Time-Resolved Measurements of Fast Electrons and Protons Emitted in Ultra-Intense Laser-Solid Matter Interactions at SPARC_LAB

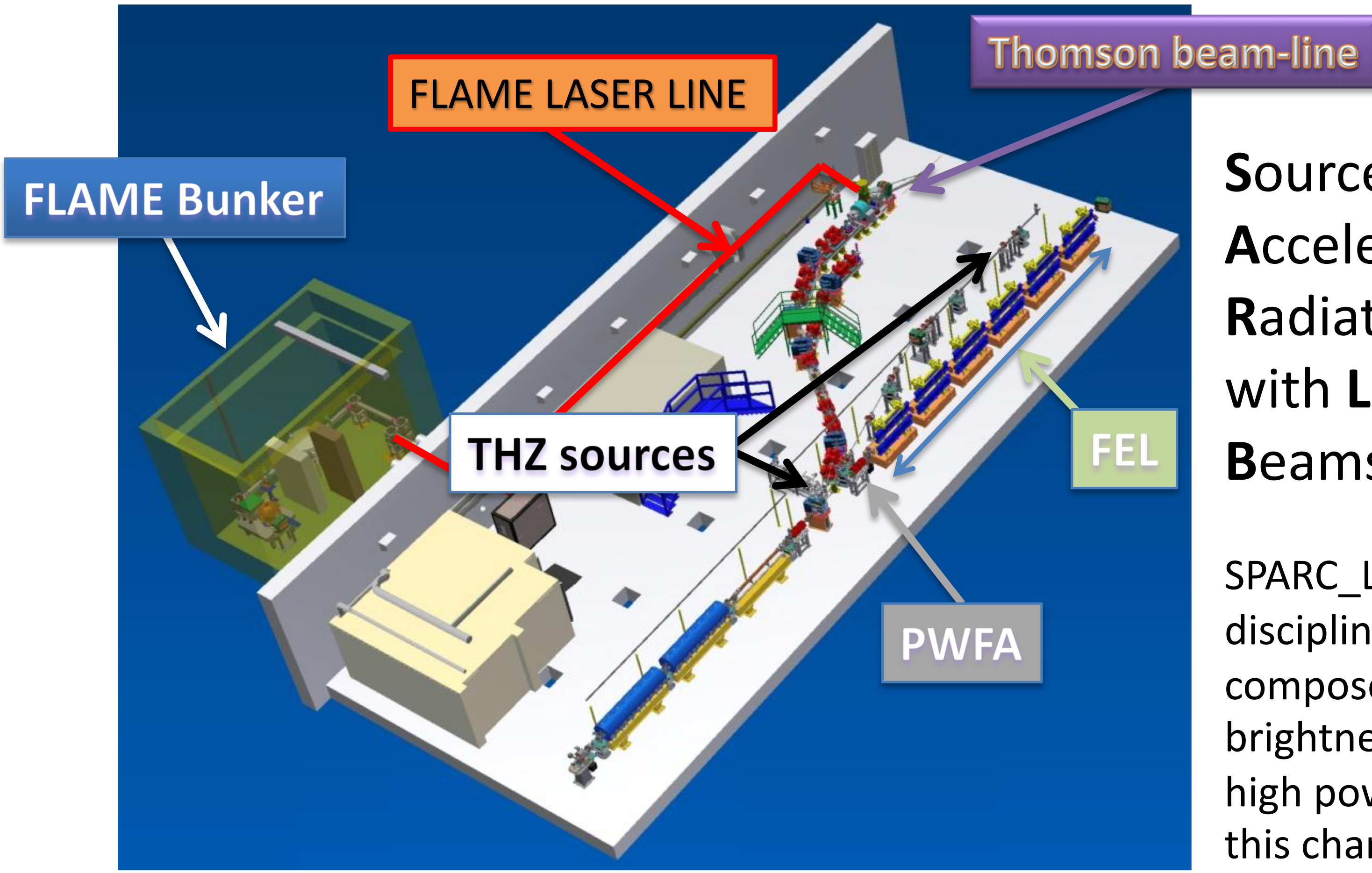
F. Bisesto

On behalf of SPARC_LAB collaboration

Outline

- The FLAME laser @ SPARC_LAB
  - SPARC_LAB Test Facility
  - FLAME laser system
- FLAME-solid target interaction experiment
  - Experimental setup
  - Preliminary results
- Conclusions

SPARC_LAB Facility

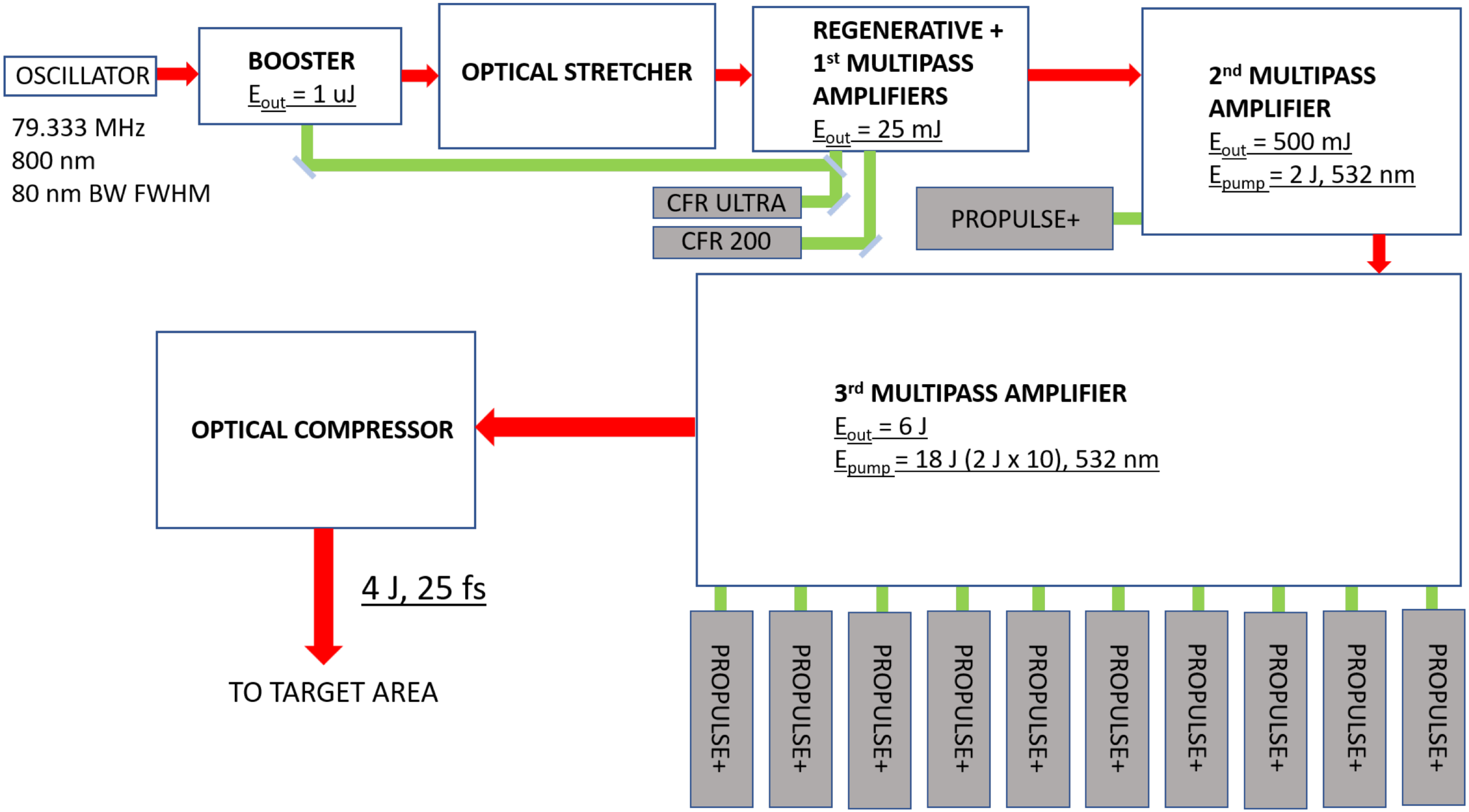


Sources for **P**lasma **A**ccelerators and **R**adiation **C**ompton with **L**asers and **B**eams

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.

