Simultaneous temporal resolved measurements of protons and fast electrons in TNSA experiments

Bisesto Fabrizio

Outline

SPARC_LAB Facility and the FLAME laser

Laser-Solid target interactions @ FLAME

Experimental results

Conclusions and future perspectives

Outline

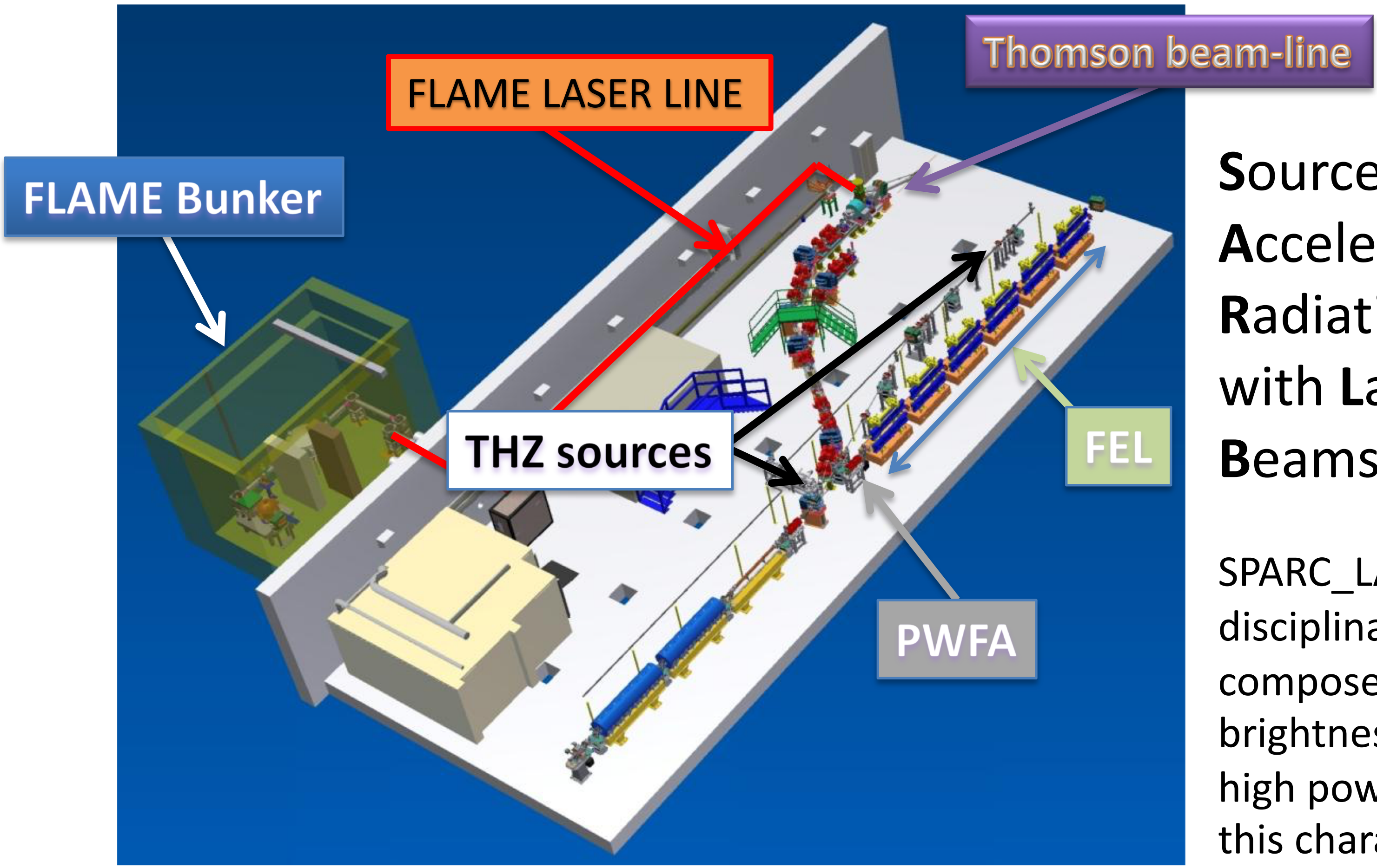
SPARC_LAB Facility and the FLAME laser

Laser-Solid target interactions @ FLAME

Experimental results

Conclusions and future perspectives

SPARC_LAB Facility

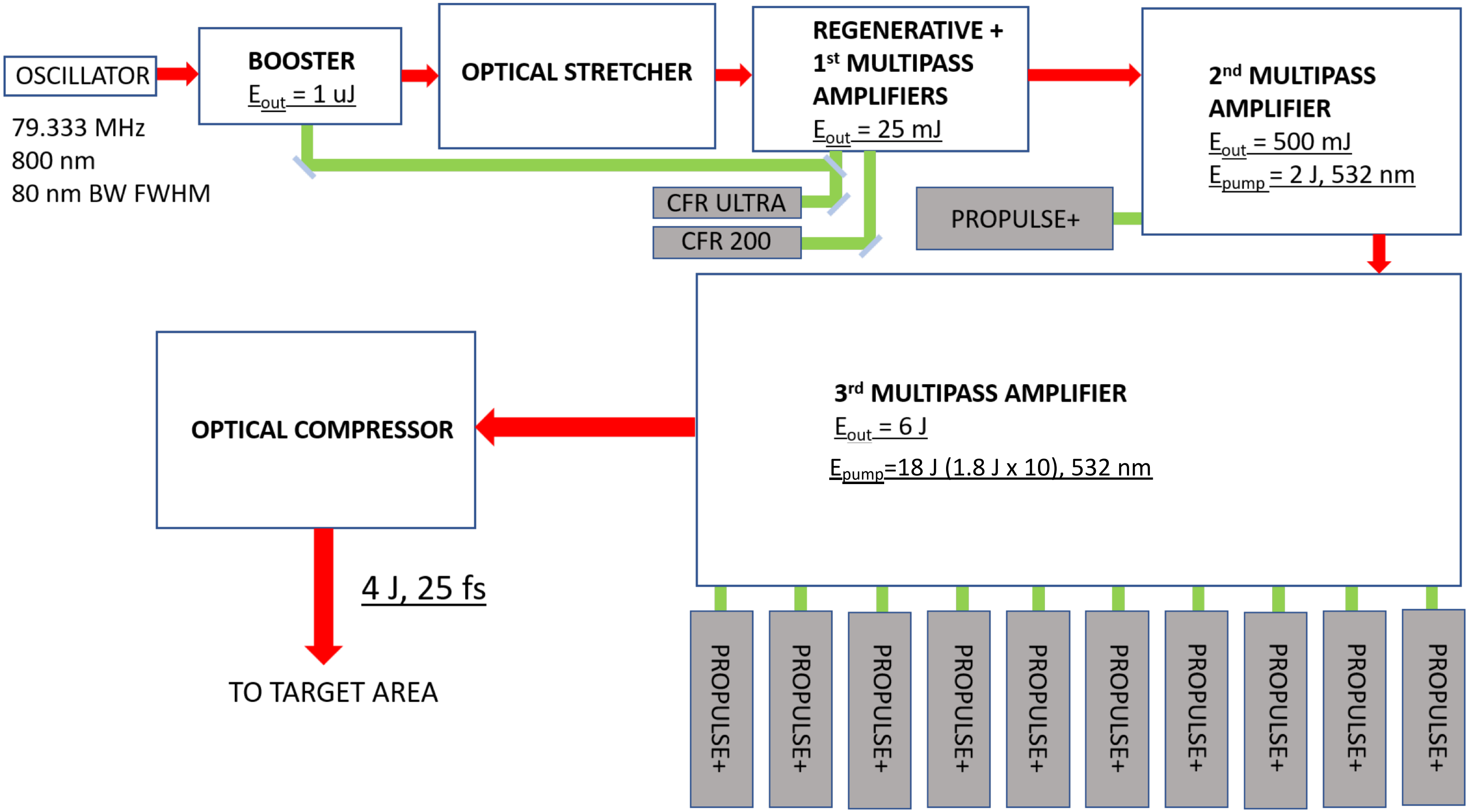


Ferrario, M., et al. "SPARC_LAB present and future." NIM B 309 (2013): 183-188

Sources for **P**lasma **A**ccelerators and **R**adiation **C**ompton with **L**asers and **B**eams

