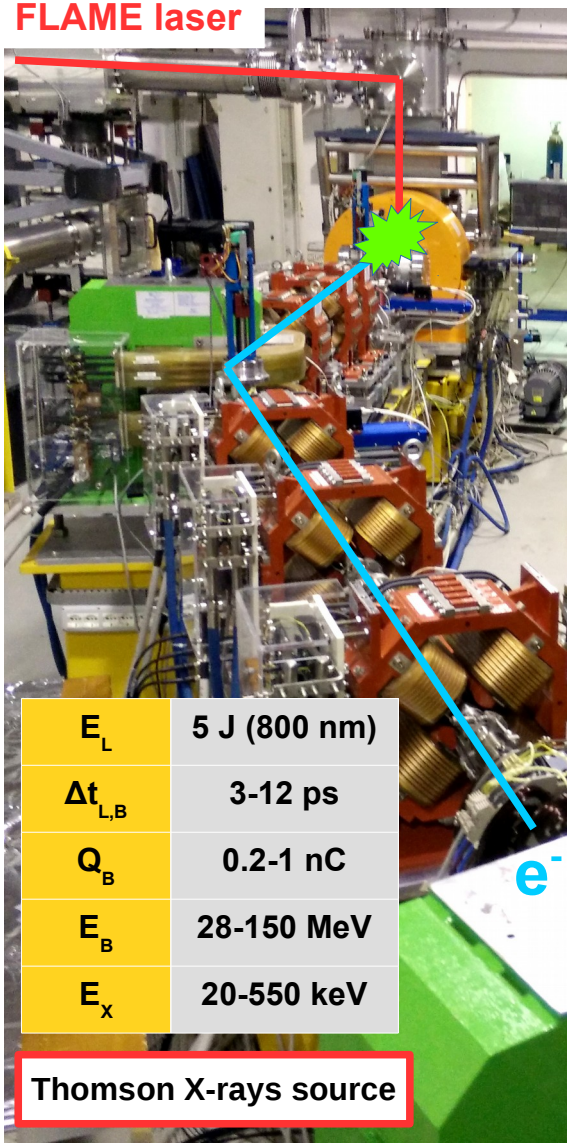
High-current operation (VB)
80-120 MeV beam energy
20 fs - 1 ps bunch duration

- **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.

Radiation source activities

FLAME laser

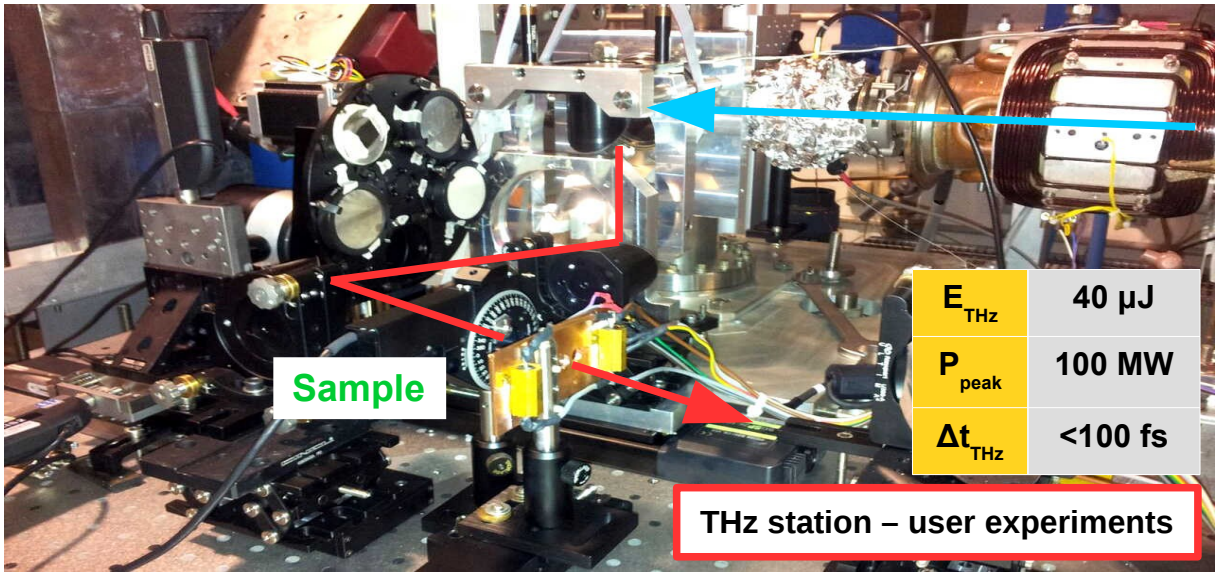


E_L	5 J (800 nm)
$\Delta t_{L,B}$	3-12 ps
Q_B	0.2-1 nC
E_B	28-150 MeV
E_X	20-550 keV

Thomson X-rays source

Free Electron Laser (SASE + seeded)

λ_u	2.8 cm
N_u	77
Gap	0.8-20 cm
K	0.38-2.1
Br	1.31 T

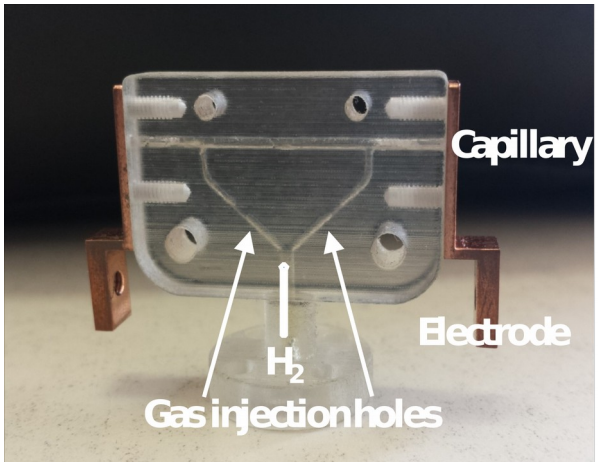


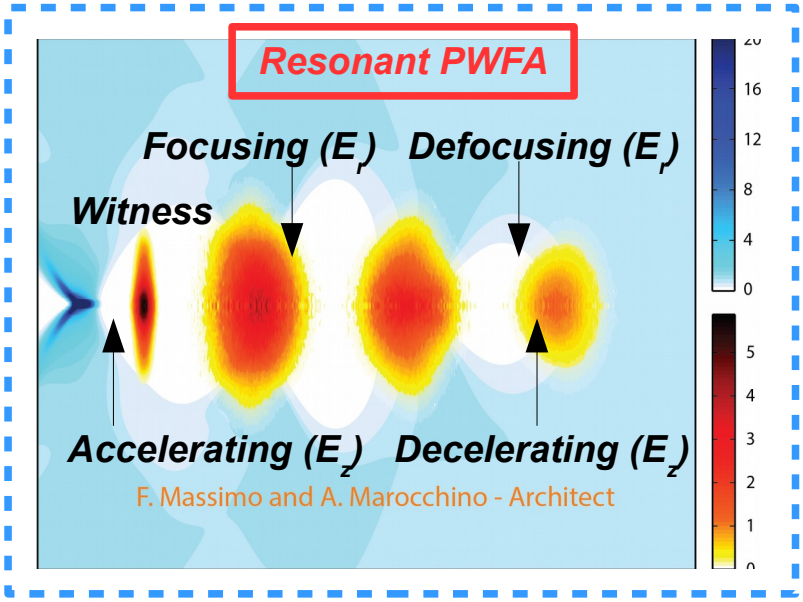
E_{THz}	40 μJ
P_{peak}	100 MW
Δt_{THz}	<100 fs