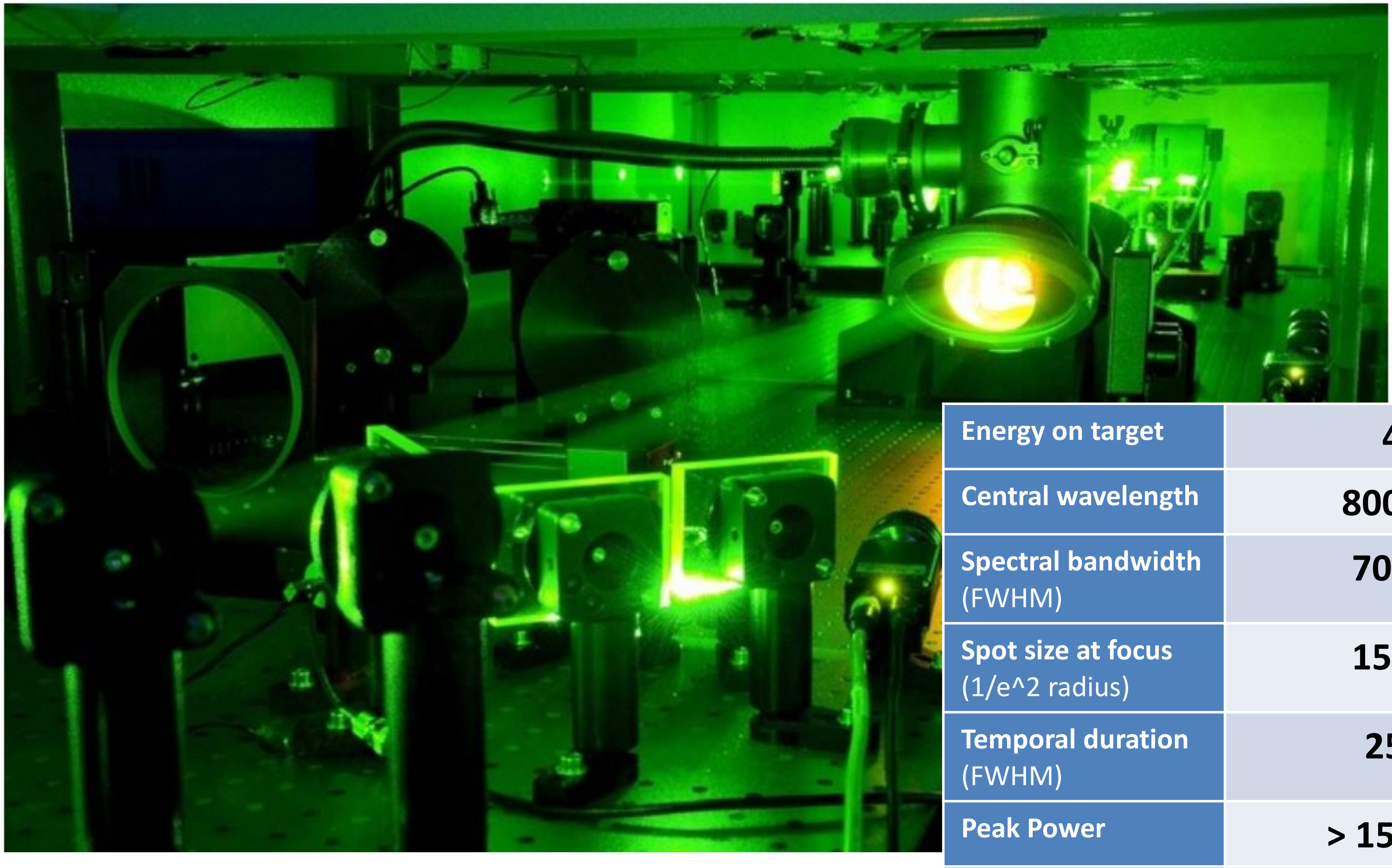
Ferrario, M., et al. "SPARC_LAB present and future." NIM B 309 (2013): 183-188

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)	70 nm
Spot size at focus (1/e^2 radius)	15 um
Temporal duration (FWHM)	25 fs
Peak Power	> 150 TW
Intensity	$5 * 10^{19}\ W/cm^2$
Contrast Ratio (@ 100 ps)	10^9

FLAME experimental activities

High intensity laser - matter interaction

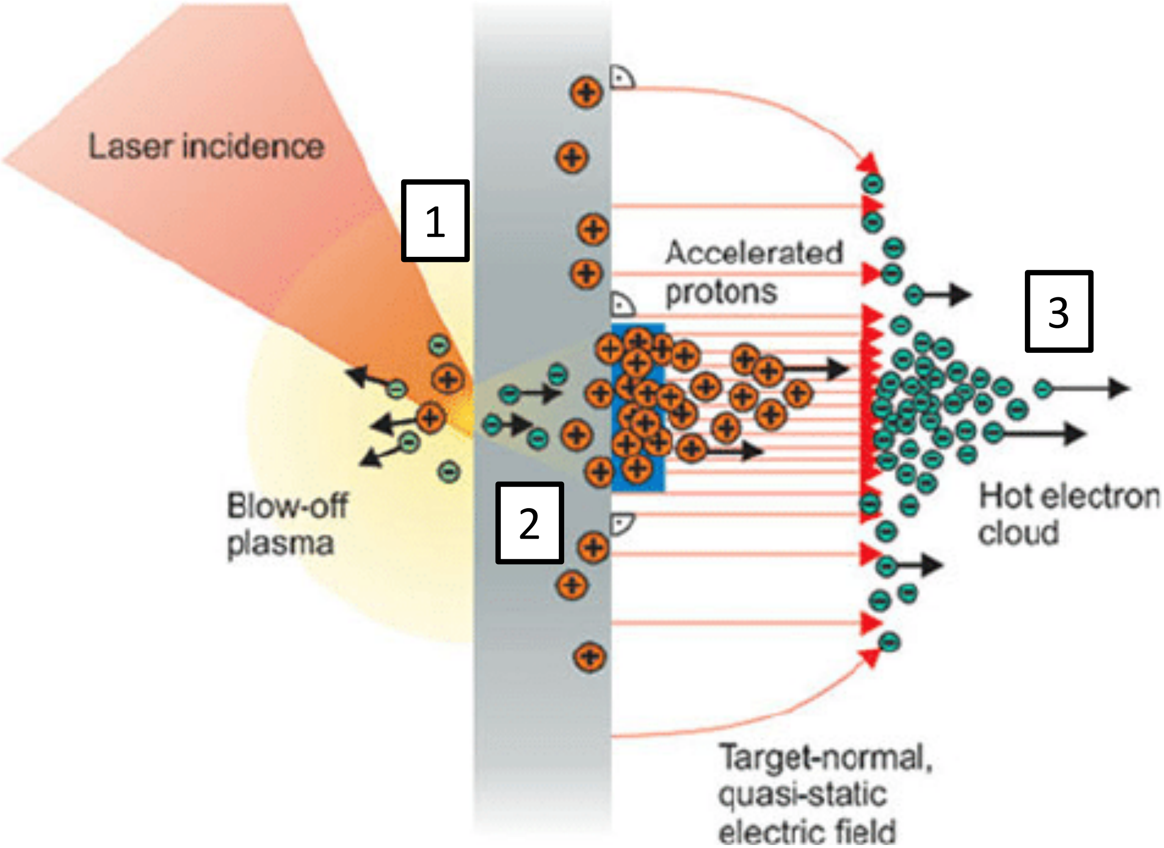
Gas target

- **LWFA** electron acceleration in self-injection scheme.
- Generation and characterization of betatron-based **X-ray sources.**
- Study and realization of new single shot electron **beam diagnostics.**
- NEW! **Laser guiding** in plasma channel.

Solid state target

- Electro-Optic Sampling diagnostics to characterize **fast electrons.**
- Study of **target geometry** influence on fast electron emission.
- NEW! Detection and characterization of accelerated **protons** via TNSA.

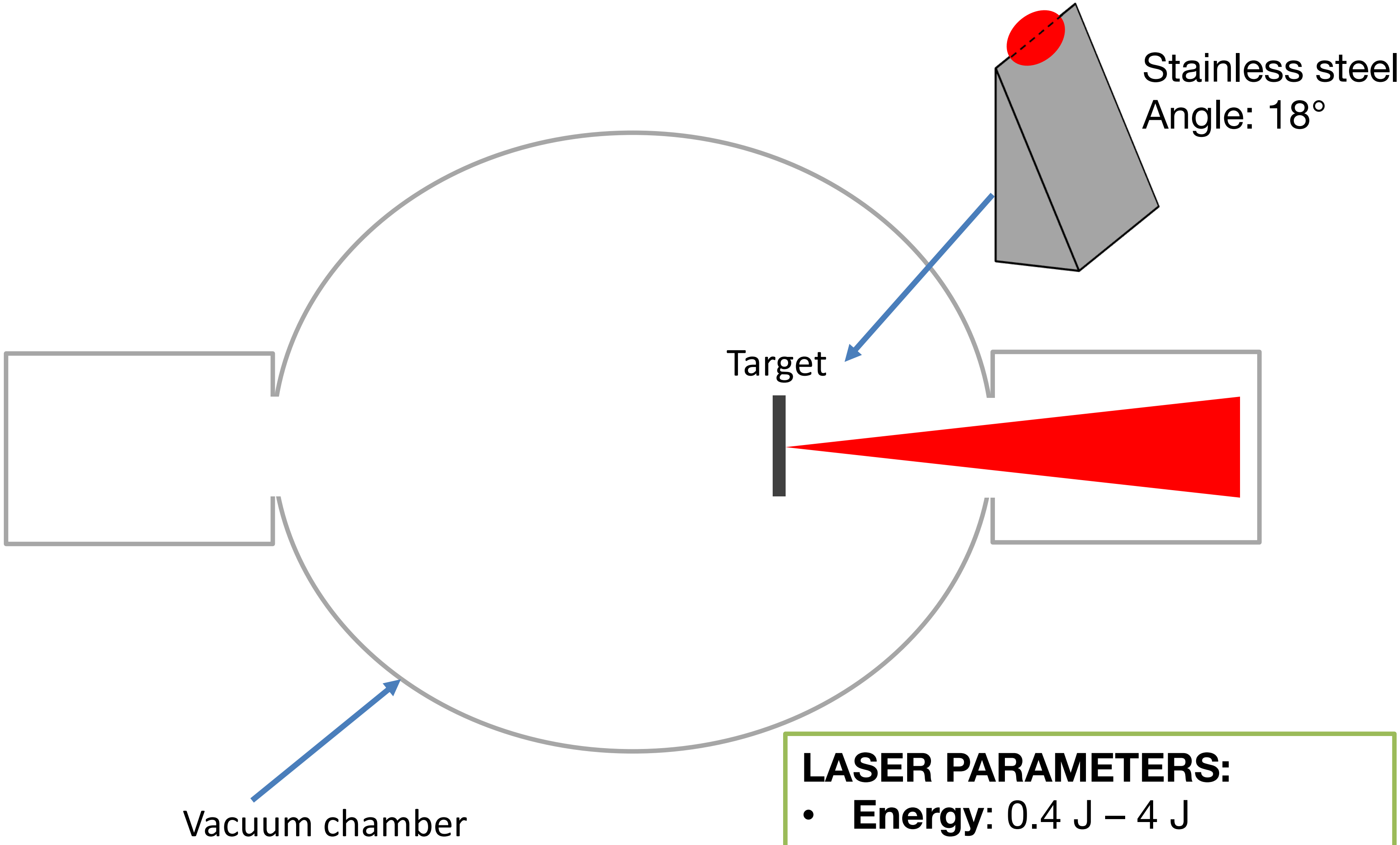
Laser-solid target interaction



1) Laser interacts with pre-formed plasma.
2) Electron acceleration and positive charge left on target.
3) Only more energetic electrons escape and their electric field causes proton and ion acceleration.