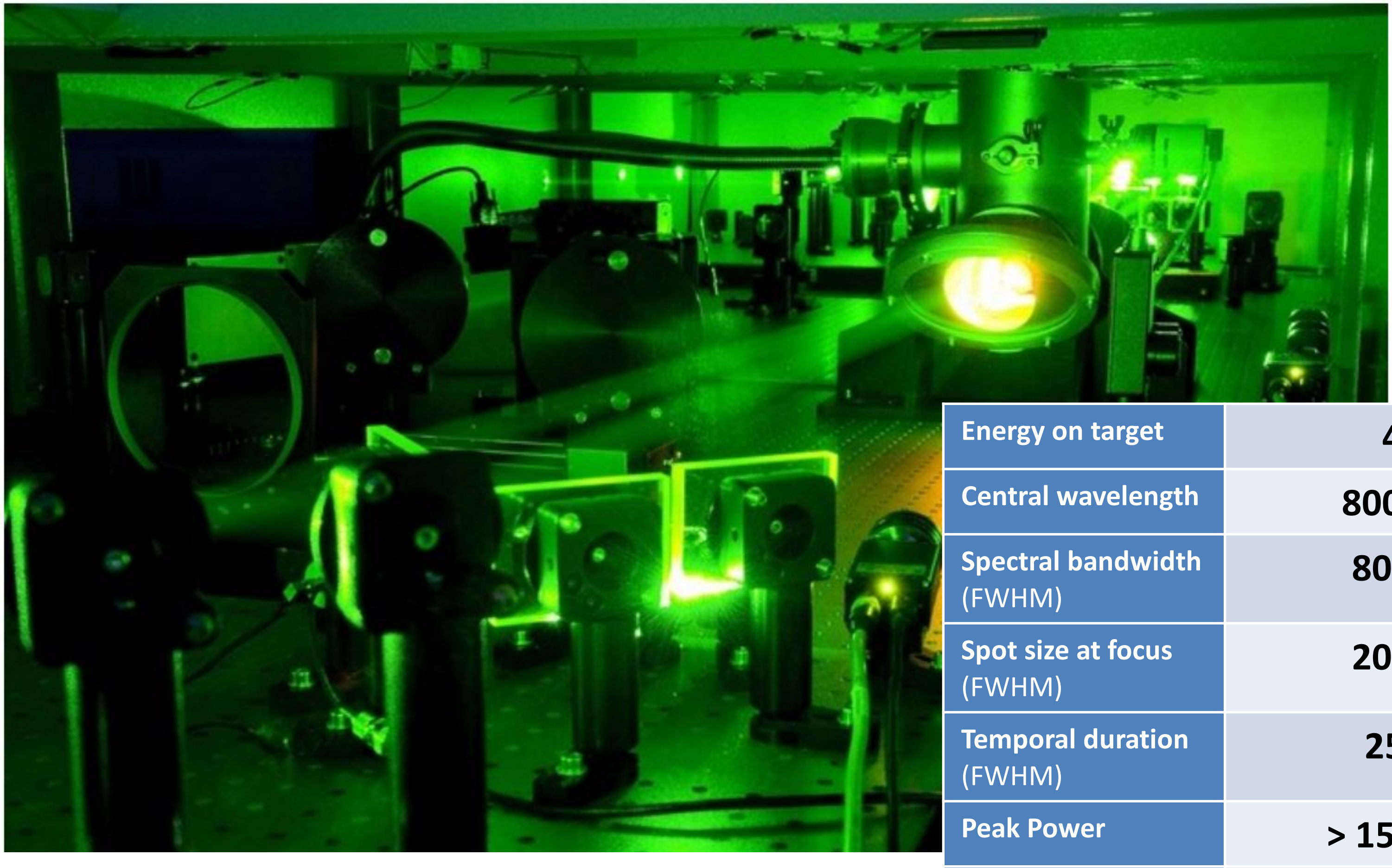
SPARC_LAB is a multi-disciplinary TEST Facility composed by a high brightness LINAC and the high power laser FLAME: this characteristic makes it unique.

The FLAME laser system



Bisesto, F., et al. "The FLAME laser at SPARC_LAB." NIM A (2018)

The FLAME laser: parameters on target



FLAME laser last amplifier.

Energy on target	**4 J**
Central wavelength	**800 nm**
Spectral bandwidth (FWHM)	**80 nm**
Spot size at focus (FWHM)	**20 um**
Temporal duration (FWHM)	**25 fs**
Peak Power	**> 150 TW**
Intensity	$5 * 10^{19}\ W/cm^2$
Contrast Ratio (@ 100 ps)	10^9

Outline

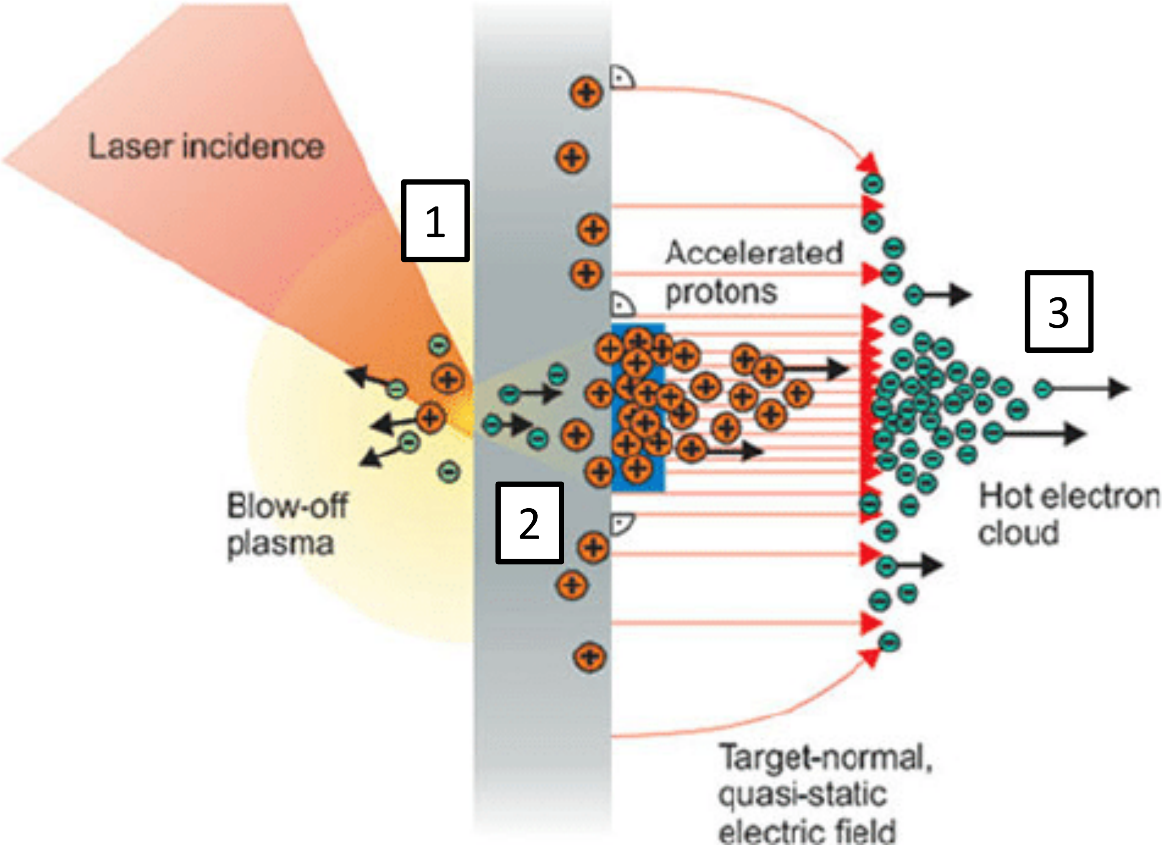
SPARC_LAB Facility and the FLAME laser

Laser-Solid target interactions @ FLAME

Experimental results

Conclusions and future perspectives

Laser-solid target interaction: a simple sketch



H. Schwoerer et al., *Nature* 439, 445-448 (2006)

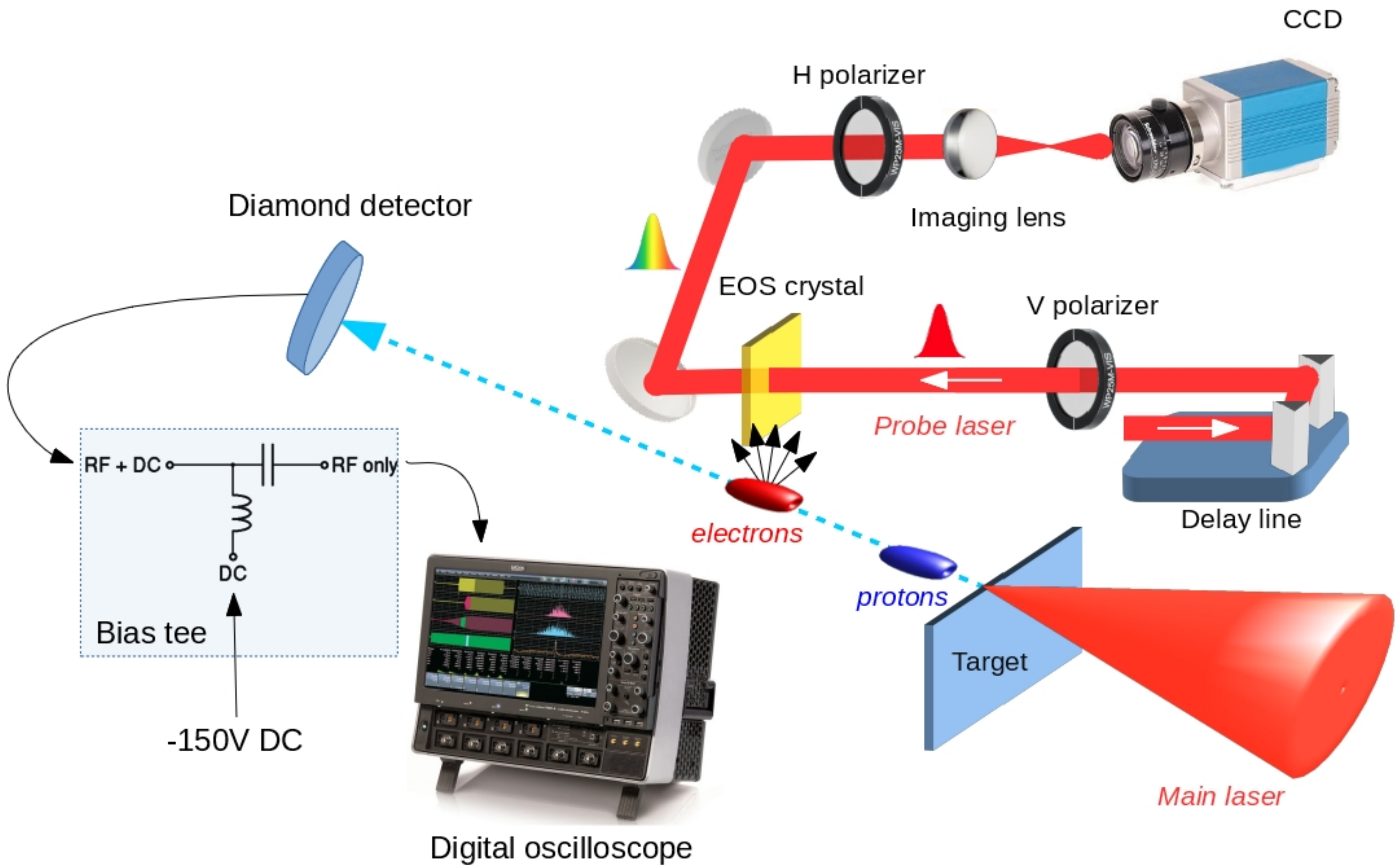
1) Laser interacts with pre-formed plasma and **electron acceleration** occurs.
2) **Hot electrons** leave the target and are locked in its vicinity: a **positive charge** is left and a quasi-static electric field is established (accelerating field).
3) Only more energetic electrons (**fast electrons**) can escape.