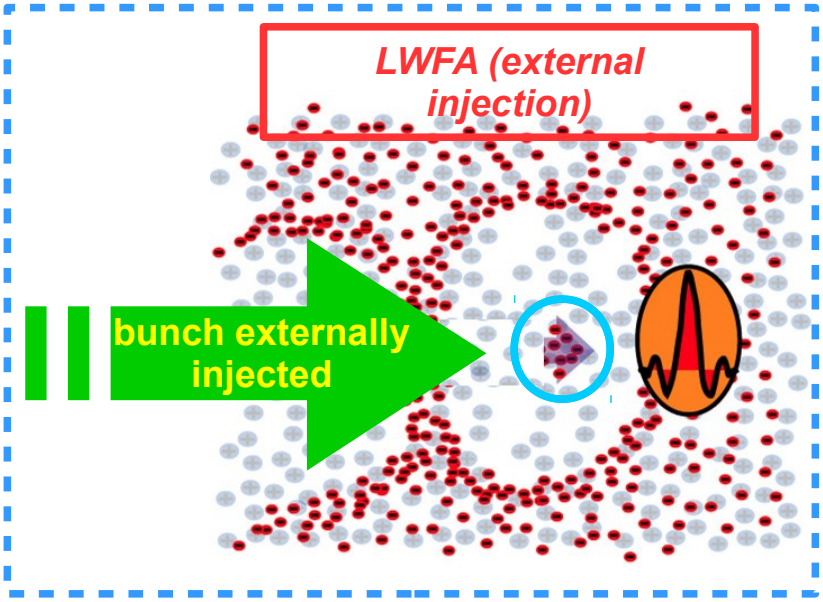
THz station – user experiments

Plasma-based acceleration

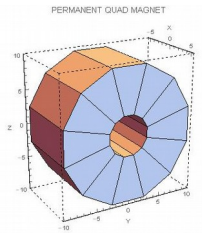
- Several plasma-based schemes will be tested
  - ***PWFA** resonant scheme → **1-2 GV/m** expected*
    - ***n_e~10^{16} cm^{-3}, 1 mm diameter capillary, Hydrogen***
  - ***LWFA**, external injection → **5-10 GV/m** expected*
    - ***n_e~10^{17} cm^{-3}, 100 μm diameter capillary, Hydrogen***
- Goal: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





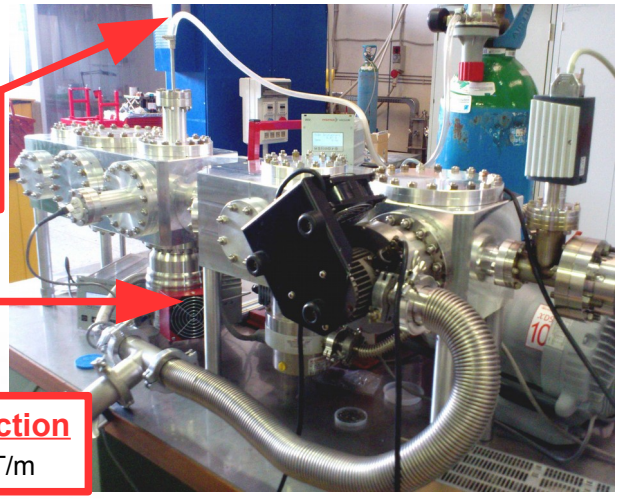


Beam-driven PWFA



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 FEL

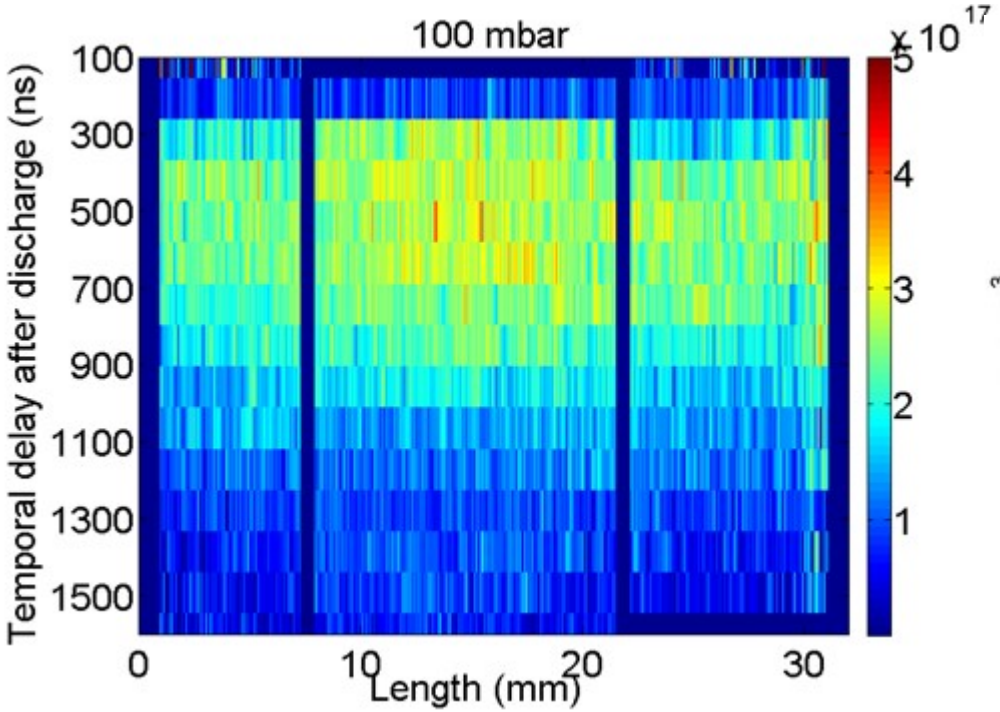
SPARC linac
- 2 S-band TW sections (3 m)
- Last S-band section replaced with a C-band one (1.3 m)