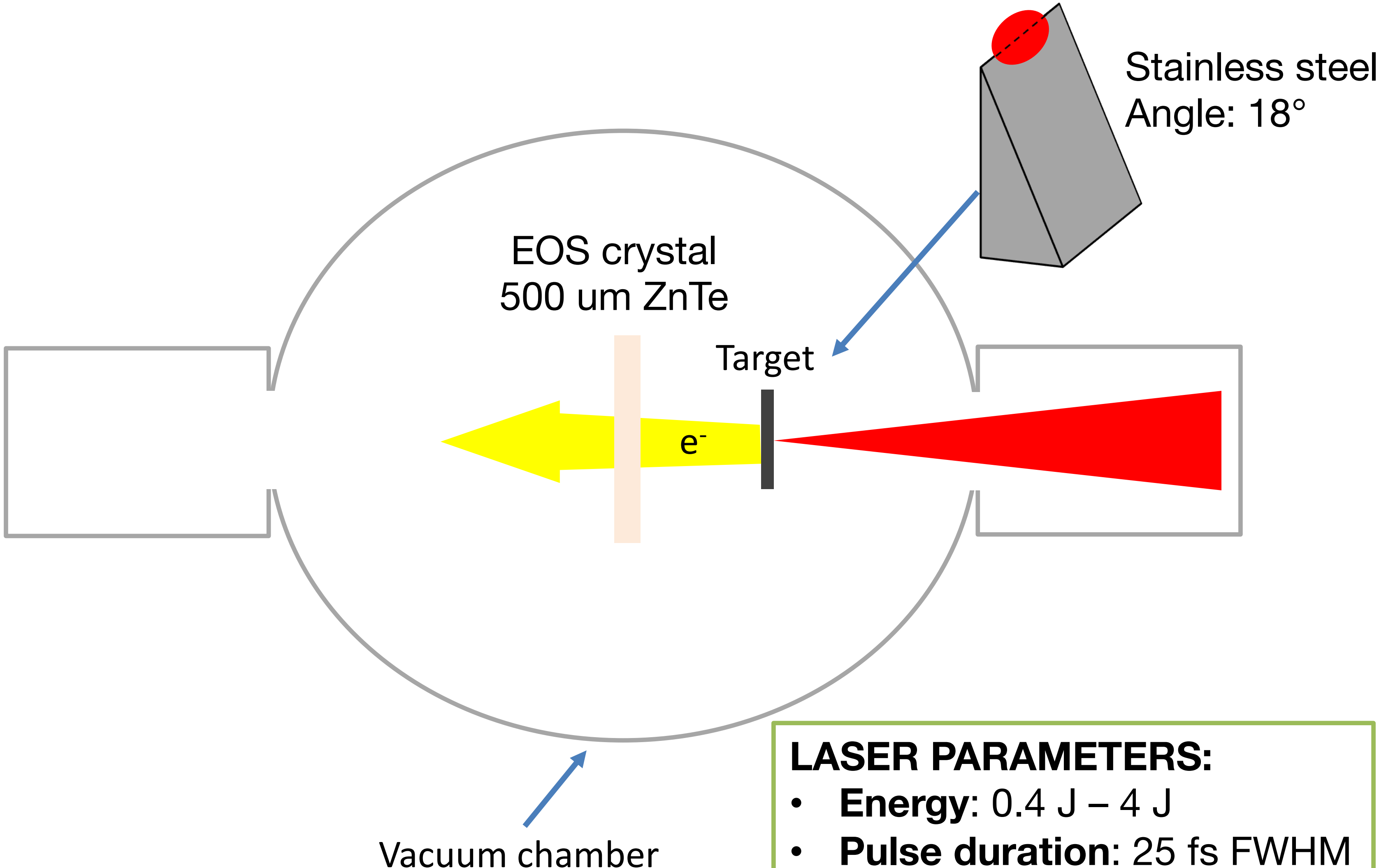
H. Schwoerer et al., *Nature* 439, 445-448 (2006)

FLAME-solid target interaction experiment



LASER PARAMETERS:
- **Energy**: 0.4 J – 4 J
- **Pulse duration**: 25 fs FWHM
- **Spot radius 1/e²** = 15 μm

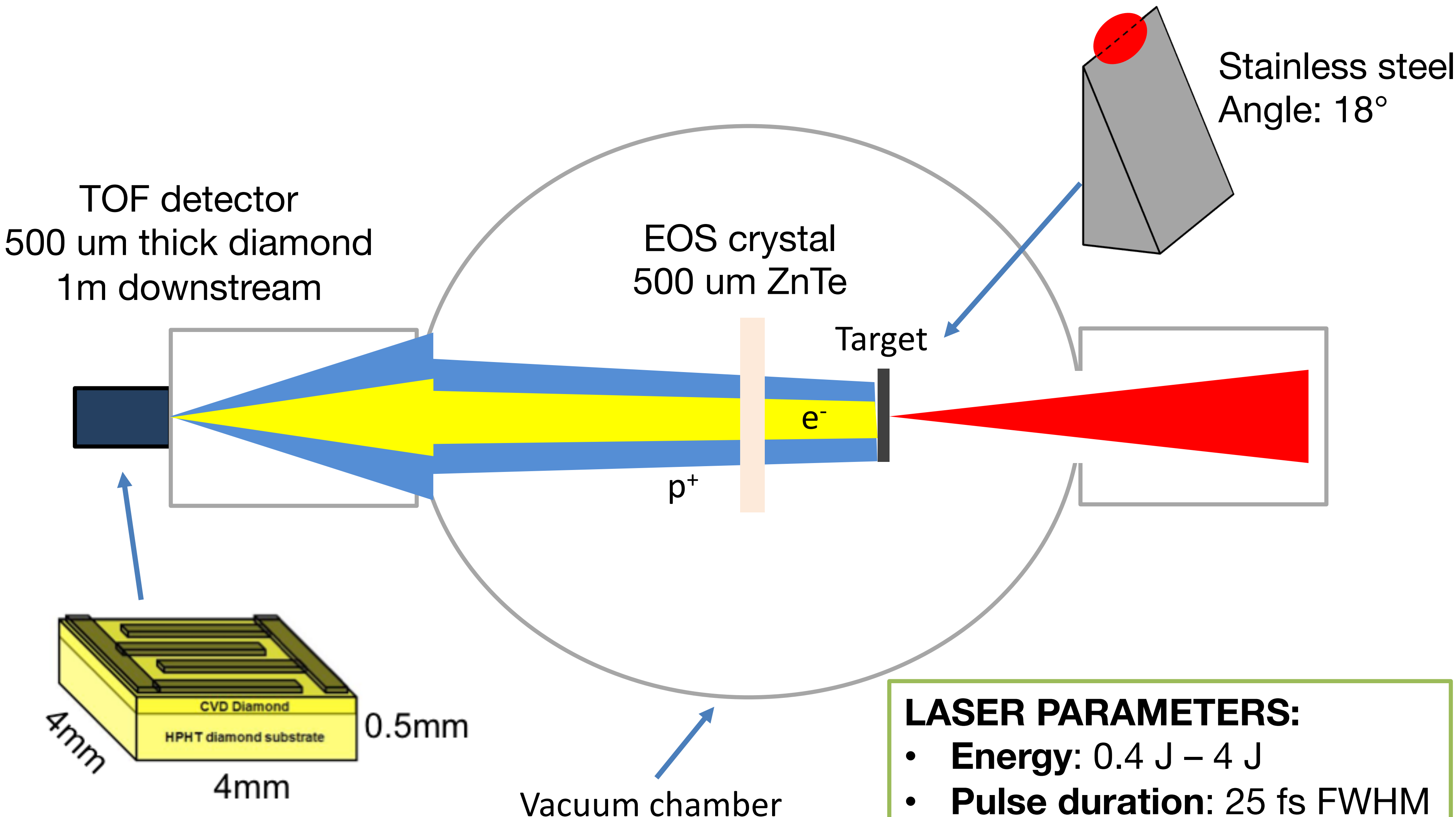
FLAME-solid target interaction experiment



LASER PARAMETERS:

- **Energy**: 0.4 J – 4 J
- **Pulse duration**: 25 fs FWHM
- **Spot radius 1/e²** = 15 μm

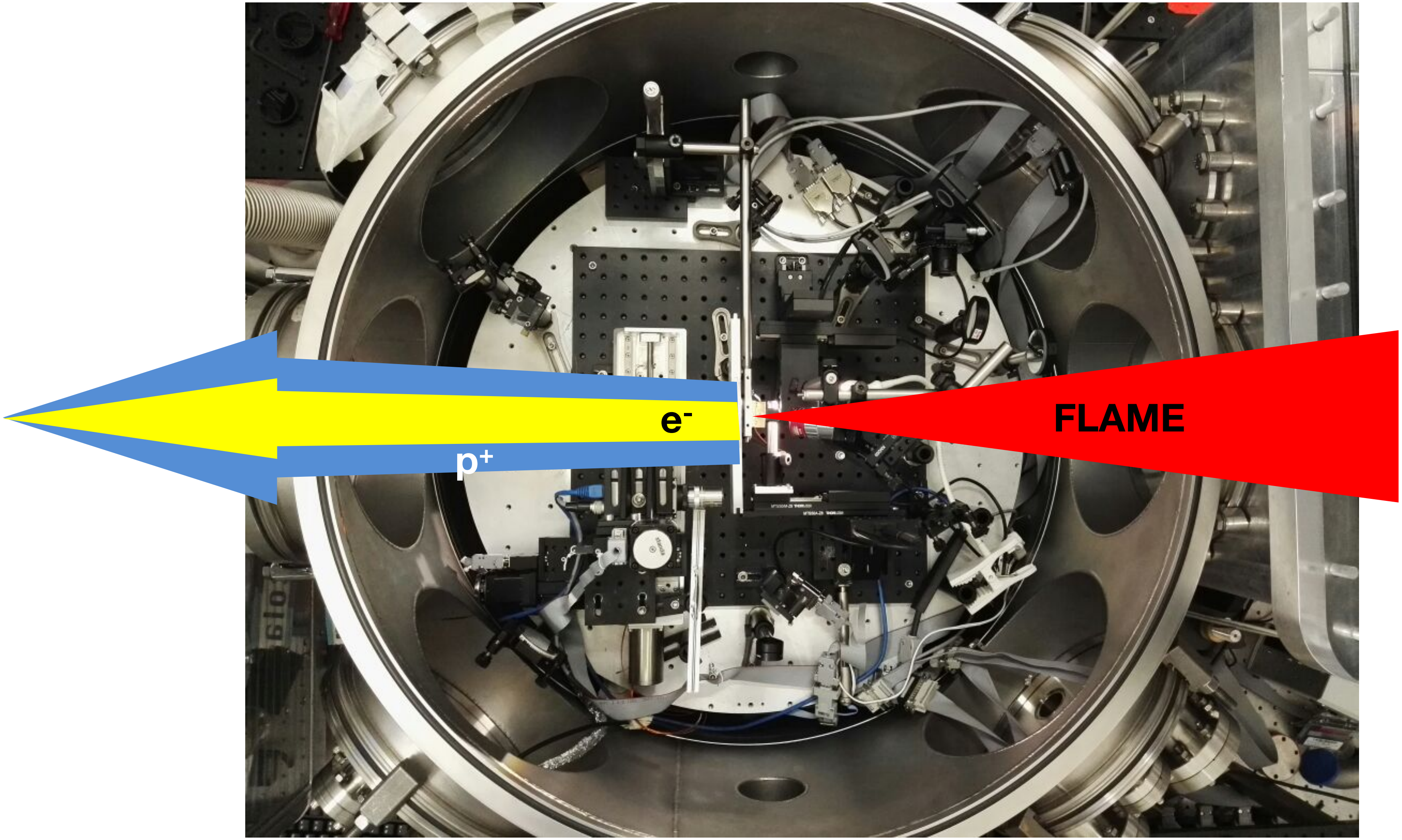
FLAME-solid target interaction experiment