Laser-Solid target interactions @ FLAME

- **Electro-Optic Sampling** diagnostic to characterize the interaction:
  - Measurement of fast electrons temporal charge density
  - Study of target geometry influence on fast electron emission.
  - Detection of ultrafast evolution of electric fields.

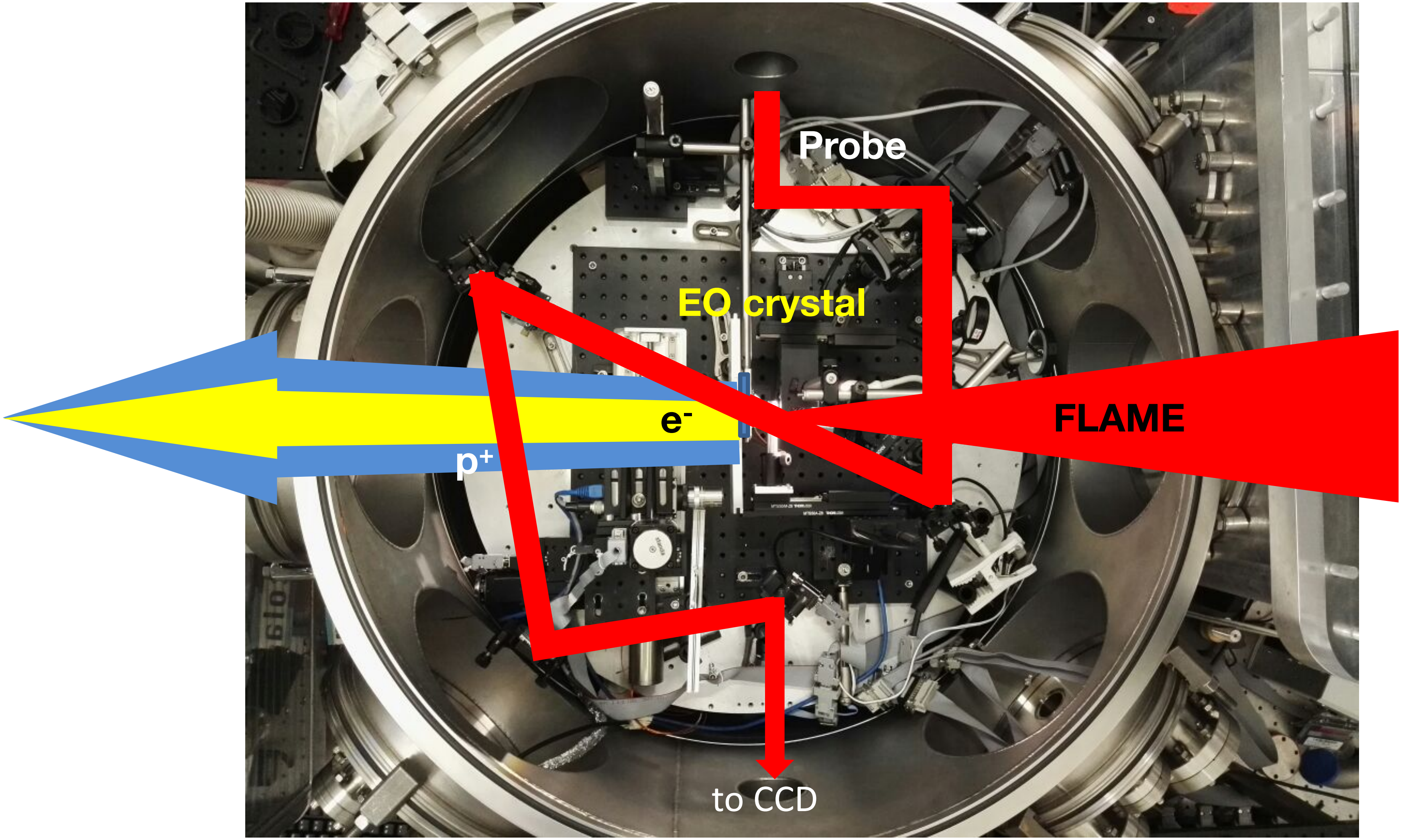
- **NEW! Simultaneous detection and characterization of accelerated fast electrons and protons via TNSA.**

Experimental setup: particle diagnostics

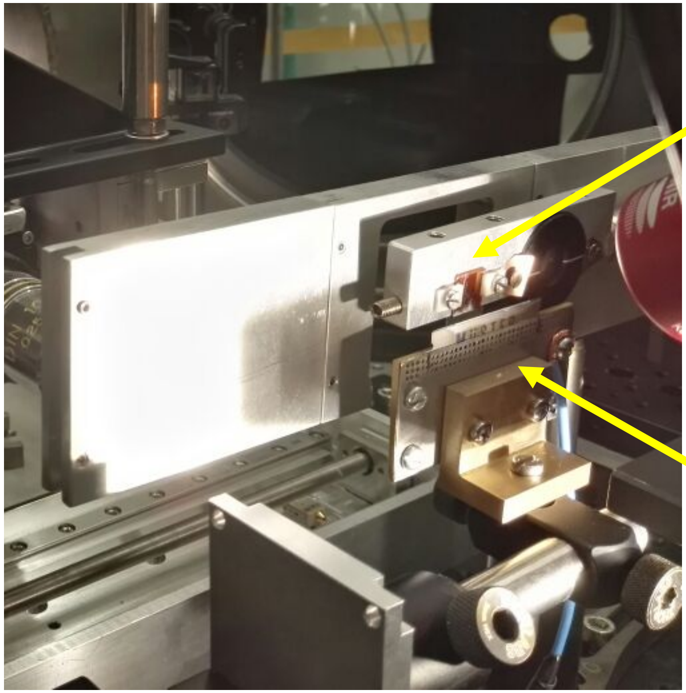


Bisesto, F., et al. "Single-shot electrons and protons time-resolved detection from high-intensity laser–solid matter interactions at SPARC_LAB.", High Power Lasers, **7** (2019)

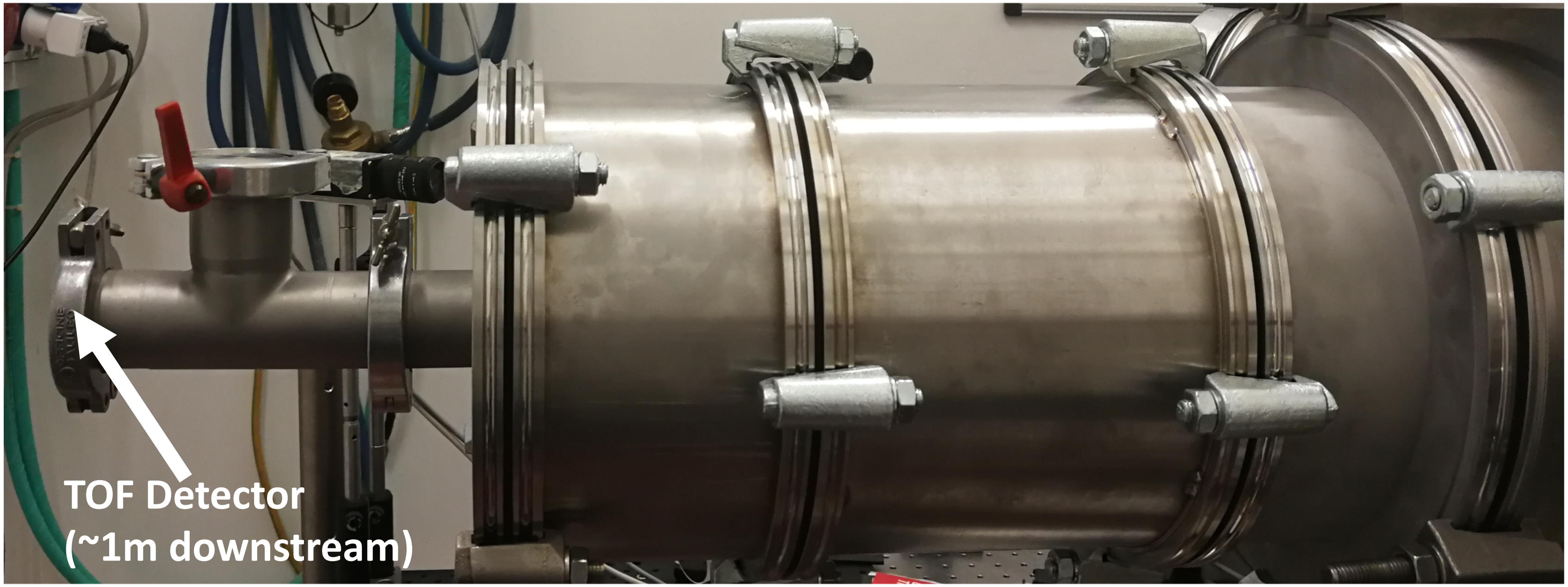
Experimental set-up in FLAME target area