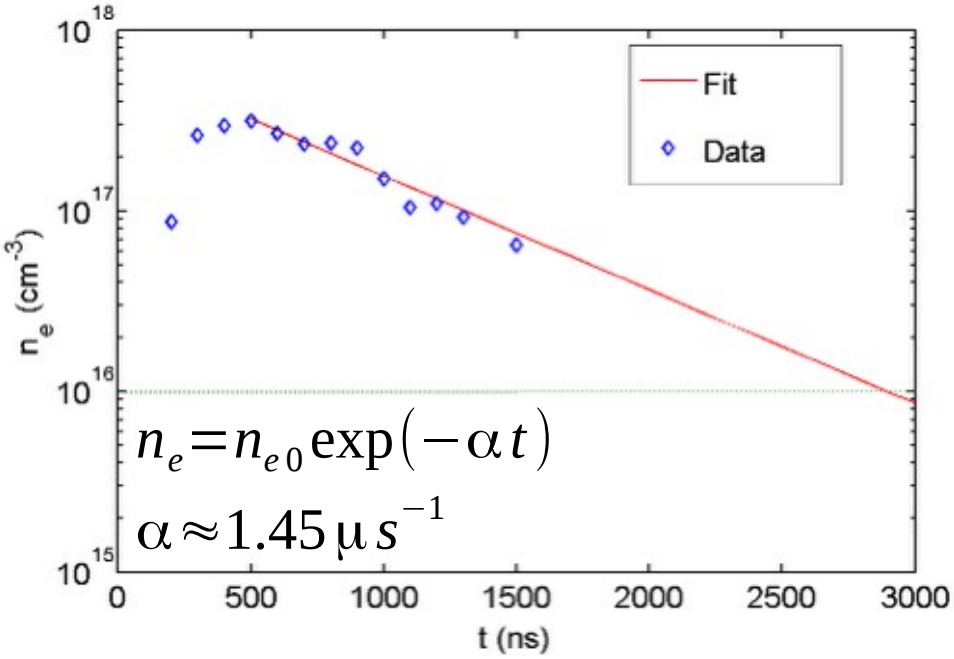
Acceleration + diagnostics
- 3 cm length capillary
- 1 mm hole diameter
- n_0 measure by Stark broadening

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

Plasma characterization

Plasma density measurement from H_α Stark broadening





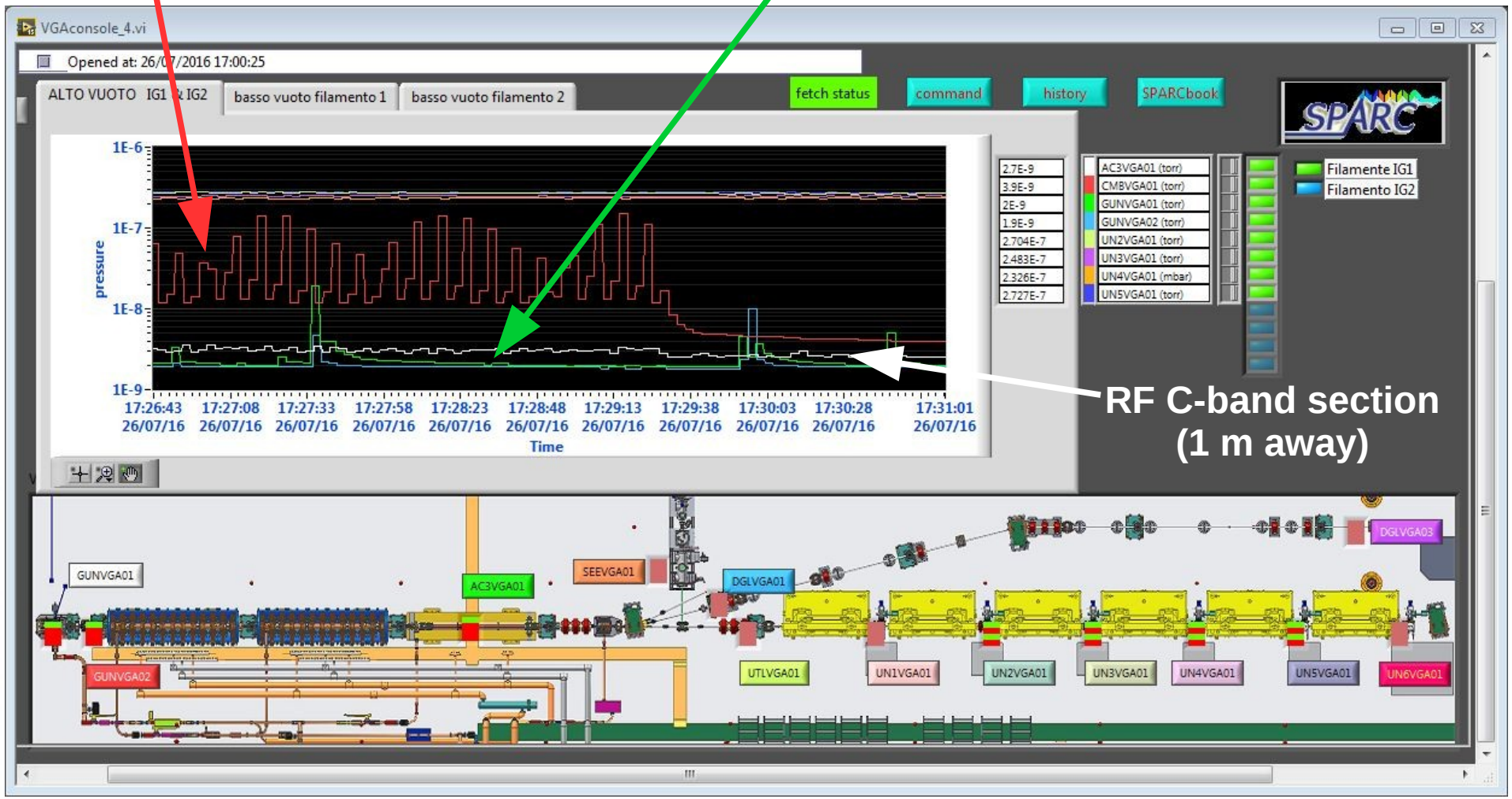
The plasma density is controlled through the delay after the discharge

Vacuum level during plasma runs

Plasma chamber

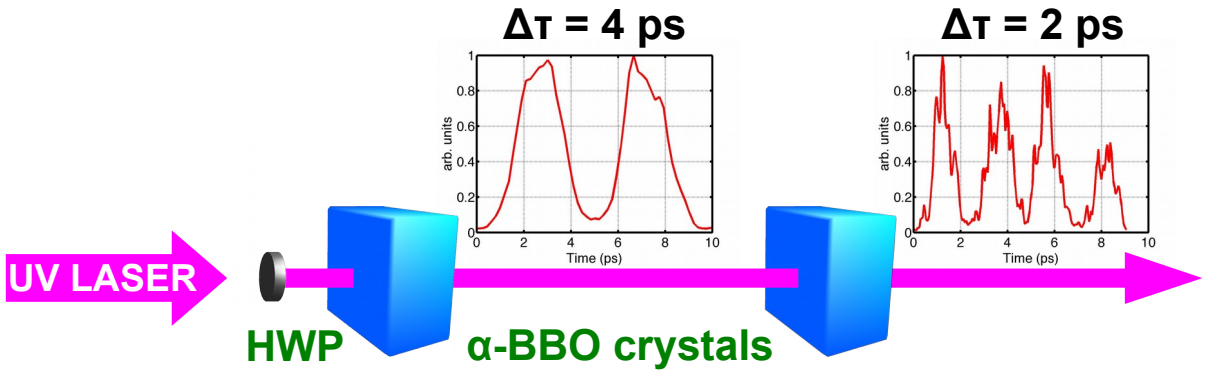
RF gun (11 m away)