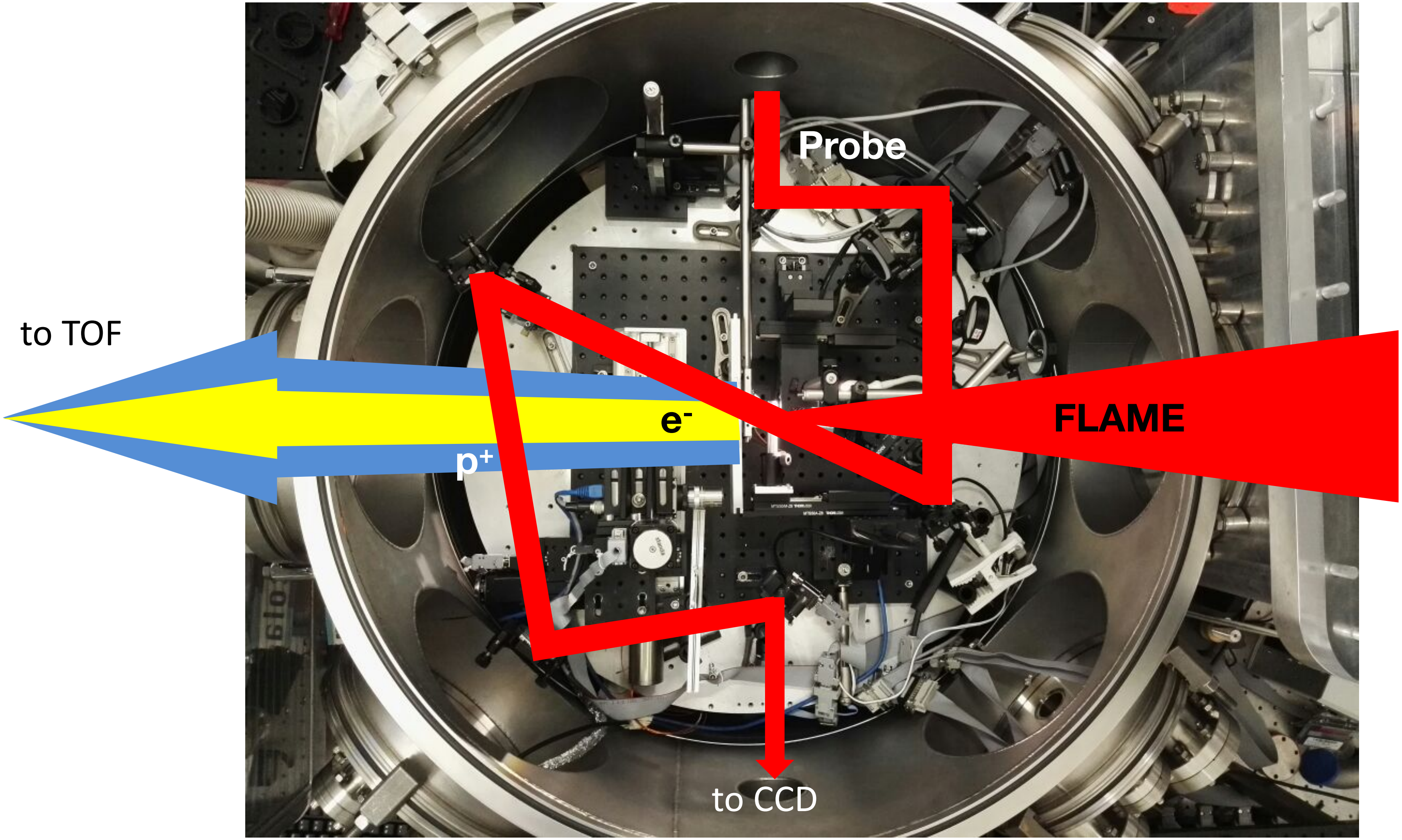
LASER PARAMETERS:

- **Energy**: 0.4 J – 4 J
- **Pulse duration**: 25 fs FWHM
- **Spot radius 1/e²** = 15 μm

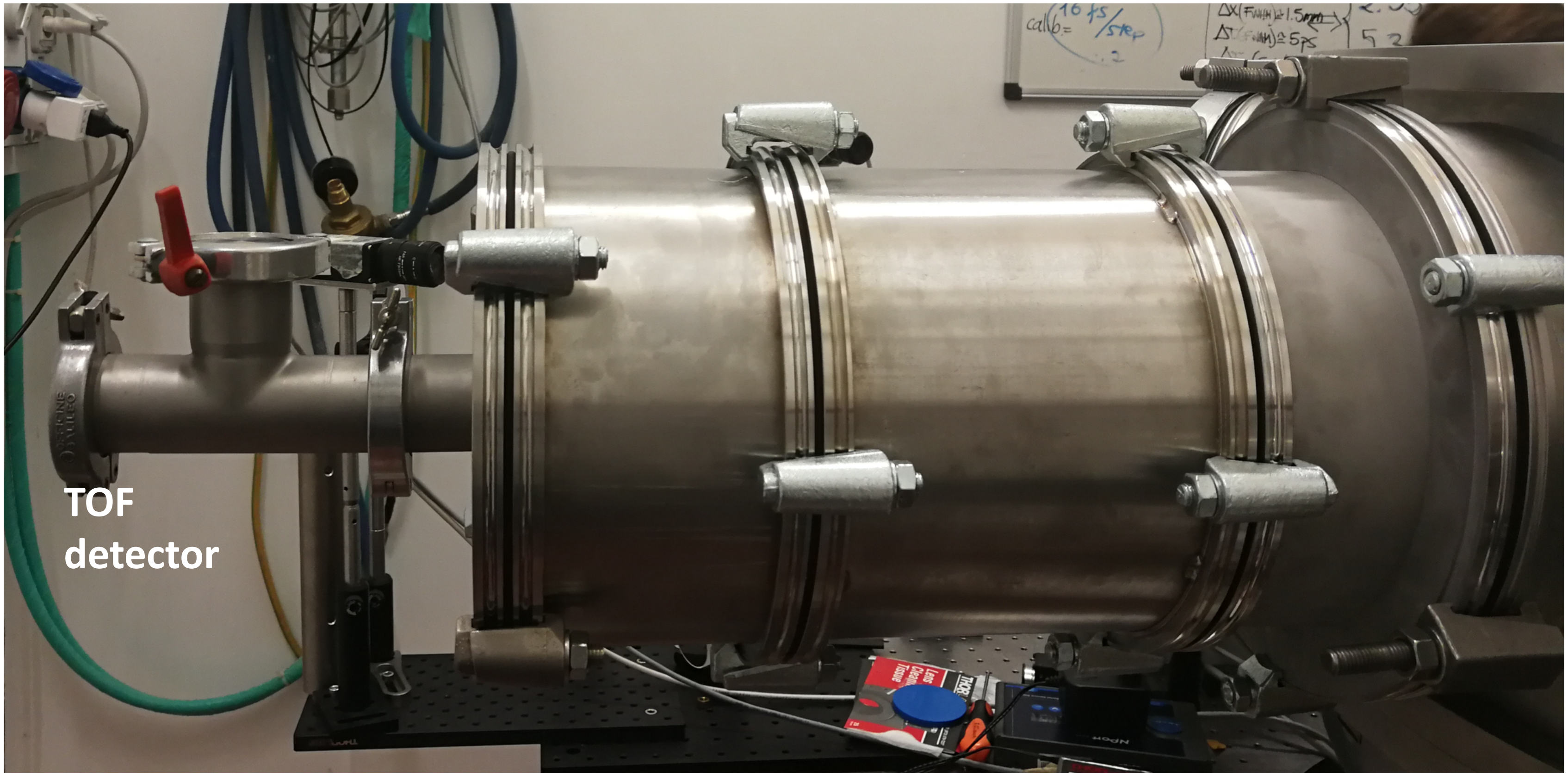
FLAME-solid target interaction experiment