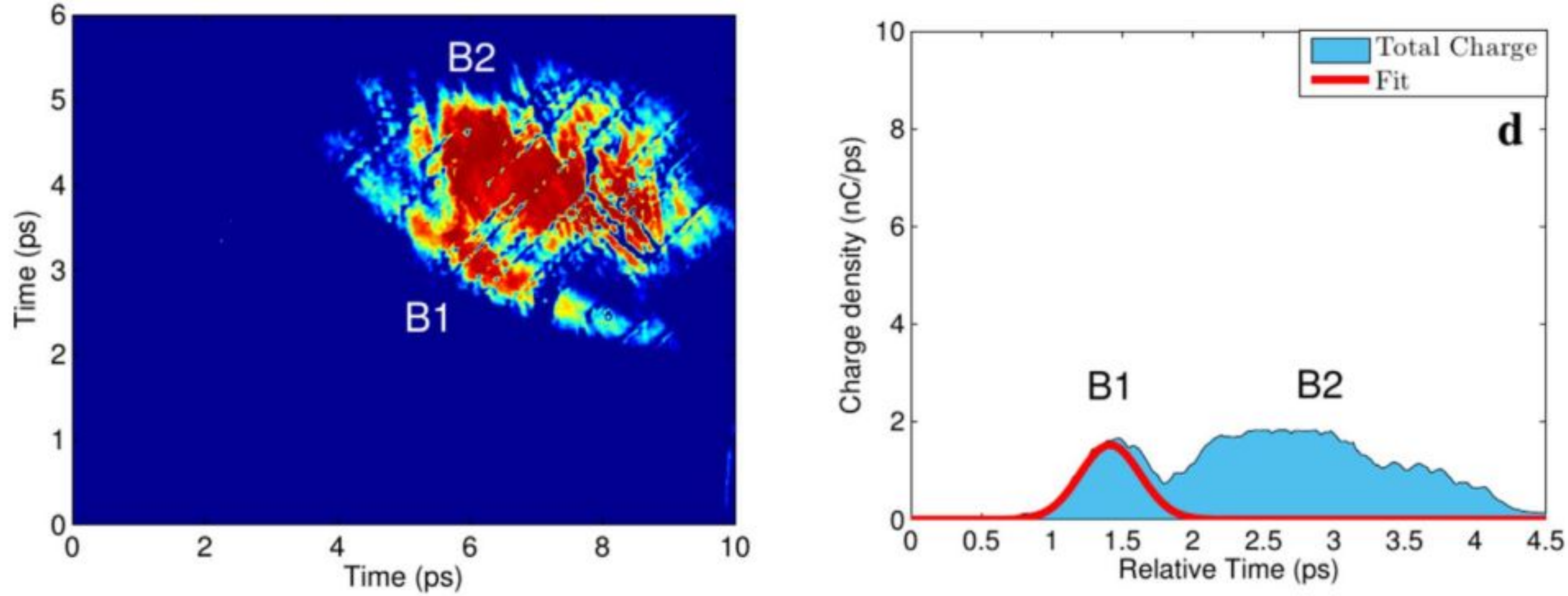
Experimental set-up in FLAME target area



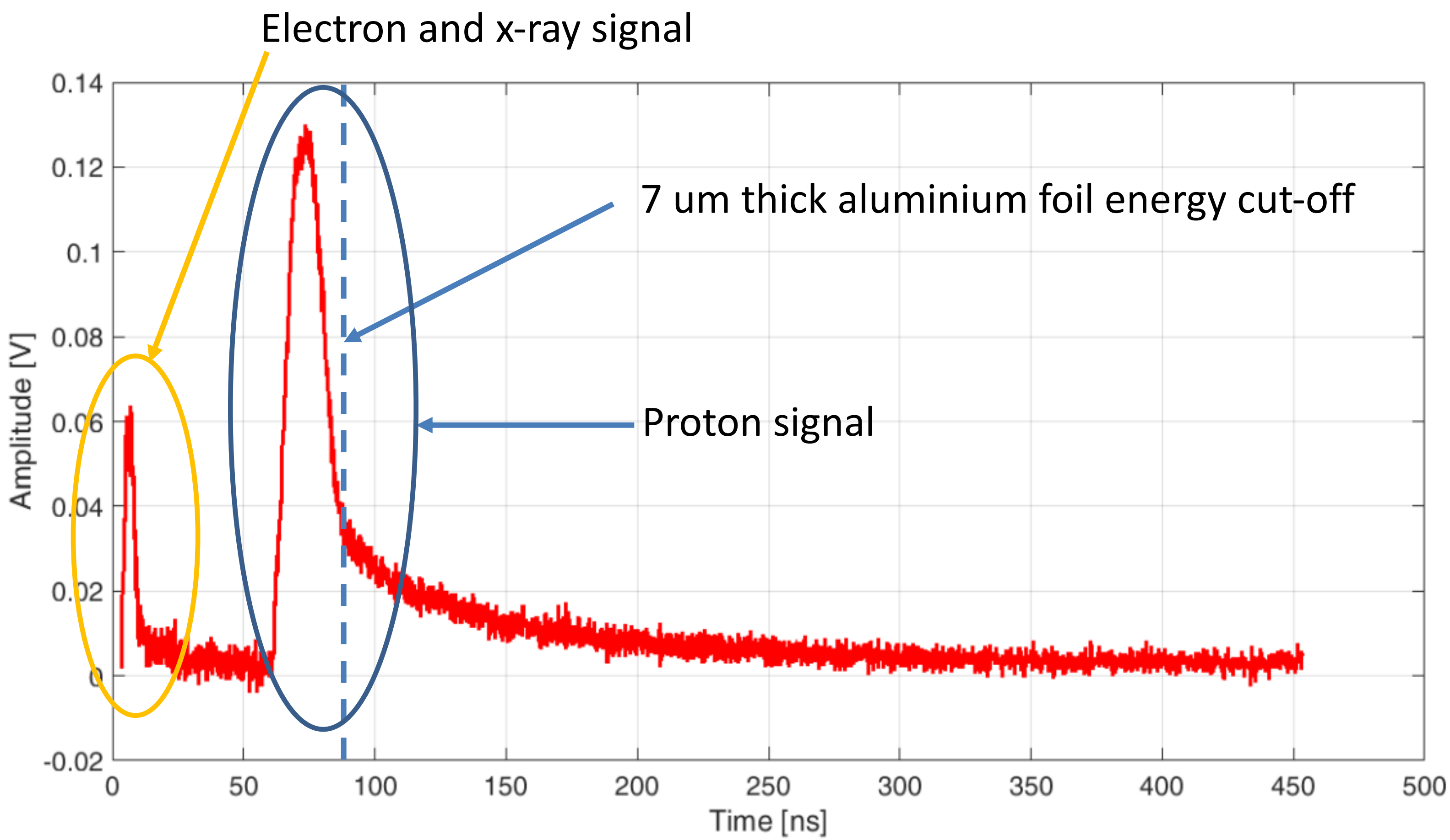
Experimental set-up in FLAME target area



EOS diagnostic: typical signal



TOF diagnostic: typical signal



Bisesto, F., et al. "Single-shot electrons and protons time-resolved detection from high-intensity laser–solid matter interactions at SPARC_LAB.", High Power Lasers, **7** (2019)