Gas flow @ 1 Hz



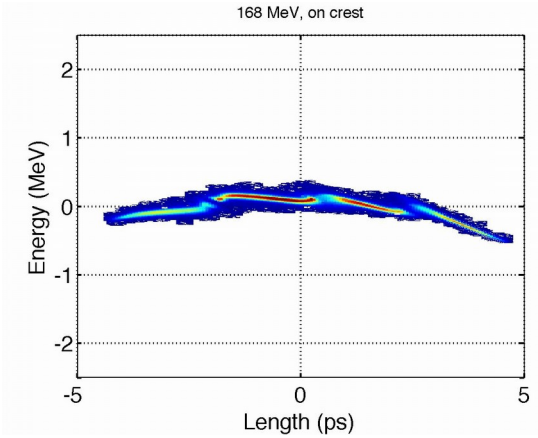
Laser-comb with velocity bunching

- **Laser-comb**: multiple bunches train produced directly at the cathode
  - ✔ *Pulses delayed by birefringent crystals, delay lines to take full control of distances*
  - ✔ *Easy setup, half-wave plates for (un)balancing (charge ramps…)*



Ferrario, M., et al "Laser comb with velocity bunching: Preliminary results at SPARC." NIM 637.1 2011 S43-S46.

- Velocity bunching for bunch compression
  - *Distance and duration tuning by moving S1 phase*
  - *Different approach with respect to other multi-bunches schemes, e.g. @ FACET.*



C. Ronsivalle et al. "Large-bandwidth two-color free-electron laser driven by a comb-like electron beam." New Journal of Physics (2014): 033018.

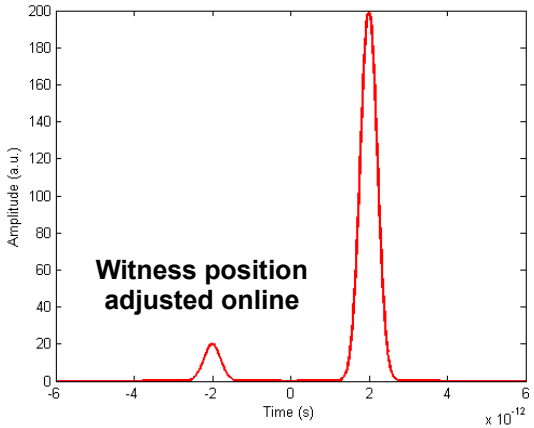
Hogan, M. J., et al "Plasma wakefield acceleration experiments at FACET." New Journal of Physics 2010 055030.

Multi-bunch setup: 1 driver + witness

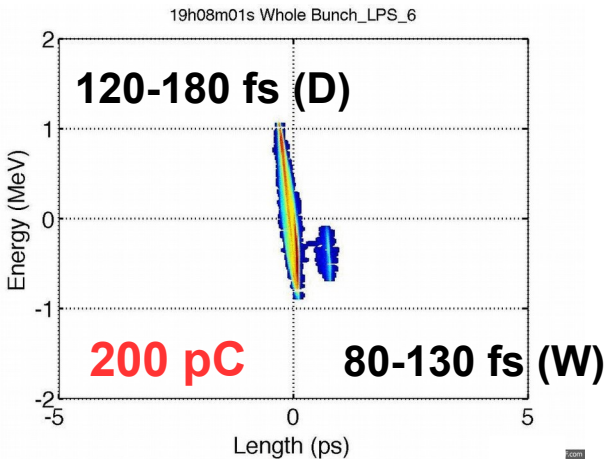
Experimental results!

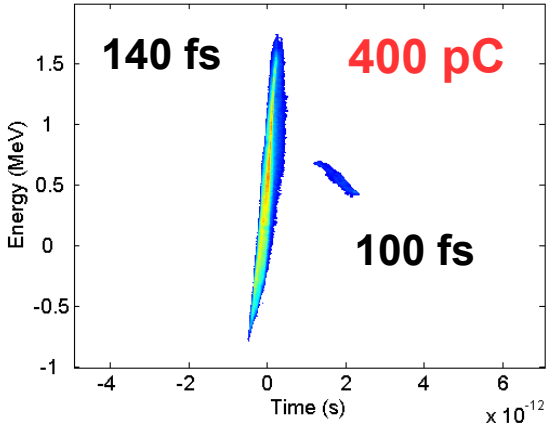
Laser profile on photo-cathode

Driver + witness (20 pC)