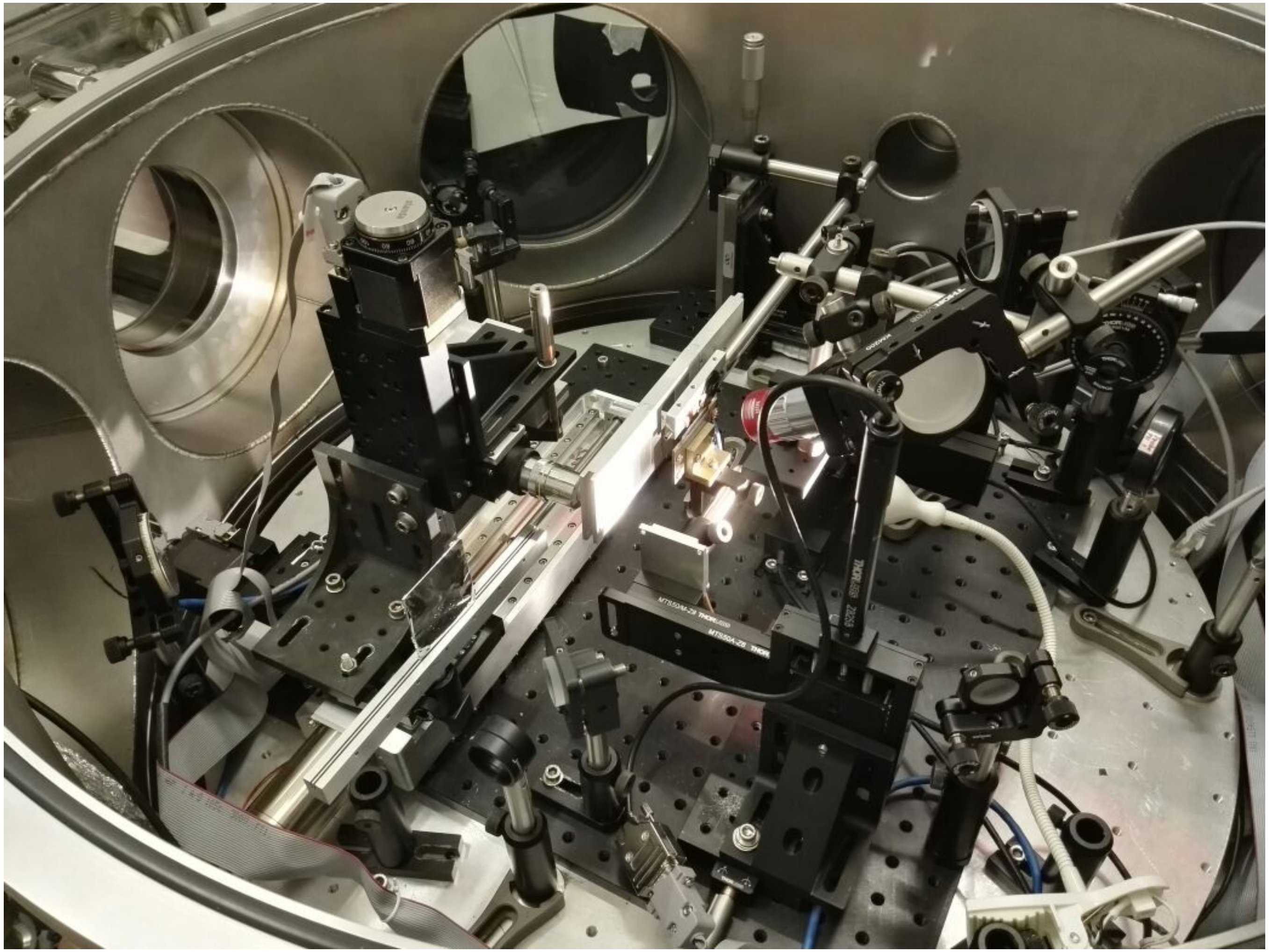
FLAME-solid target interaction experiment



FLAME-solid target interaction experiment



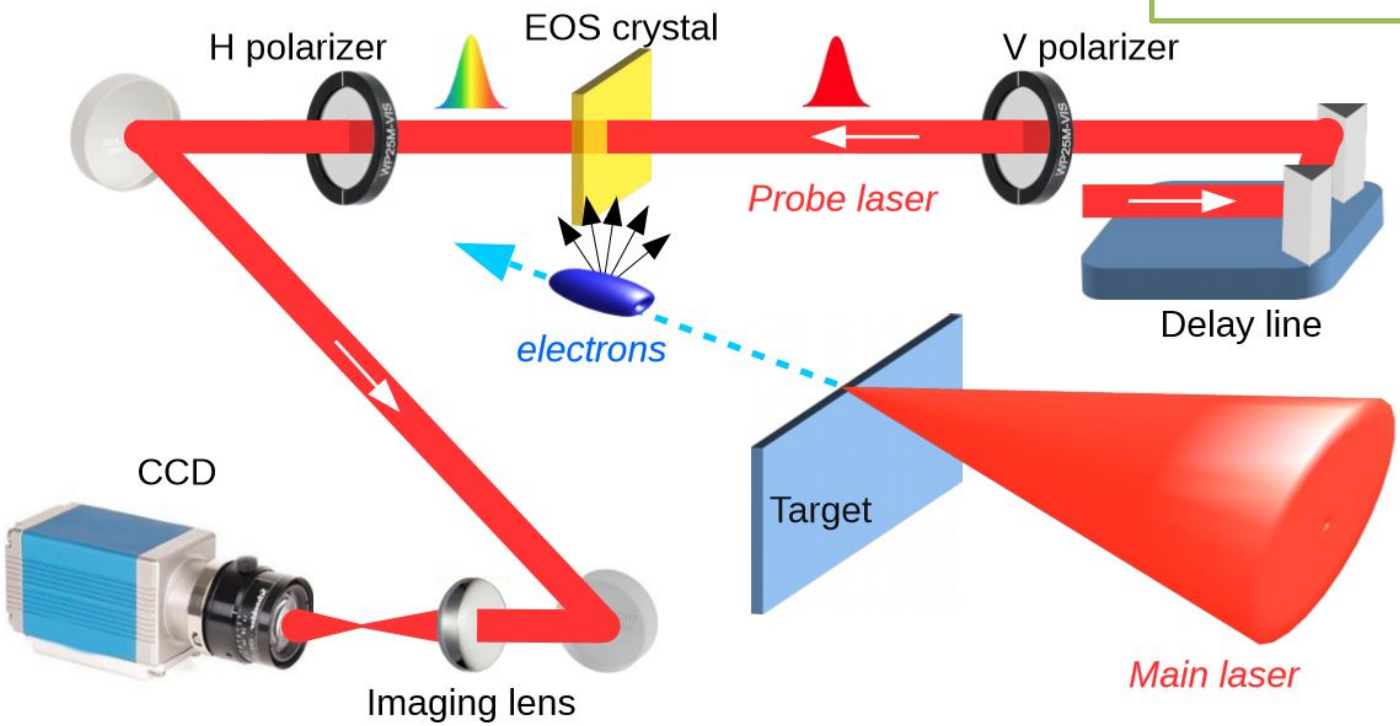
FLAME-solid target interaction experiment



Fast electrons diagnostics

Experimental setup: EOS diagnostics

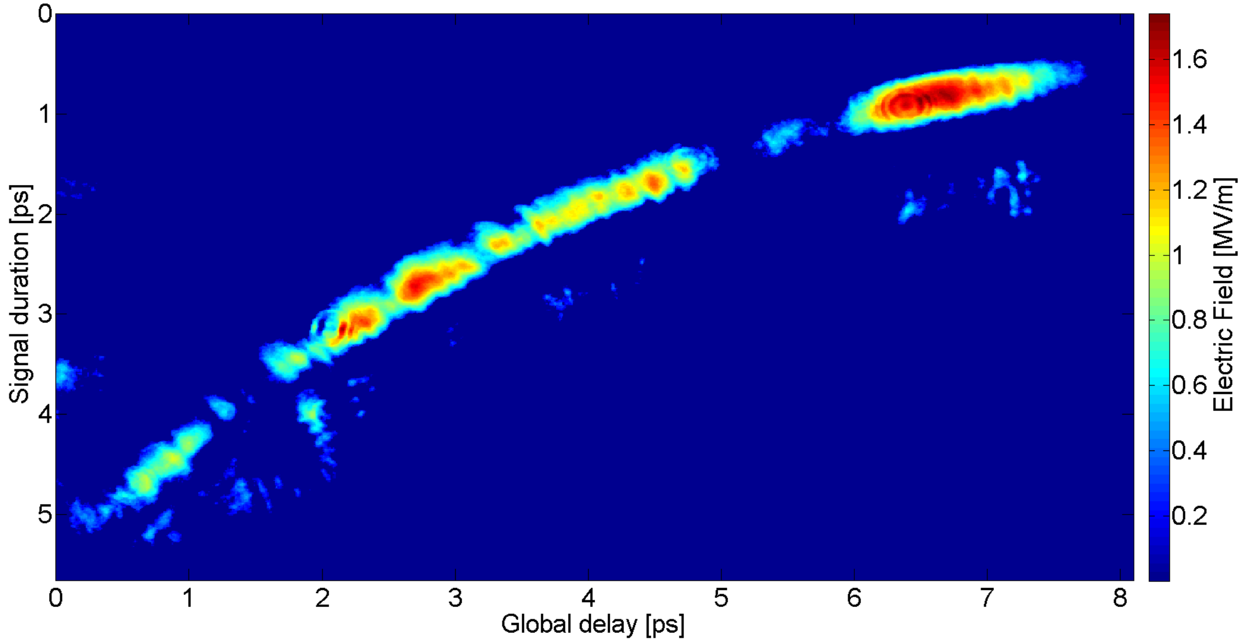
Probe energy: 60 uJ
Probe duration: 30 fs