Outline

SPARC_LAB Facility and the FLAME laser

Laser-Solid target interactions @ FLAME

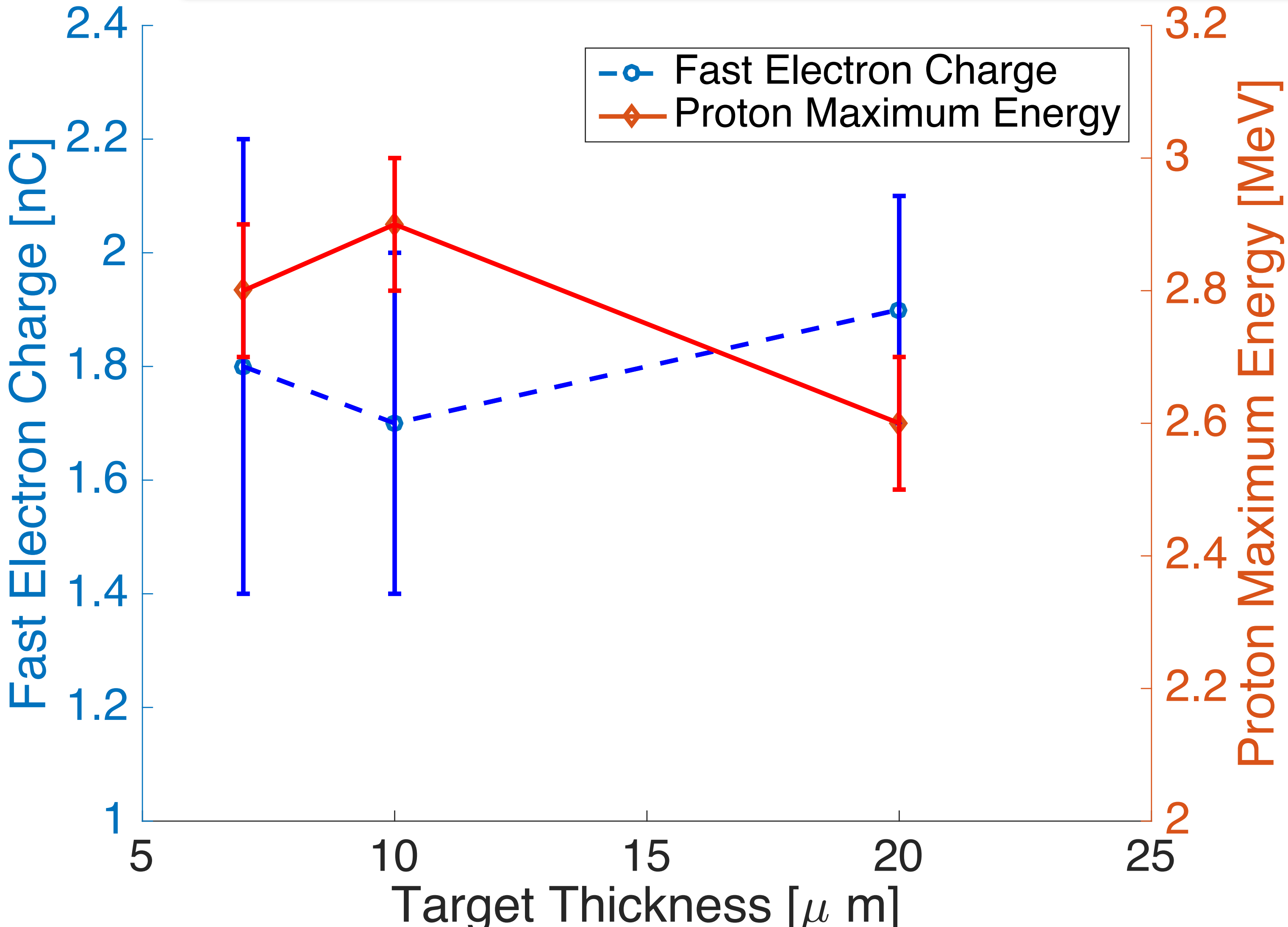
Experimental results

Conclusions and future perspectives

Experimental results

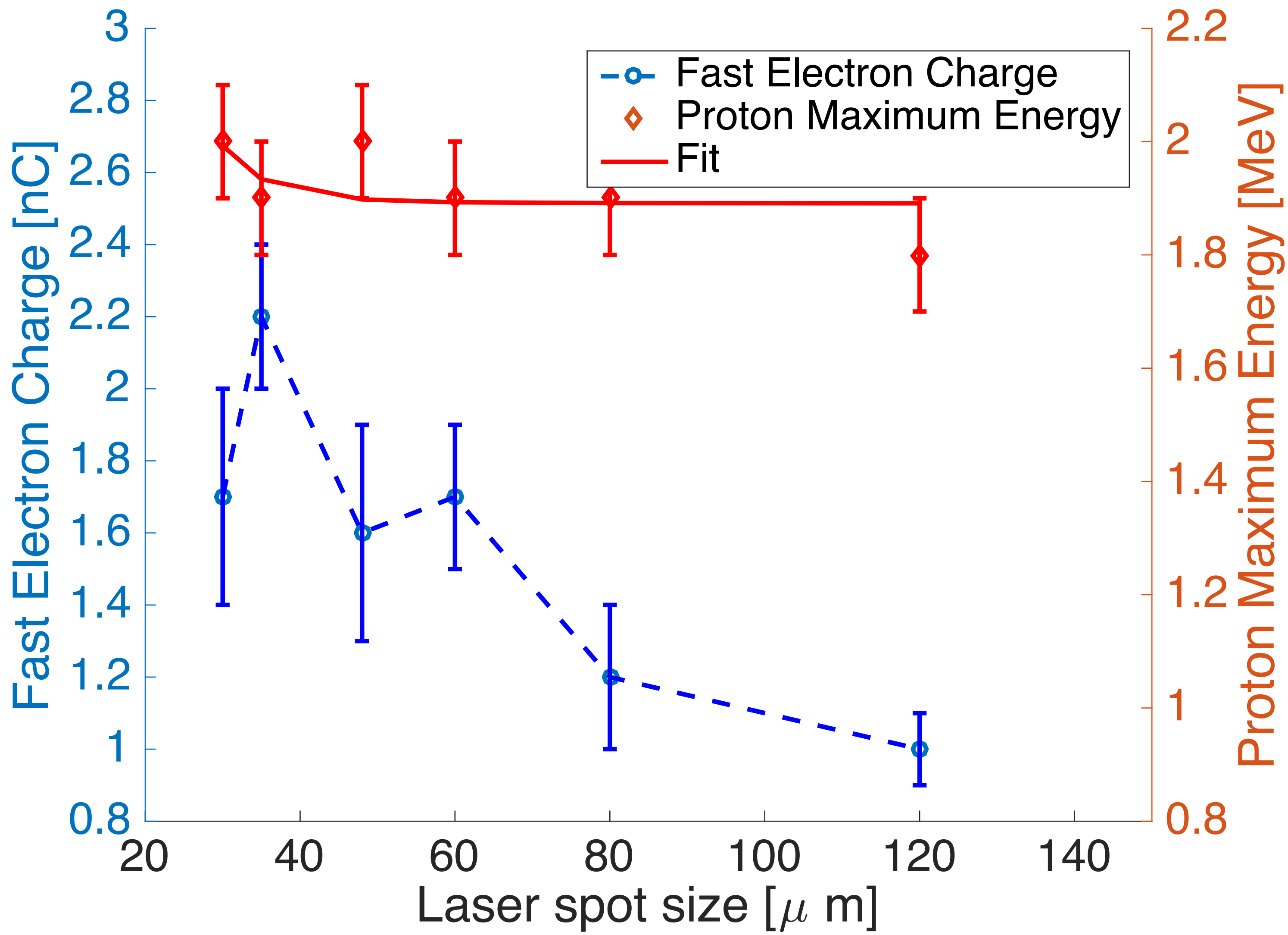
- Simultaneous detection of fast electrons and accelerated protons.
- Parametric studies:
  – Target thickness
  – Laser spot size
  – Laser temporal duration