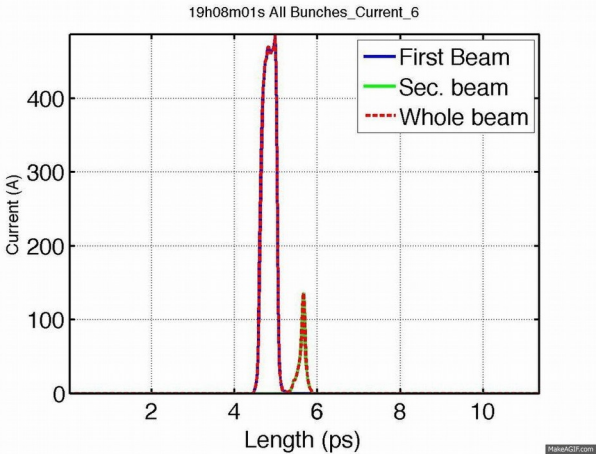


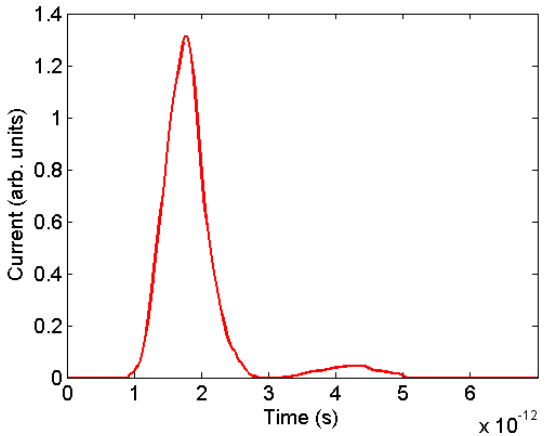
LPS at linac exit





Current profile





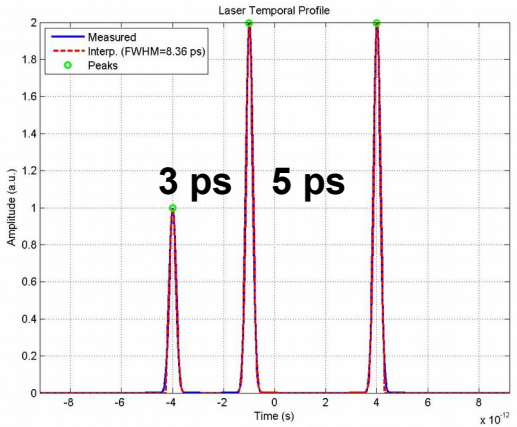
Multi-bunch setup: N driver + witness

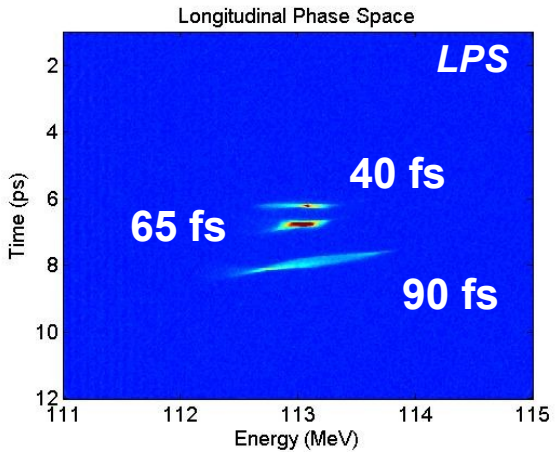
Experimental results!

50 pC drivers + 20 pC witness

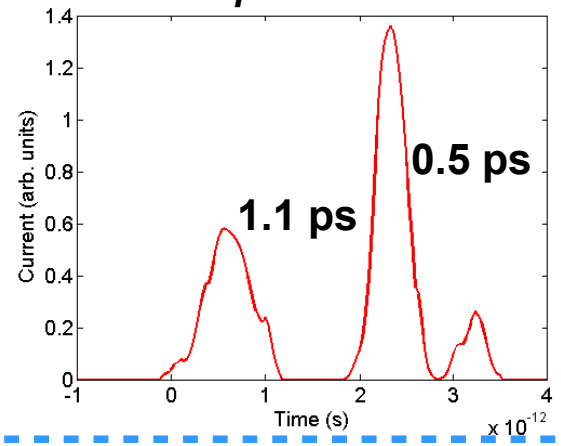
resonant scheme @ $n_p = 10^{16}$ cm^{-3} → bunch distance = λ_p ~ 1.1 ps