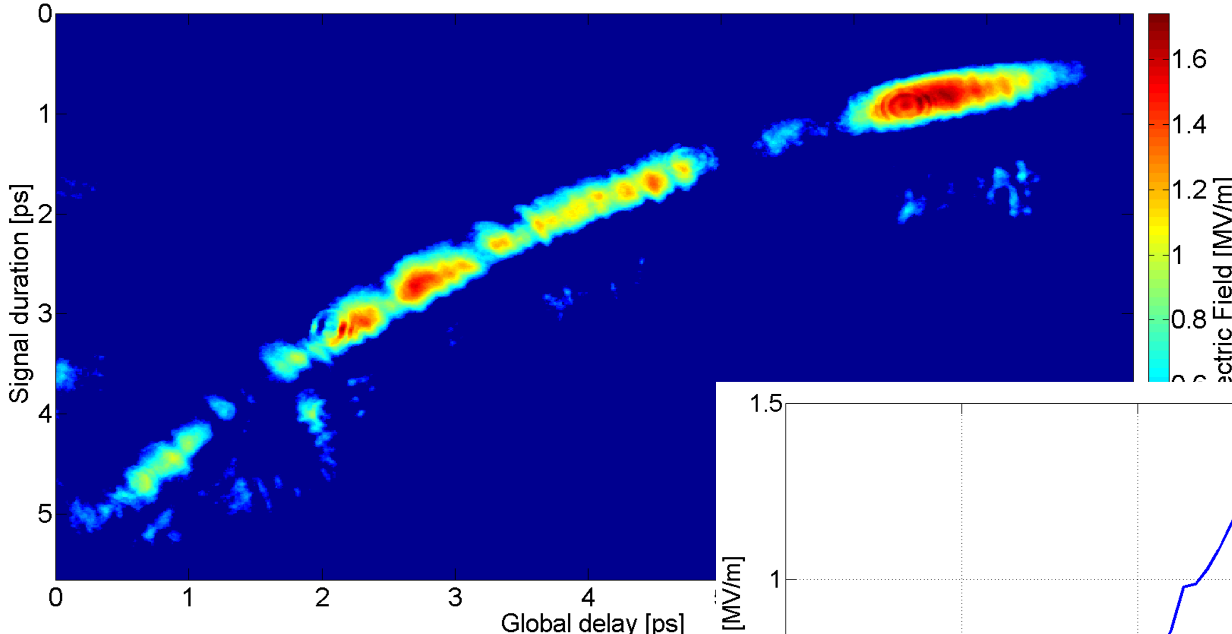
Temporal resolution: 100 fs
Temporal window: 8 ps

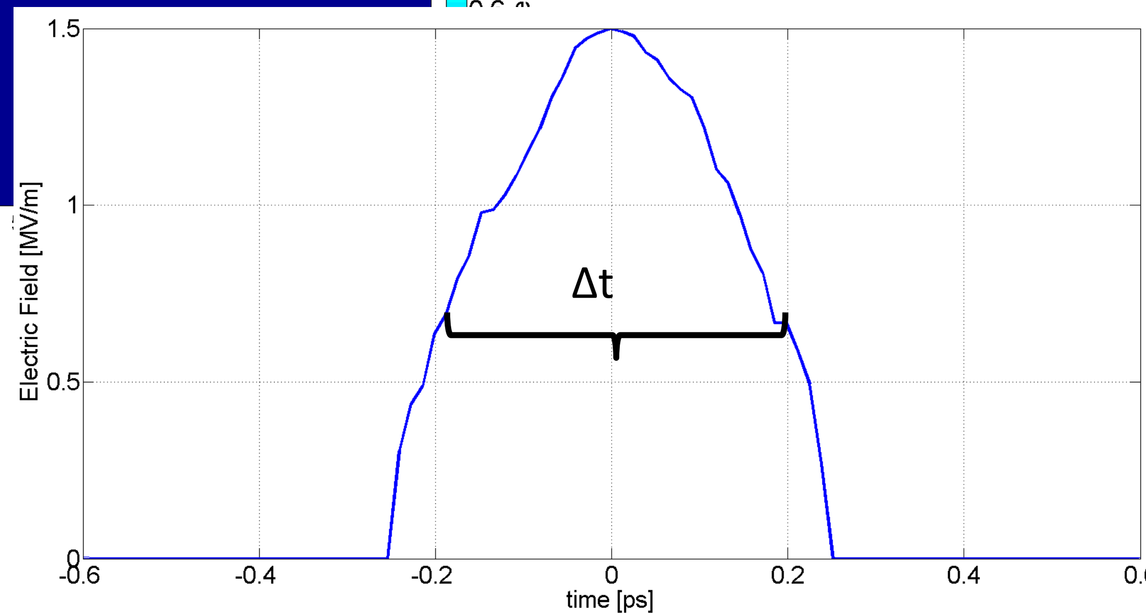
Pompili, R., et al. "Sub-picosecond snapshots of fast electrons from high intensity laser-matter interactions ." Opt.Exp. 24 (2016)

Preliminary results: EOS diagnostics



Preliminary results: EOS diagnostics

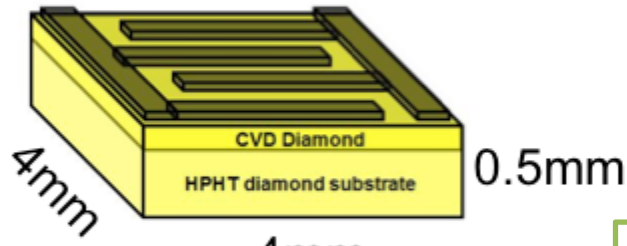


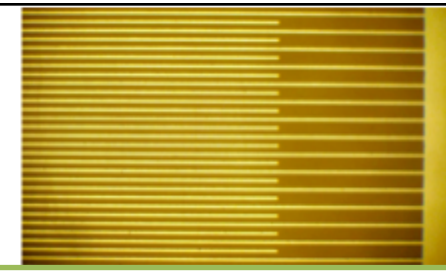


Bunch length Δt: 0.4 ps
Peak electric field: 1.5 MV/m
Charge: 1 nC
Energy: ~10 MeV

Protons diagnostics

Experimental setup: TOF diagnostics

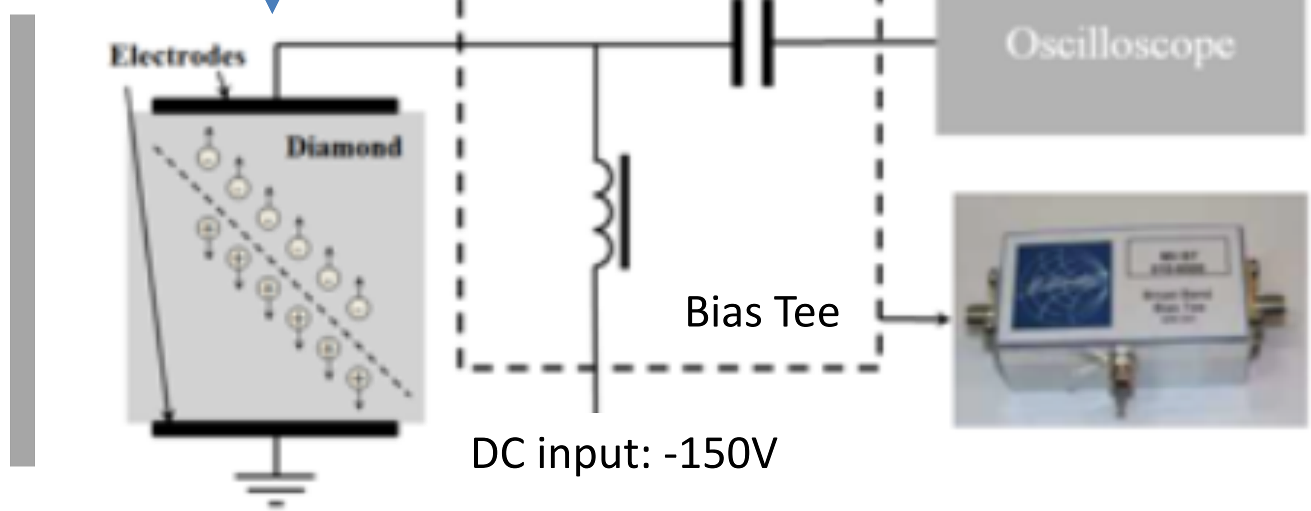




Temporal resolution: 0.5 ns

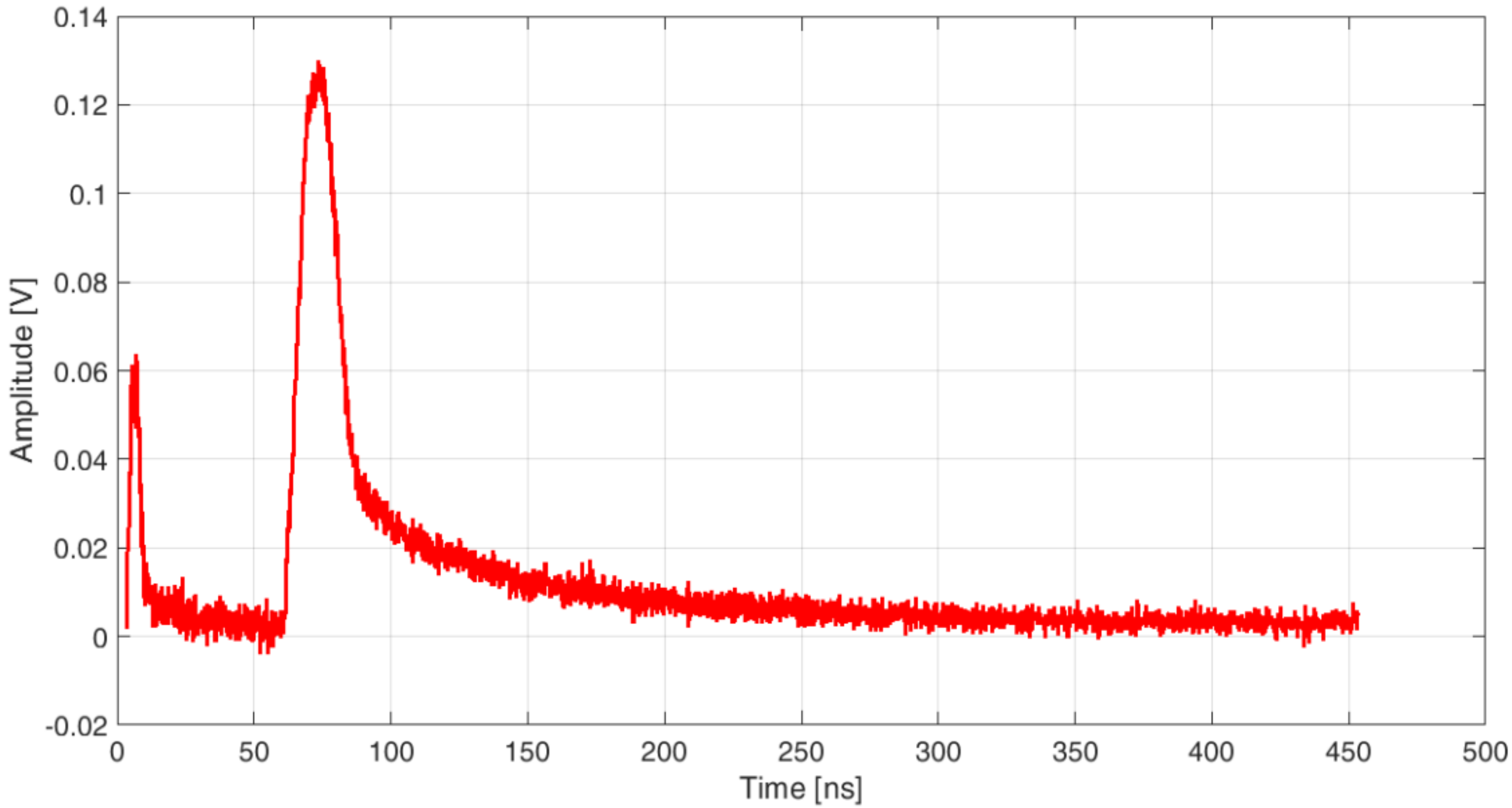
10 um thick
aluminum foil

Particles
(photons,electrons,
protons,ions)