Experimental results: target thickness scan



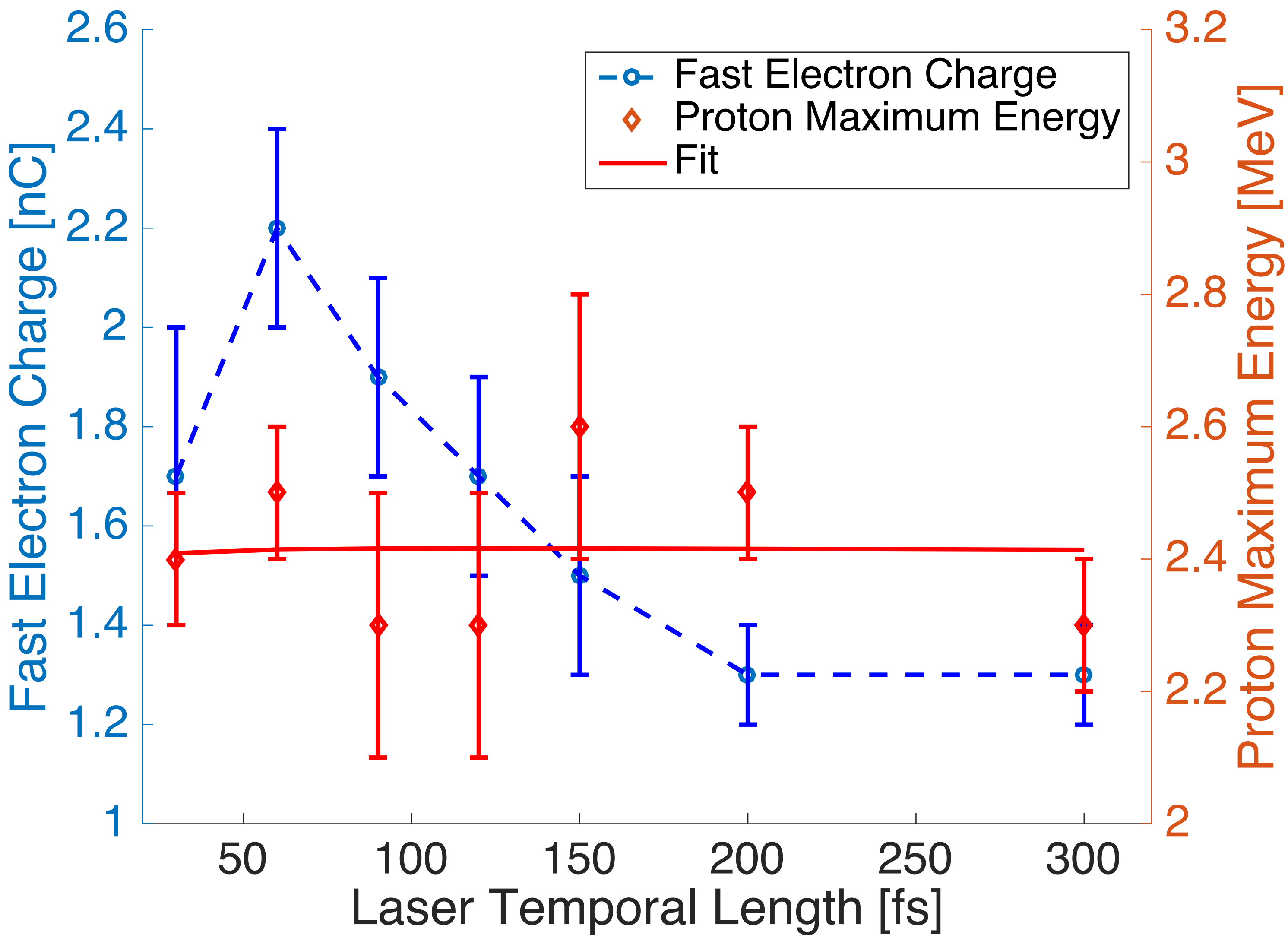
Bisesto, F., et al. In preparation

Experimental results: laser spot scan



Bisesto, F., et al. In preparation

Experimental results: laser duration scan



Bisesto, F., et al. In preparation

Outline

SPARC_LAB Facility and the FLAME laser

Laser-Solid target interactions @ FLAME

Experimental results

Conclusions and future perspectives

Conclusions and future perspectives

- We have reported about temporal characterization of emitted charged particles from laser-solid target interactions
  - EOS diagnostics has provided the fast electrons bunch length with femtosecond resolution.
  - TOF diamond detector has been employed to measure the proton temporal structure and energy spectrum.
- Parametric studies have been performed by changing laser and target parameters.
- Data analysis and simulations are still undergoing to study fast electrons-protons correlations.

Thanks for your attention!

Fabrizio Bisesto
Maria Pia Anania
Gemma Costa
Riccardo Pompili
Massimo Ferrario

Istituto Nazionale di Fisica Nucleare

Science & Technology Facilities Council Central Laser Facility
TÉCNICO LISBOA

Mario Galletti

THE HEBREW UNIVERSITY OF JERUSALEM

Arie Zigler
Jenia Papeer

Agenzia nazionale per le nuove tecnologie, l'energia e lo sviluppo economico sostenibile

Fabrizio Consoli
Martina Salvadori
Mattia Cipriani
Pierluigi Andreoli

Università di Roma Tor Vergata

Claudio Verona

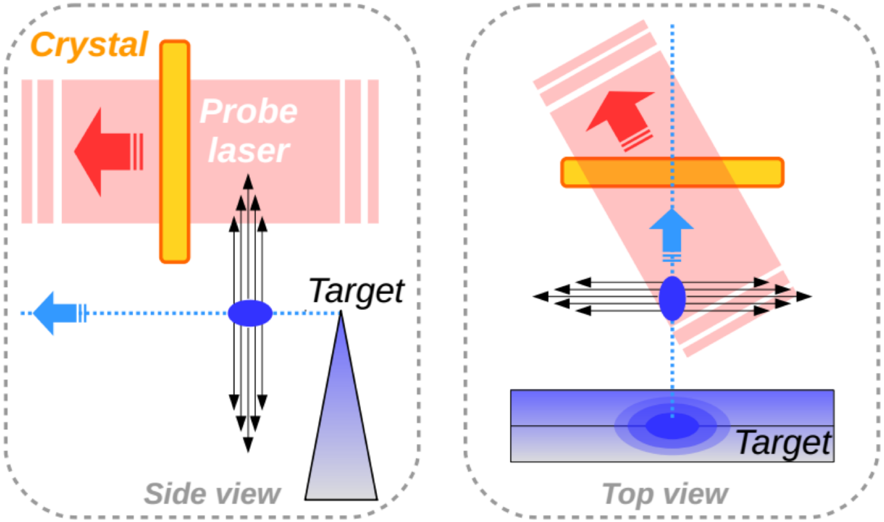
fabrizio.giuseppe.bisesto@lnf.infn.it

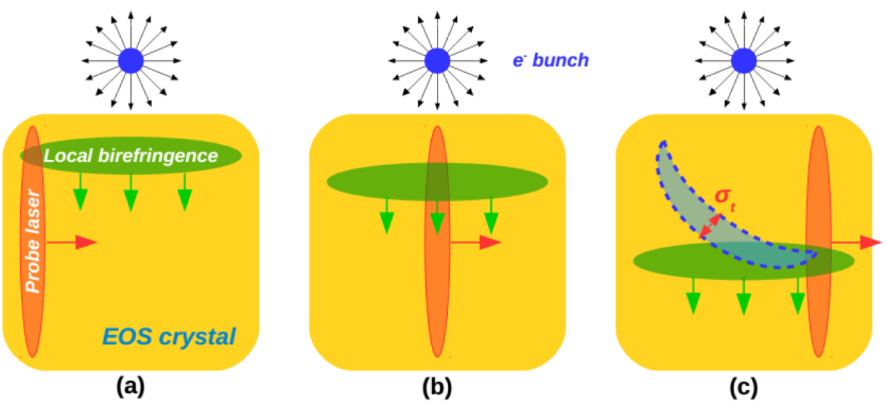
Main references

- **Pompili, R., et al.** "Femtosecond dynamics of energetic electrons in high intensity laser-matter interactions." Sci.Rep. **6** (2016)
- **Pompili, R., et al.** "Sub-picosecond snapshots of fast electrons from high intensity laser-matter interactions ." Opt.Exp. **24** (2016)
- **Bisesto, F., et al.** «Novel single-shot diagnostics for electrons from laser-plasma interaction at SPARC_LAB.» Quantum Beam Science, 1(3):13 (2017).
- **Bisesto, F., et al.** "The FLAME laser at SPARC_LAB." NIM A (2018)
- **Pompili, R., et al.** «Ultrafast evolution of electric fields from high-intensity laser-matter interactions.» Sci.Rep. **8** (2018)
- **Bisesto, F., et al.** "Single-shot electrons and protons time-resolved detection from high-intensity laser–solid matter interactions at SPARC_LAB.", High Power Lasers, **7** (2019)
- **Bisesto, F., et al.** " Review on TNSA diagnostics and recent developments at SPARC LAB.", High Power Lasers, **7** (2019)

Backup slides

Electron diagnostic: EOS working principle





The emitted bunch travels normally to the crystal surface and moves below it while the probe laser crosses the crystal with a non-zero incidence angle.

ENCODING SIGNAL

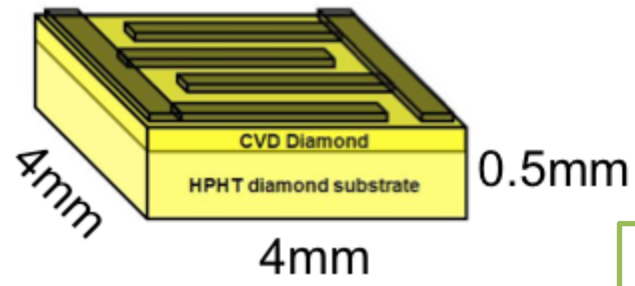
a) the bunch Coulomb field makes the crystal birefringent .

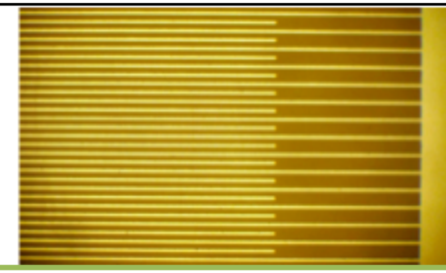
b) while the electric field penetrates in the crystal, the local birefringence shifts downwards .

c) The probe laser crosses the crystal and its polarization is rotated; the resulting signal comes from where the local birefringence and the probe laser are temporally overlapped.

