FLAME laser facility at SPARC_LAB

Federica Stocchi

INFN-LNF & University of Roma Tor Vergata

On behalf of SPARC_LAB collaboration

Outline

- FLAME laser system
- FLAME experimental activity
- Laser, particle and plasma diagnostics
- Outlook

Outline

✓ FLAME laser system

➢ FLAME experimental activity

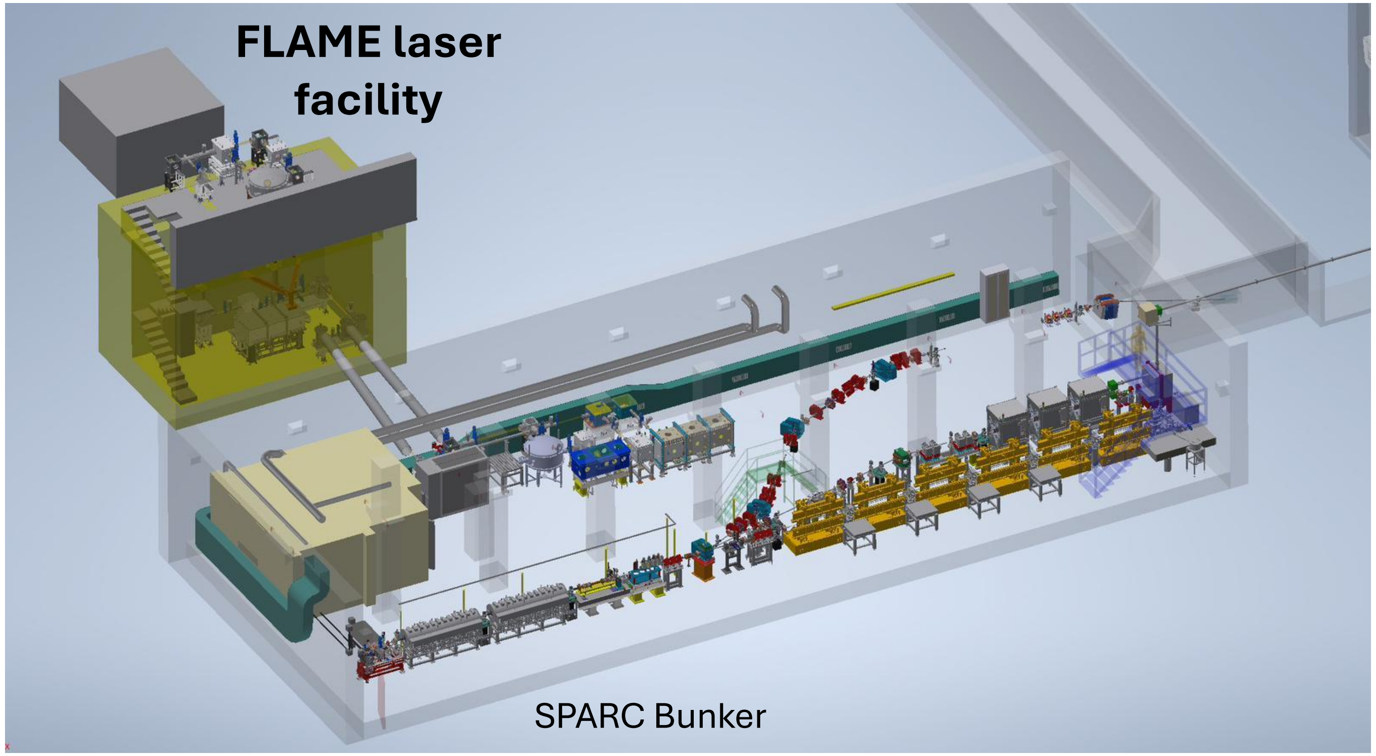
➢ Laser, particle and plasma diagnostics

➢ Outlook

FLAME laser facility at SPARC_LAB

SPARC_LAB is a multidisciplinary TEST Facility composed by a high-brightness LINAC and the high-power laser FLAME (**F**rascati **L**aser for **A**cceleration and **M**ultidisciplinary **E**xperiments).

- Laser-matter interaction for electron acceleration, ion and proton generation;
- Laser system upgrade for new X-rays radiation sources.