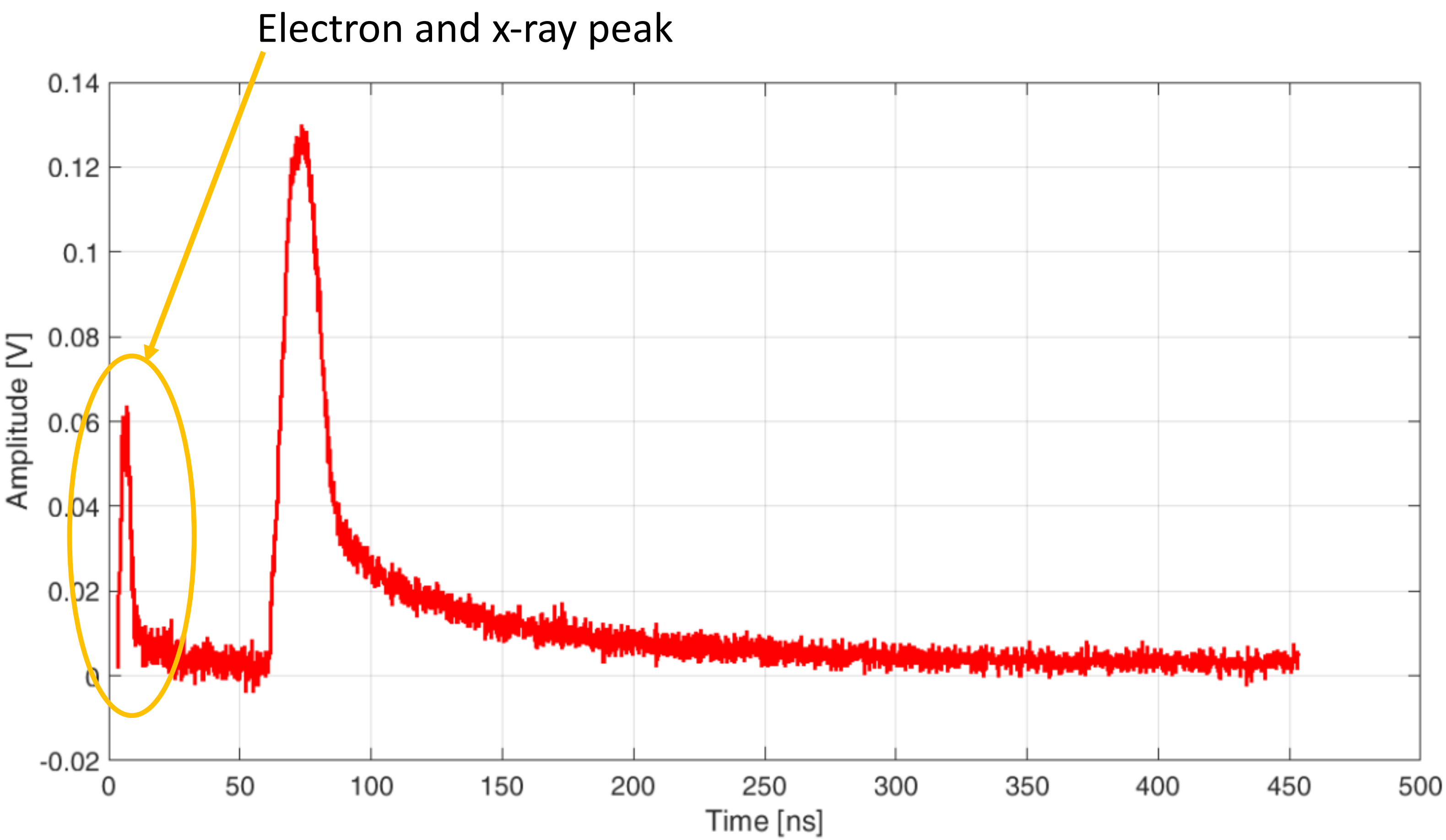


De Angelis, R., et al. "High performance diagnostics for Time-Of-Flight and X ray measurements in laser produced plasmas, based on fast diamond detectors." *Journal of Instrumentation* 11.12 (2016)