Pompili, R., et al. "Sub-picosecond snapshots of fast electrons from high intensity laser-matter interactions ." Opt.Exp. 24 (2016)

Proton diagnostic: diamond TOF

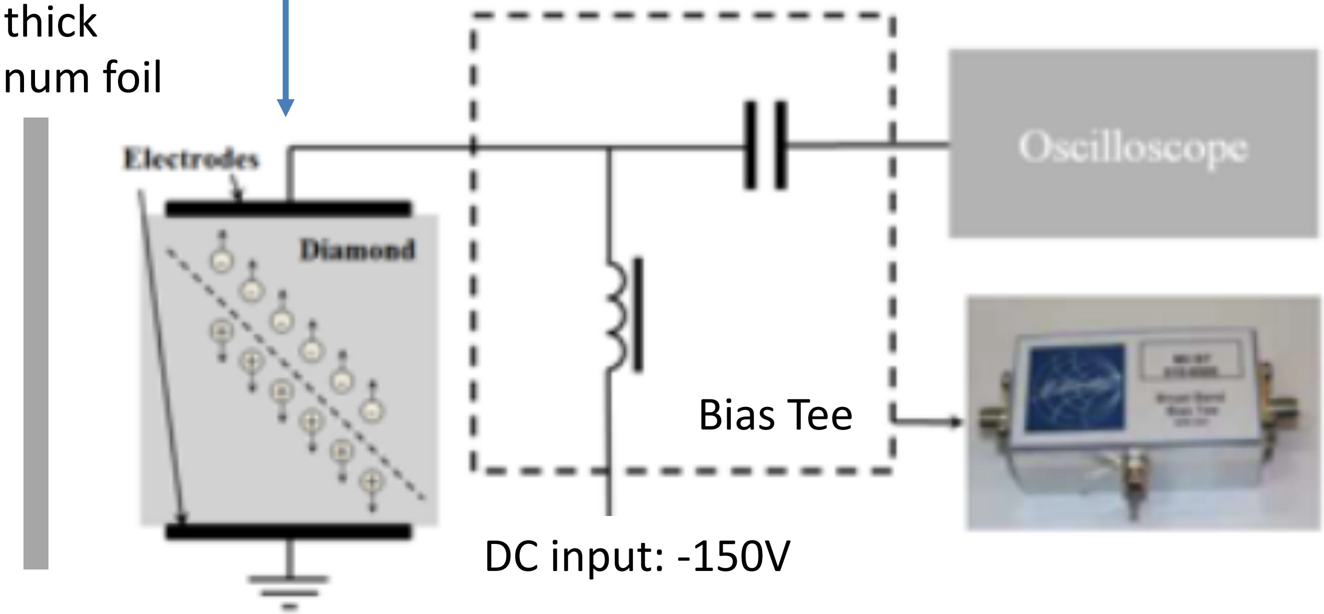




Temporal resolution: ~0.5 ns

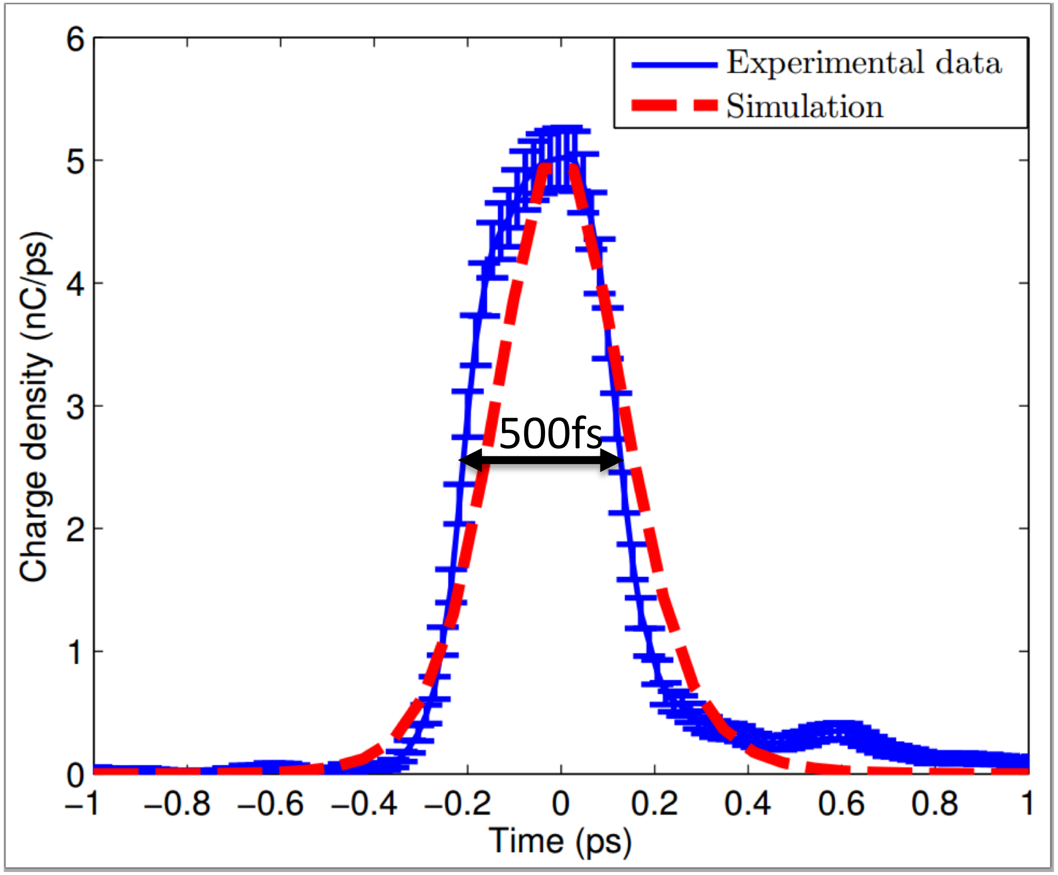
7 um thick
aluminum foil

Particles
(photons,electrons,
protons,ions)



De Angelis, R., et al. "High performance diagnostics for Time-Of-Flight and X ray measurements in laser produced plasmas, based on fast diamond detectors." *Journal of Instrumentation*11.12 (2016)

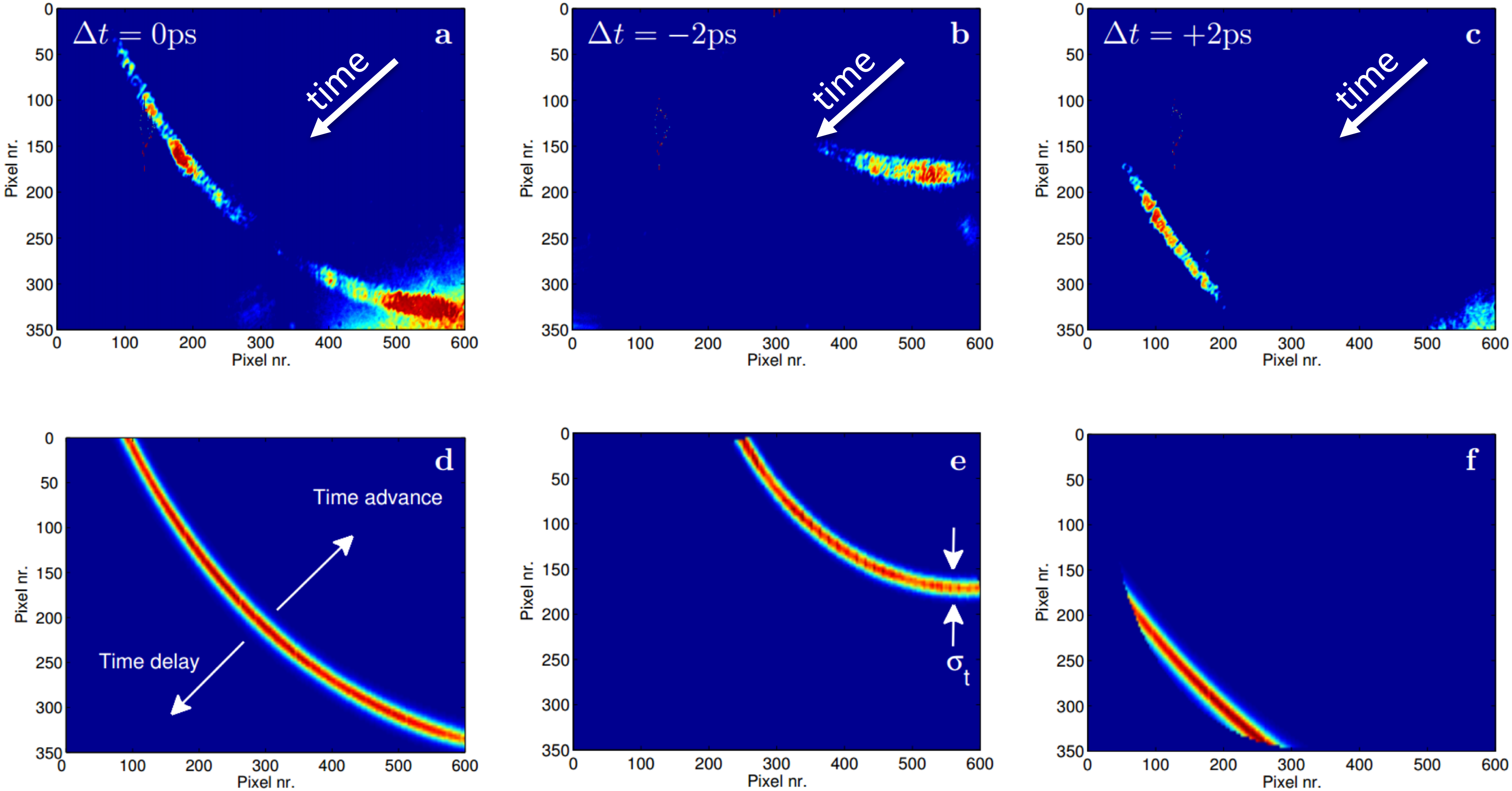
Temporal profile



- The profile is obtained by averaging a series of line-outs performed along the time direction compared with the corresponding profile provided by the numerical simulation.
- The errorbars are calculated as the standard deviation of line-outs average.