M. Ferrario, et al. NIM B 309 (2013): 183-188

FLAME laser system

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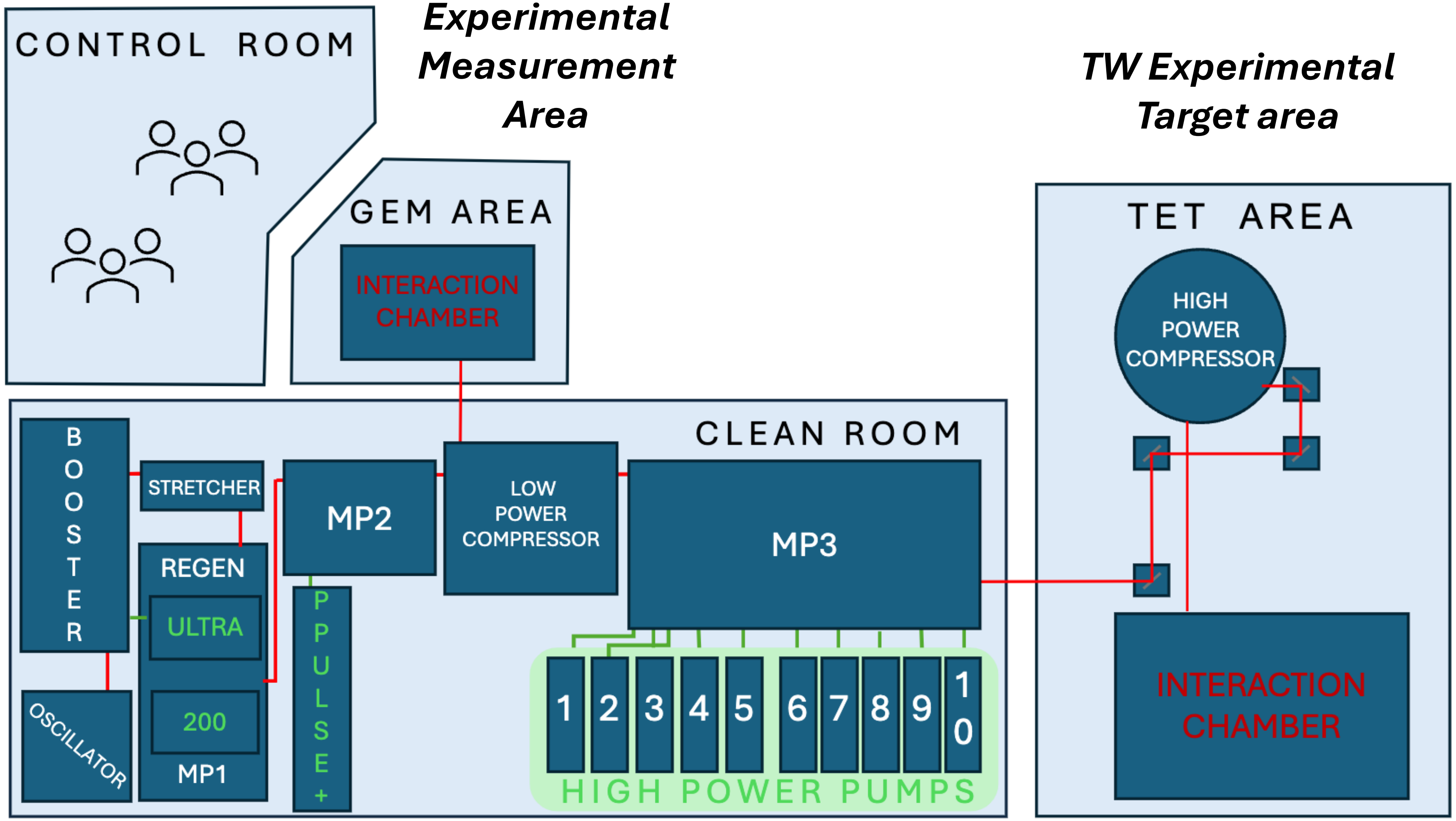
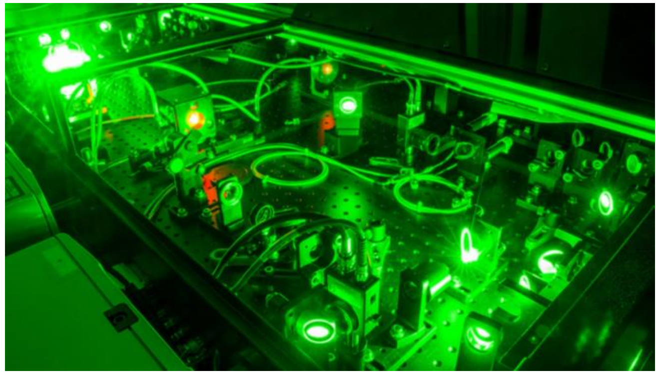
Laboratori Nazionali di Frascati