Laser profile on photo-cathode

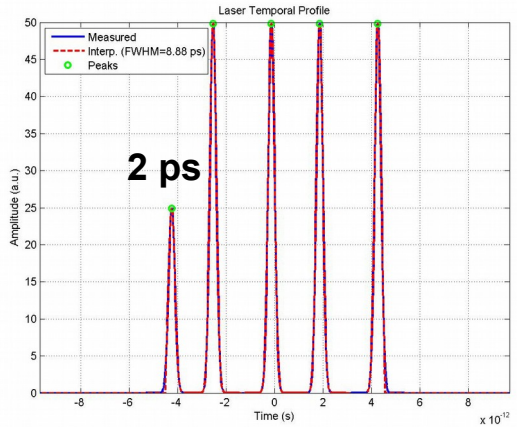


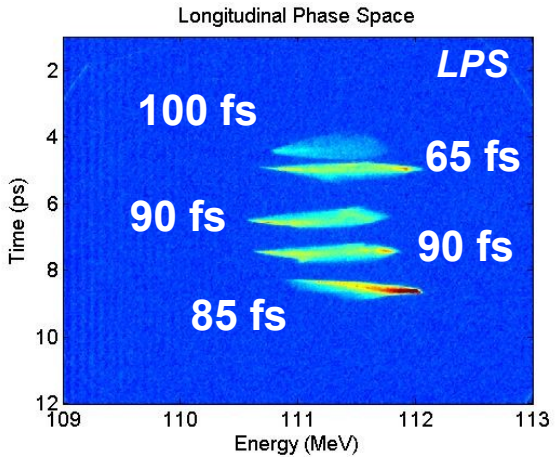


Current profile

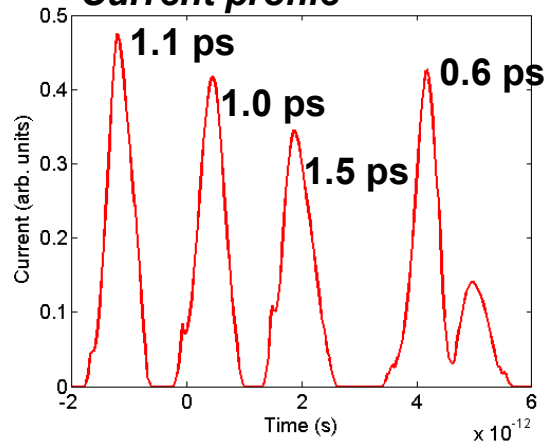


Laser profile on photo-cathode



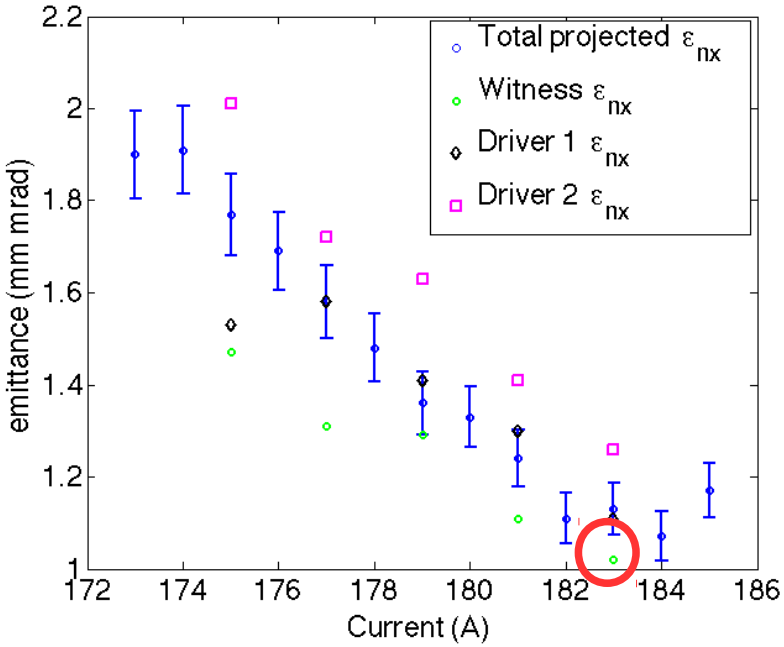


Current profile

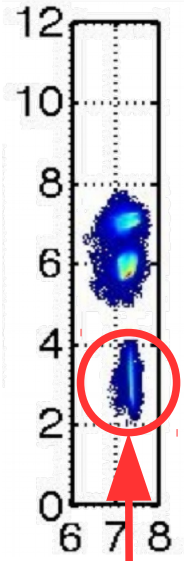


Witness – tuning and characterization

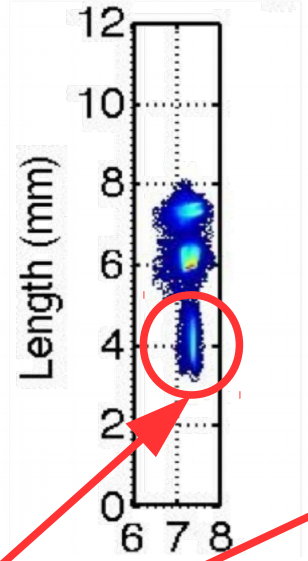
Single bunch emittance scan



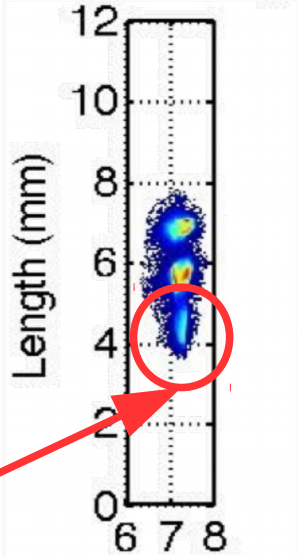
+1.67 ps



Reference

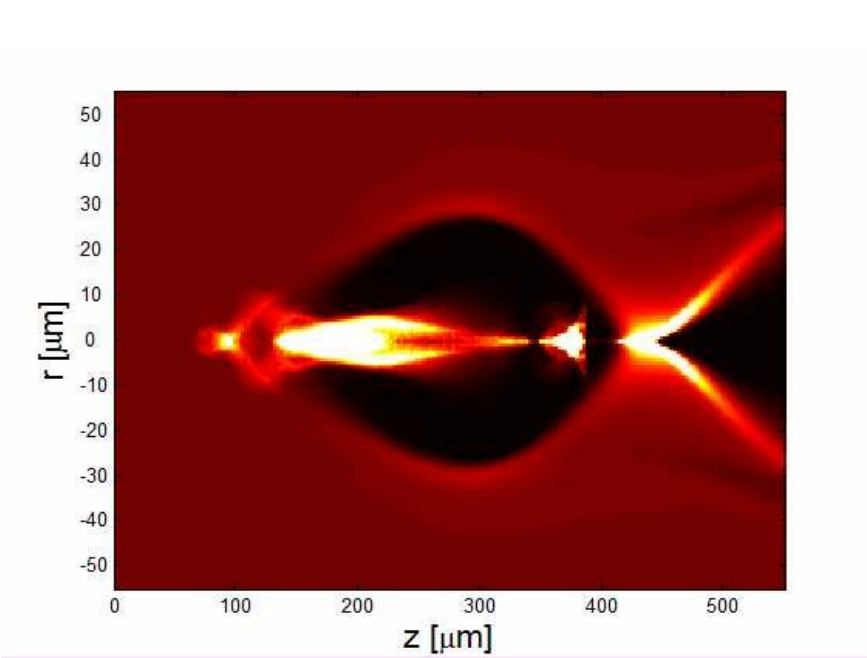


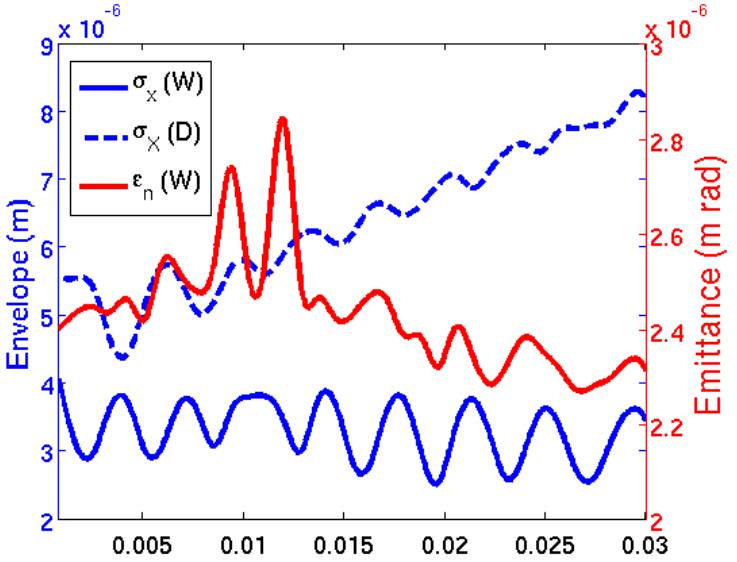
-1.67 ps

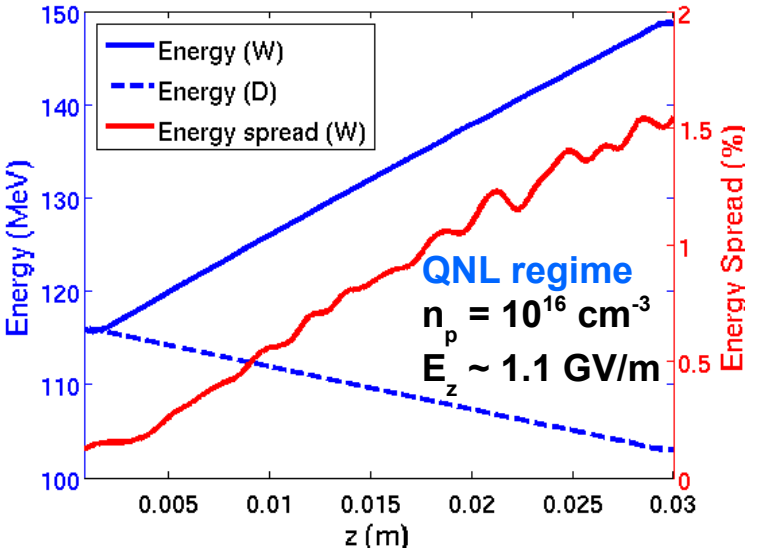


Witness position tuning with laser delay line!

Acceleration in plasma







- *Hybrid kinetic-fluid simulation by **Architect***
  - ***PIC** (bunch), **fluid** (plasma), 3-5 hours for 3 cm*

	Q (pC)	σt (fs)	σx (μm)	E (MeV)	ε (μm)
Driver	**200**	**180**	**5.5**	**116**	**4.5**
Witness	**20**	**35**	**3**	**116**	**2.4**

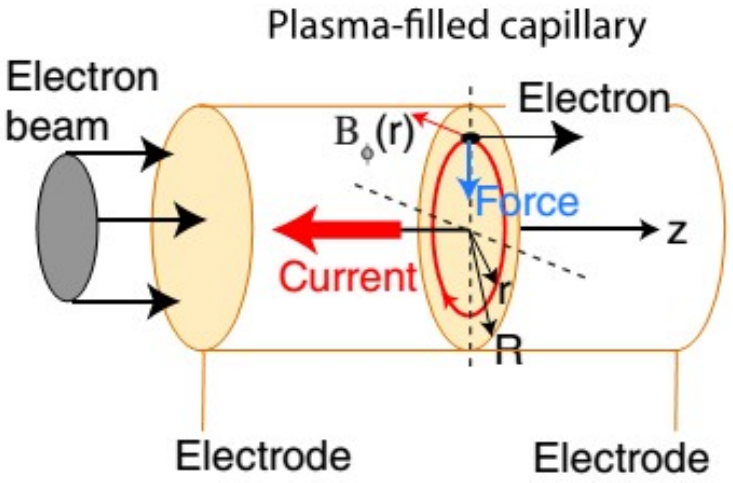
Marocchino, A., et al. "Efficient modeling of plasma wakefield acceleration in quasi-non-linear-regimes with the hybrid code Architect." Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment (2016).