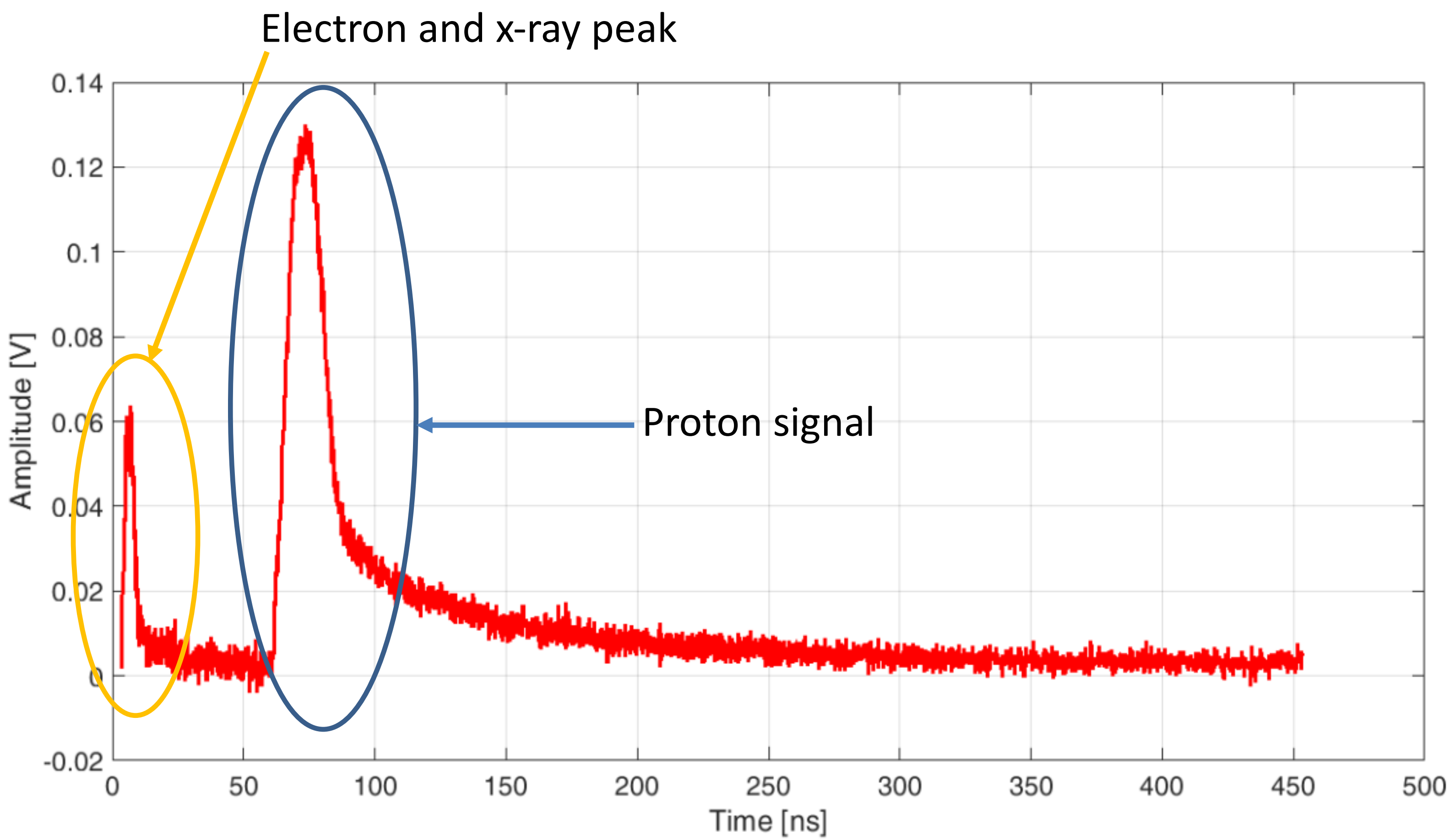
TOF diagnostics: typical signal



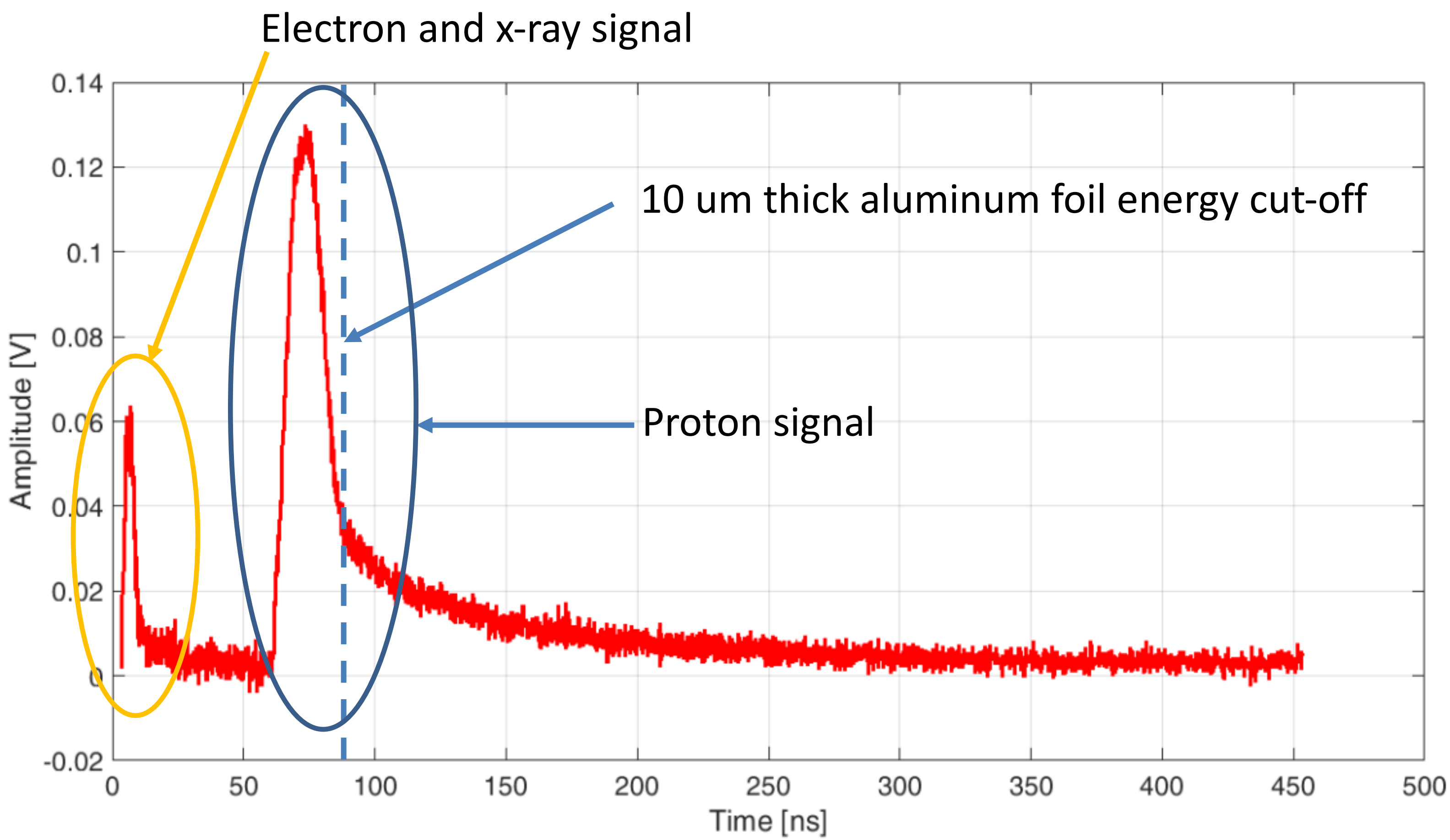
TOF diagnostics: typical signal



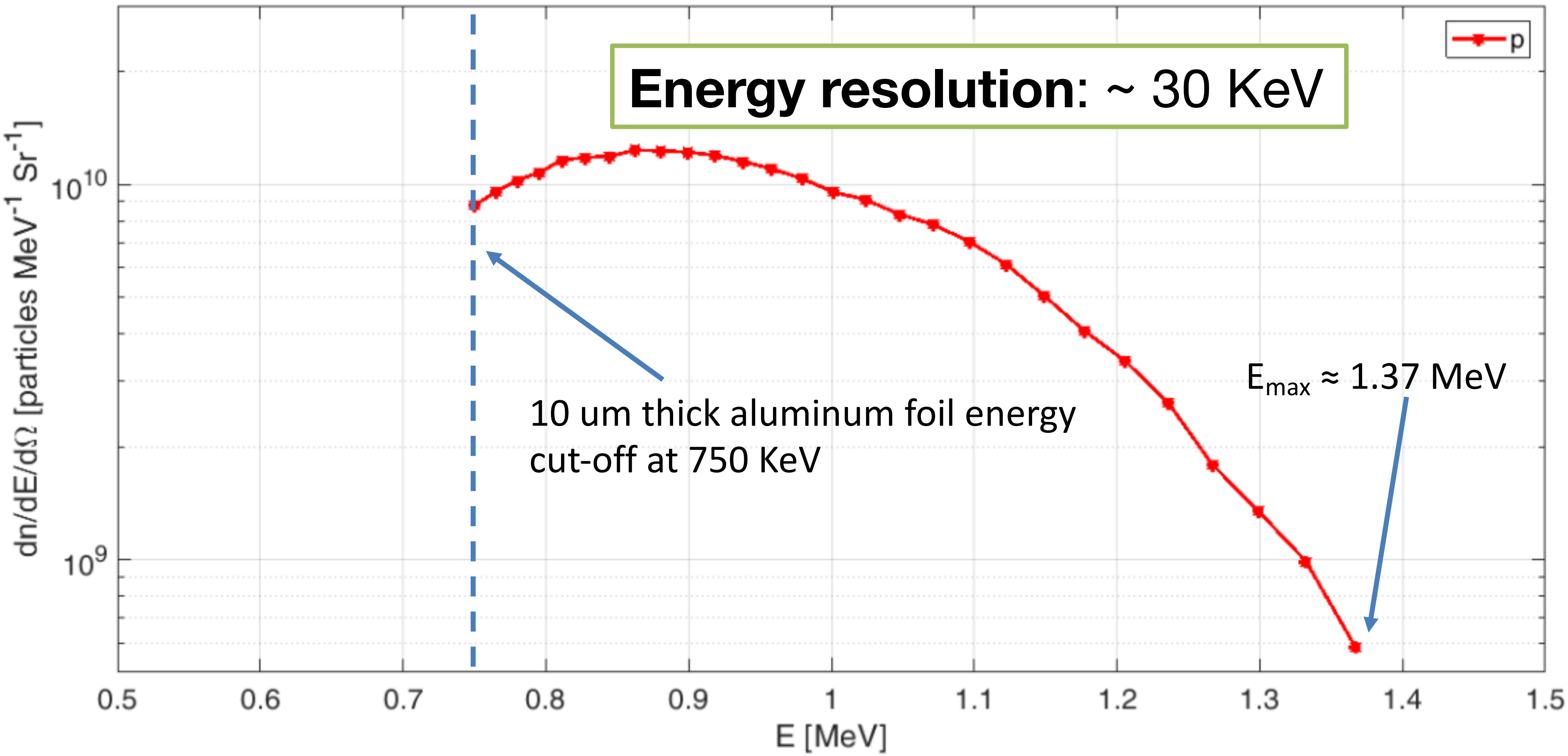
TOF diagnostics: typical signal



TOF diagnostics: typical signal



TOF diagnostics: typical energy spectrum



Charge over $\Omega_{detector}$ ~ 0.3 nC

Conclusions

- 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.
- Data analysis is still undergoing to study possible fast electrons-protons correlations.

Thanks for your attention!

Istituto Nazionale di Fisica Nucleare
Laboratori Nazionali di Frascati

Fabrizio Bisesto
Maria Pia Anania
Riccardo Pompili
Massimo Ferrario

Science & Technology Facilities Council
Central Laser Facility

TÉCNICO LISBOA

Mario Galletti

THE HEBREW UNIVERSITY OF JERUSALEM

Arie Zigler
Jenia Papeer

Università di Roma Tor Vergata

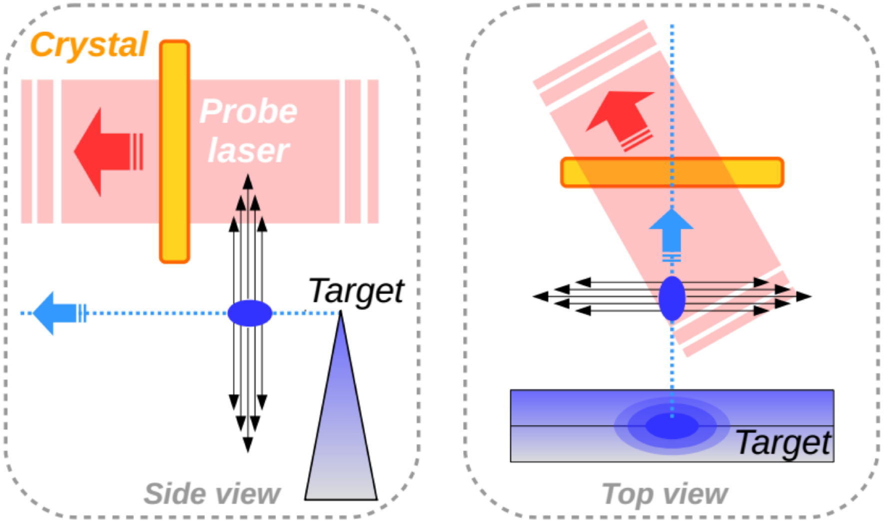
Claudio Verona
Alessandro Cianchi

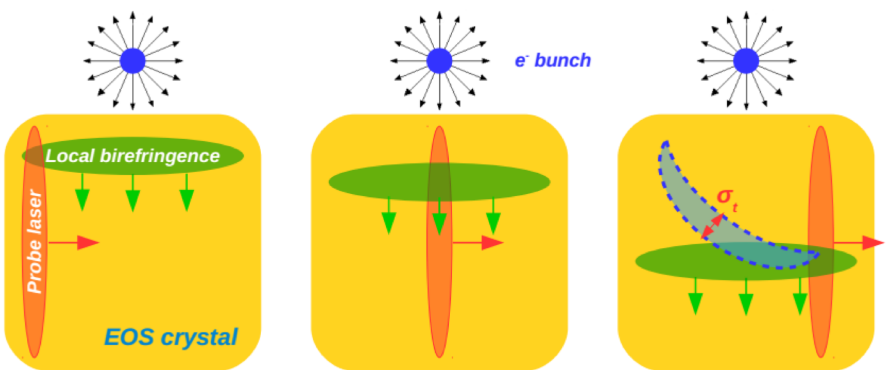
ENEA
Agenzia nazionale per le nuove tecnologie, l'energia e lo sviluppo economico sostenibile

Fabrizio Consoli
Martina Salvadori
Pierluigi Andreoli

fabrizio.giuseppe.bisesto@lnf.infn.it

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)