Guiding Experimental Measurement Area

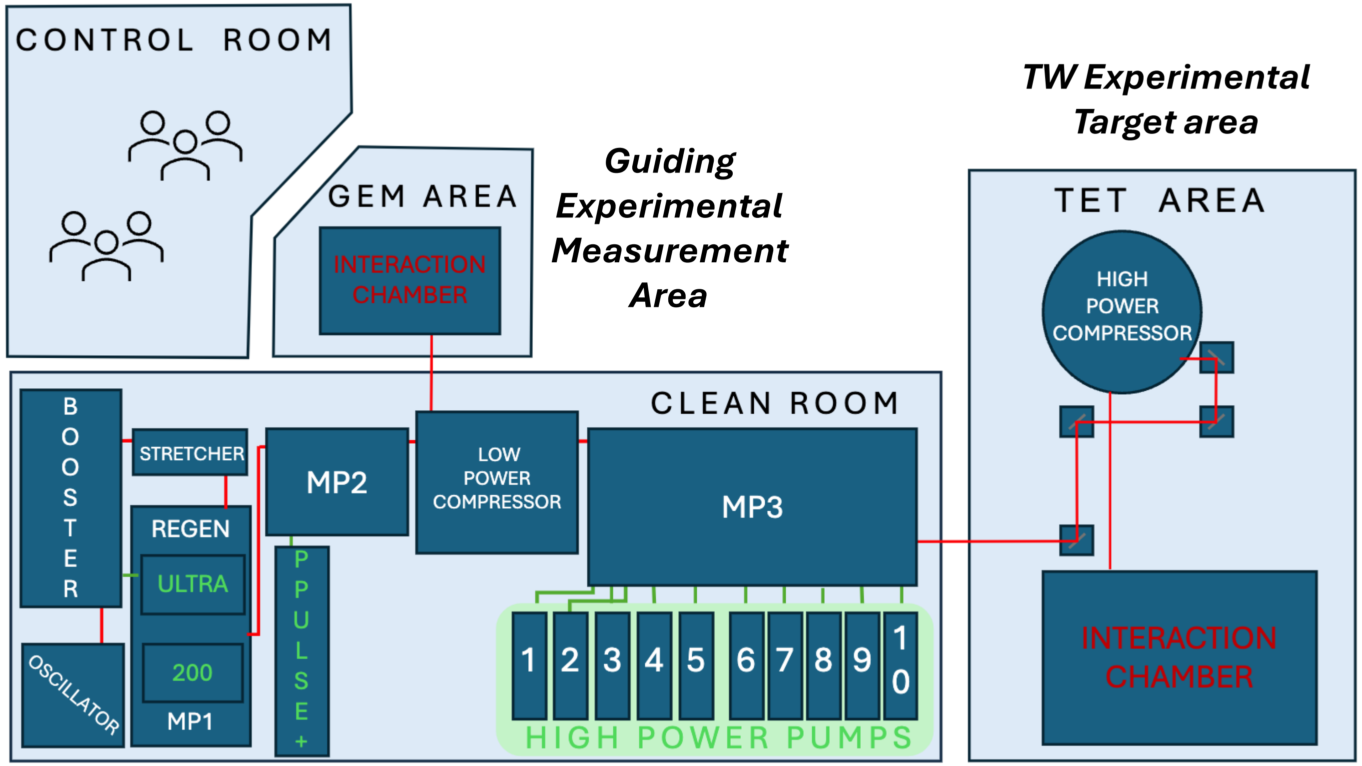
TW Experimental Target area





Energy	6 J
Duration (FWHM)	30 fs
Wavelength	800 nm
Repetition rate	10 Hz
Peak power	200 TW
Max. Intensity	$10^{19}\ W/cm^2$

FLAME laser system

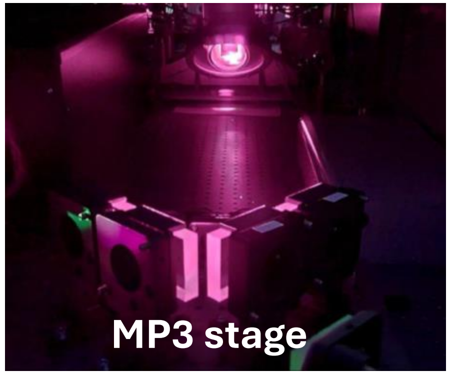


Main beamline

Third high-energy multi-pass (MP3)