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*

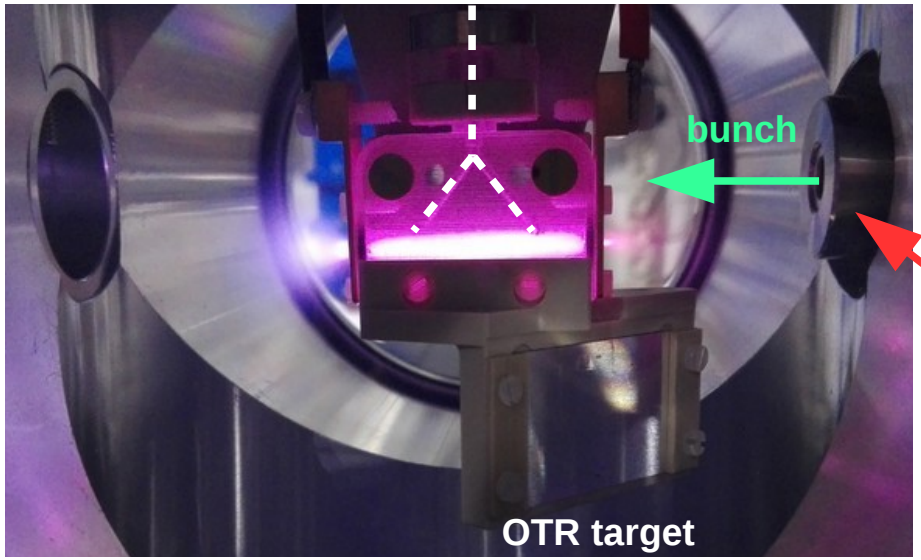
$$B_\phi(r) = \frac{1}{2}\int_0^r \mu_0 J(r')\,dr'$$

- ✔ Radial focusing
  - *X/Y planes are not dependent as in quads*
- ✔ Weak chromaticity
  - *Focusing force scales linearly with energy*
- ✔ Compactness
  - *Higher integrated field than quad triplets*
- ✔ Independent from beam distribution
  - *Not sensitive to longitudinal/transverse charge profile as in passive plasma lenses*



Van Tilborg, J., et al. "Active plasma lensing for relativistic laser-plasma-accelerated electron beams." Physical review letters 115.18 (2015): 184802.