Pompili, R., et al. "Sub-picosecond snapshots of fast electrons from high intensity laser-matter interactions ." Opt.Exp. 24 (2016)

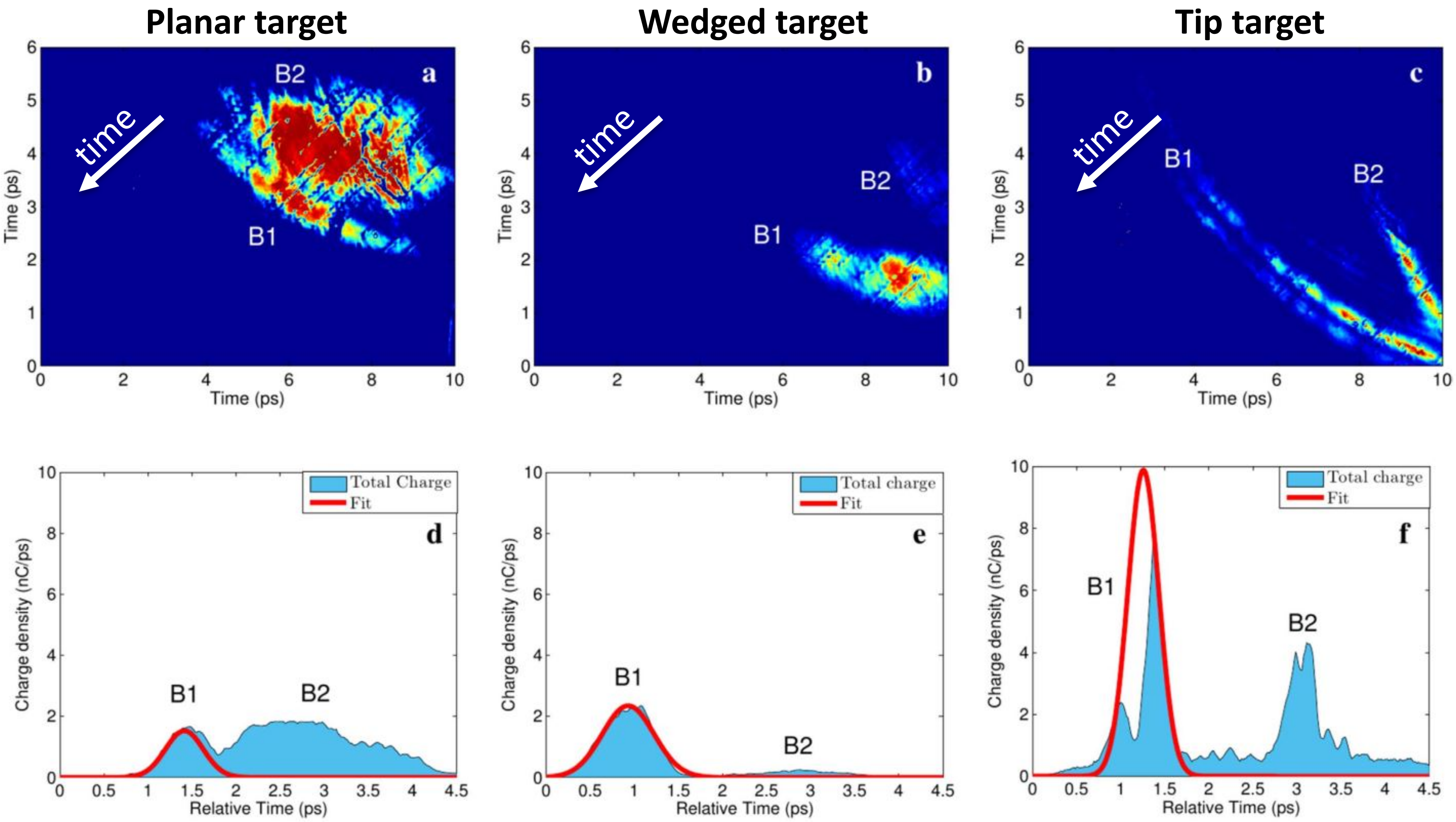
EOS as TOF: measurements and simulations



Temporal window: 10 ps.

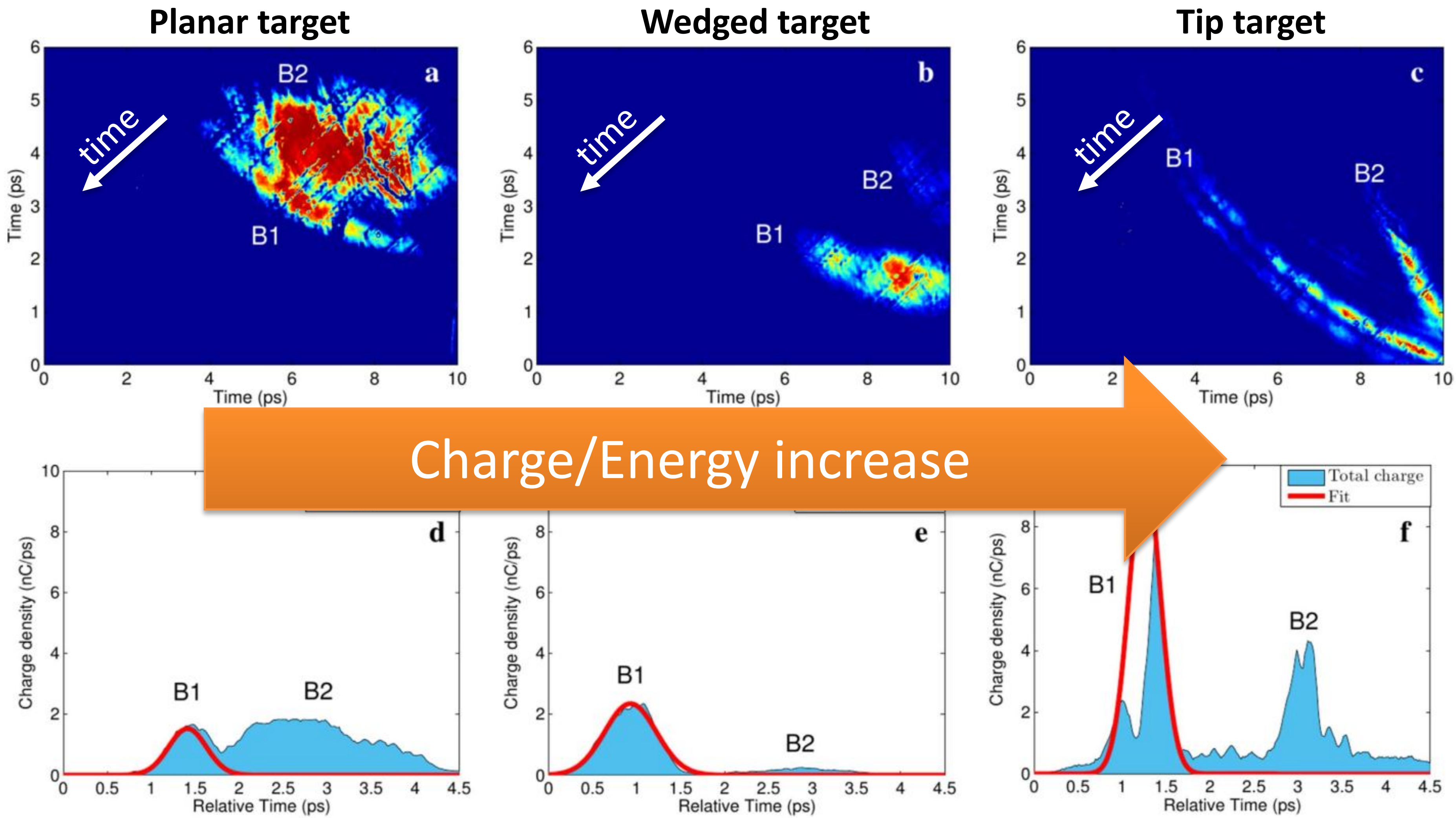
Pompili, R., et al. "Sub-picosecond snapshots of fast electrons from high intensity laser-matter interactions ." Opt.Exp. 24 (2016)

Influence of target shape



Pompili, R., et al. "Femtosecond dynamics of energetic electrons in high intensity laser-matter interactions." Sci.Rep. 6 (2016)

Influence of target shape



Pompili, R., et al. "Femtosecond dynamics of energetic electrons in high intensity laser-matter interactions." Sci.Rep. 6 (2016)

Scaling laws for E_p^{max}

$$\propto \sqrt{(1 + a_0^2)} = f(E_L, r_L, \tau_L)$$

$$E_{\max} = 2T_{\mathrm{hot}}[\ln(t_{\mathrm{p}} + (t_{\mathrm{p}}^2 + 1)^{1/2})]^2$$

$$t_{\mathrm{p}} = \omega_{\mathrm{pi}} t_{\mathrm{acc}} / (2\exp^1)^{1/2}$$

$$t_{\mathrm{acc}} \sim 1.3\tau_{\mathrm{laser}}$$

Fuchs, J., et al. "Laser-driven proton scaling laws and new paths towards energy increase." Nat.Phys. 2 (2006)