Experimental layout



Vacuum impedence

20 cm

Capillary

Bunch

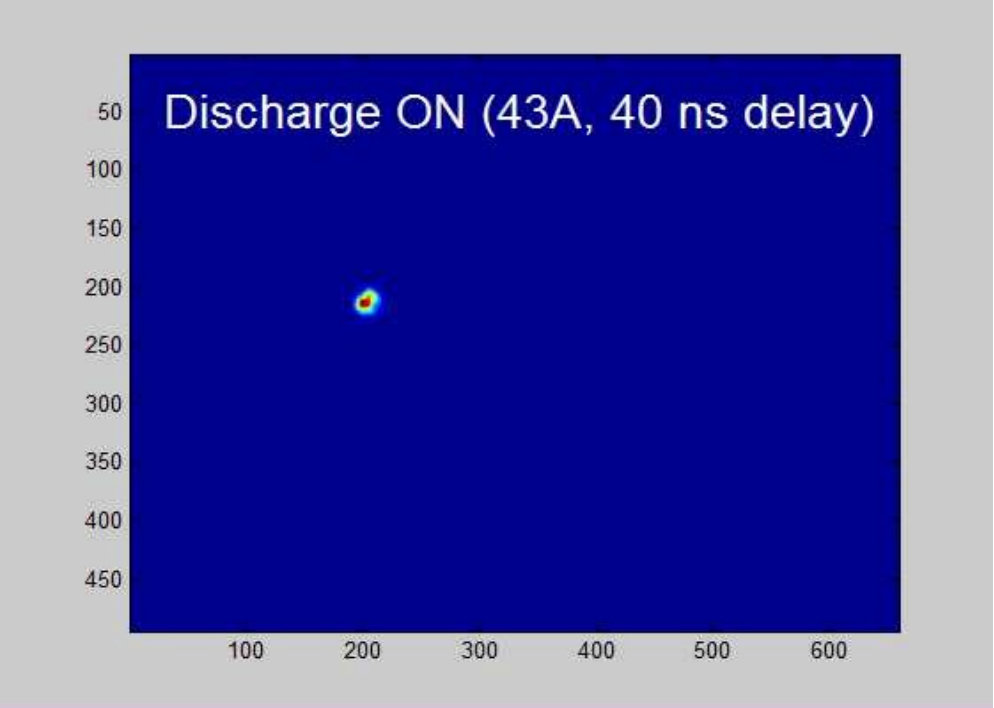
Plasma

Discharge circuit

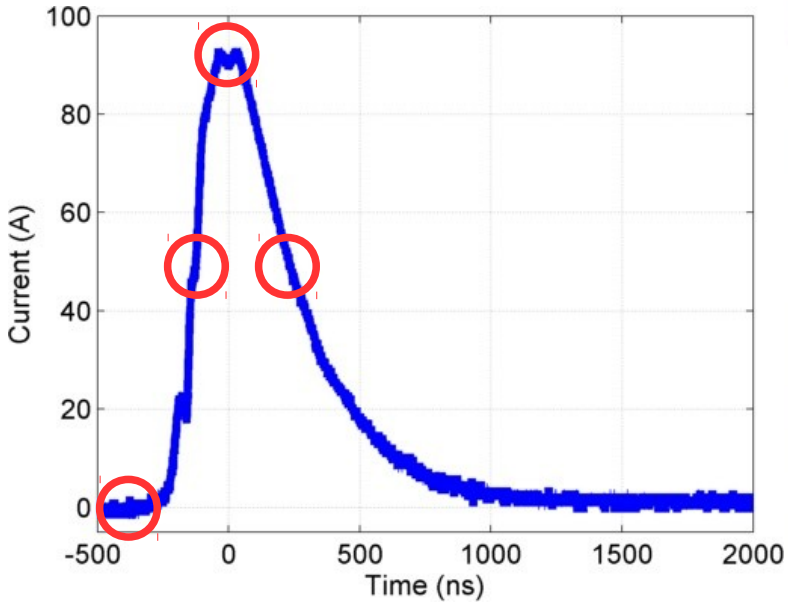
50 pC
1 ps
130 um
120 MeV
1 mm mrad

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

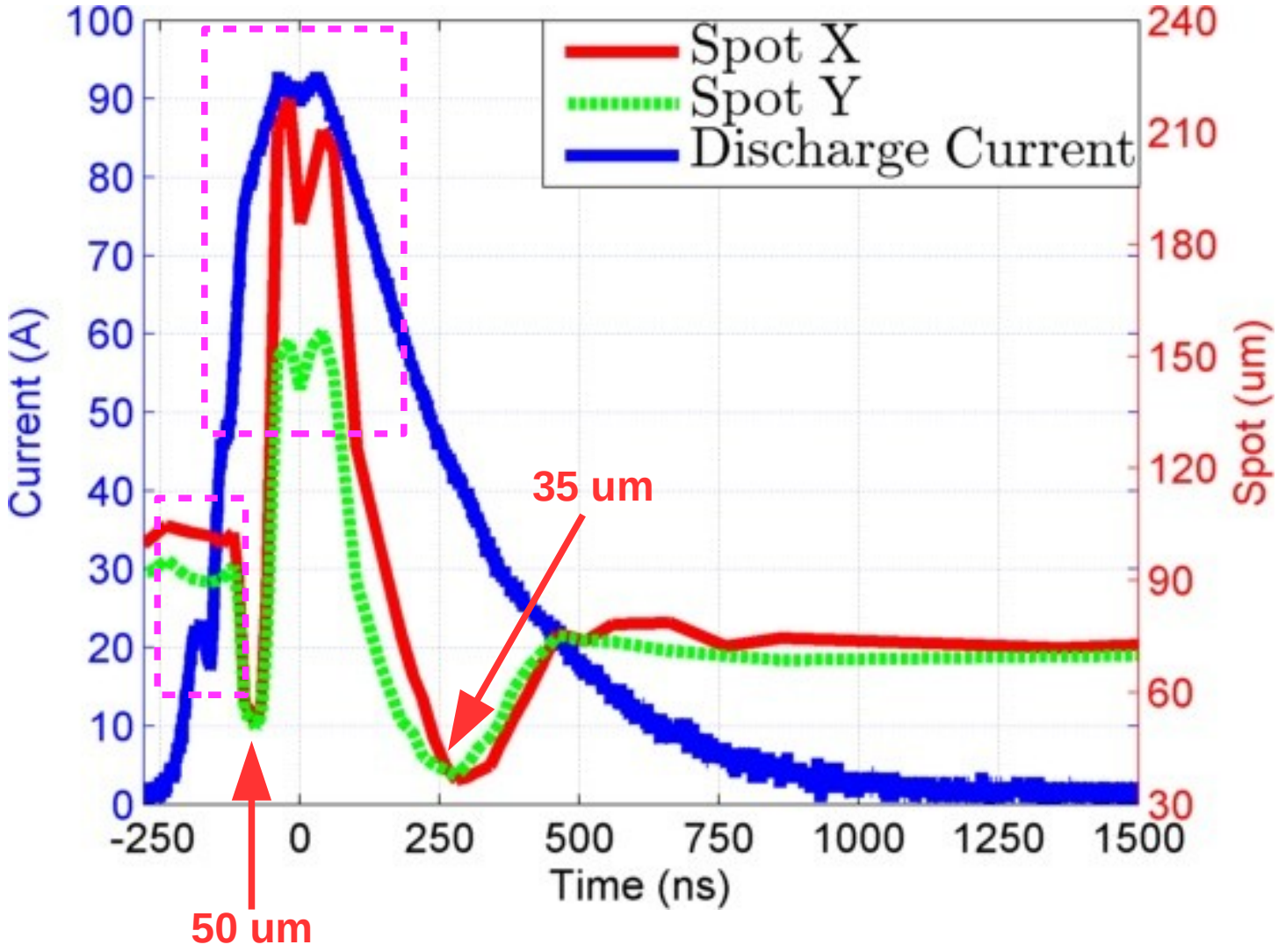
Preliminary results



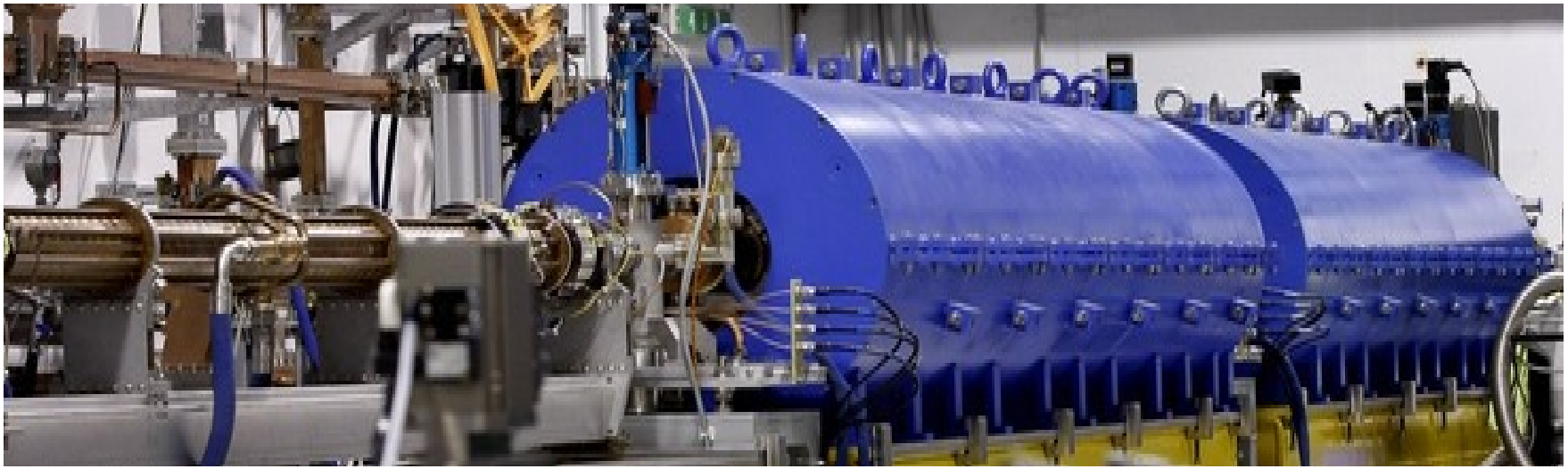
Discharge current profile



Preliminary results



Acknowledgments



- *M.P. Anania, M. Bellaveglia, A. Biagioni, E. Chiadroni, M. Croia, D. Di Giovenale, M. Ferrario, V. Lollo, A. Marocchino, G. Di Pirro, S. Romeo, J. Scifo, V. Shpakov, C. Vaccarezza, F. Villa (INFN, Frascati)*
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