↓

Laser energy 6 J



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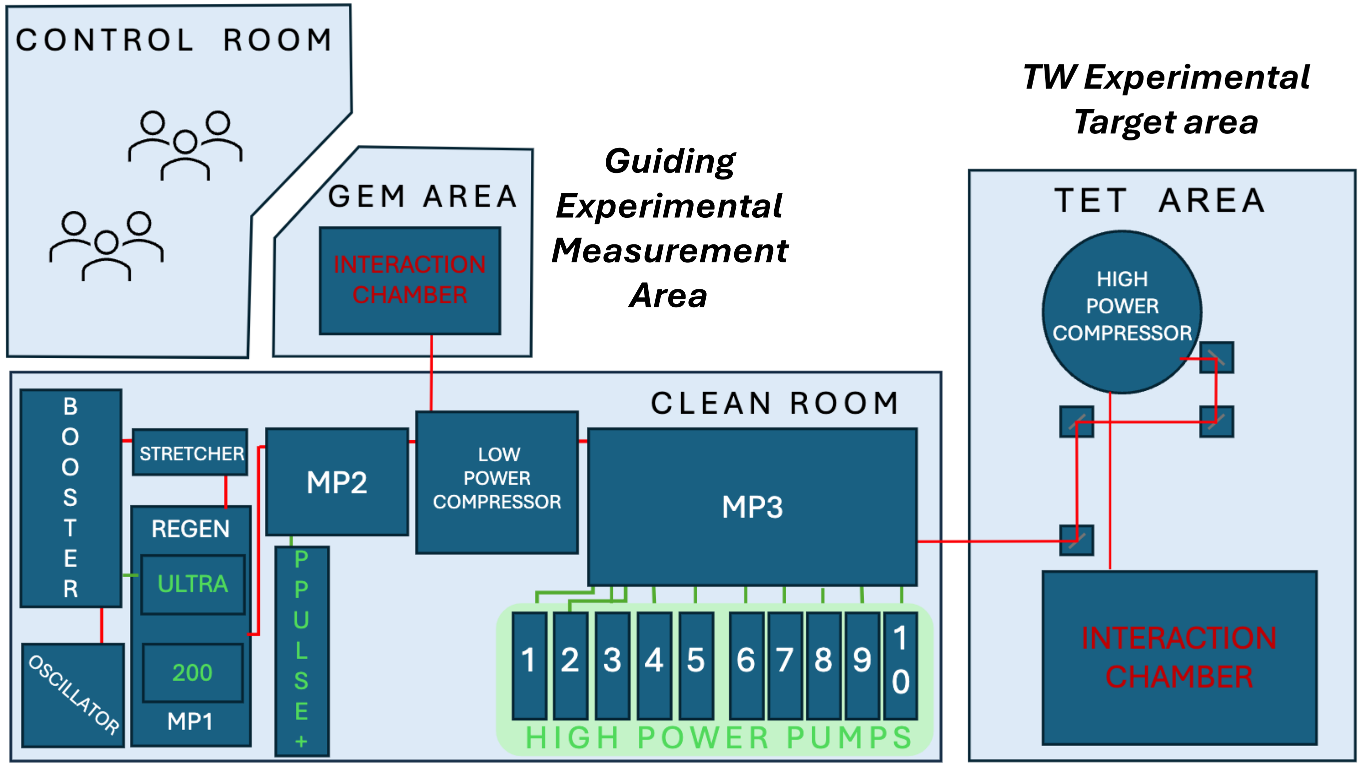
FLAME laser system



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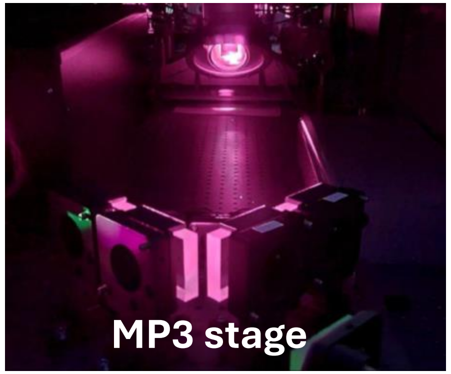
Optical high-power compressor

Temporal length of 30 fs



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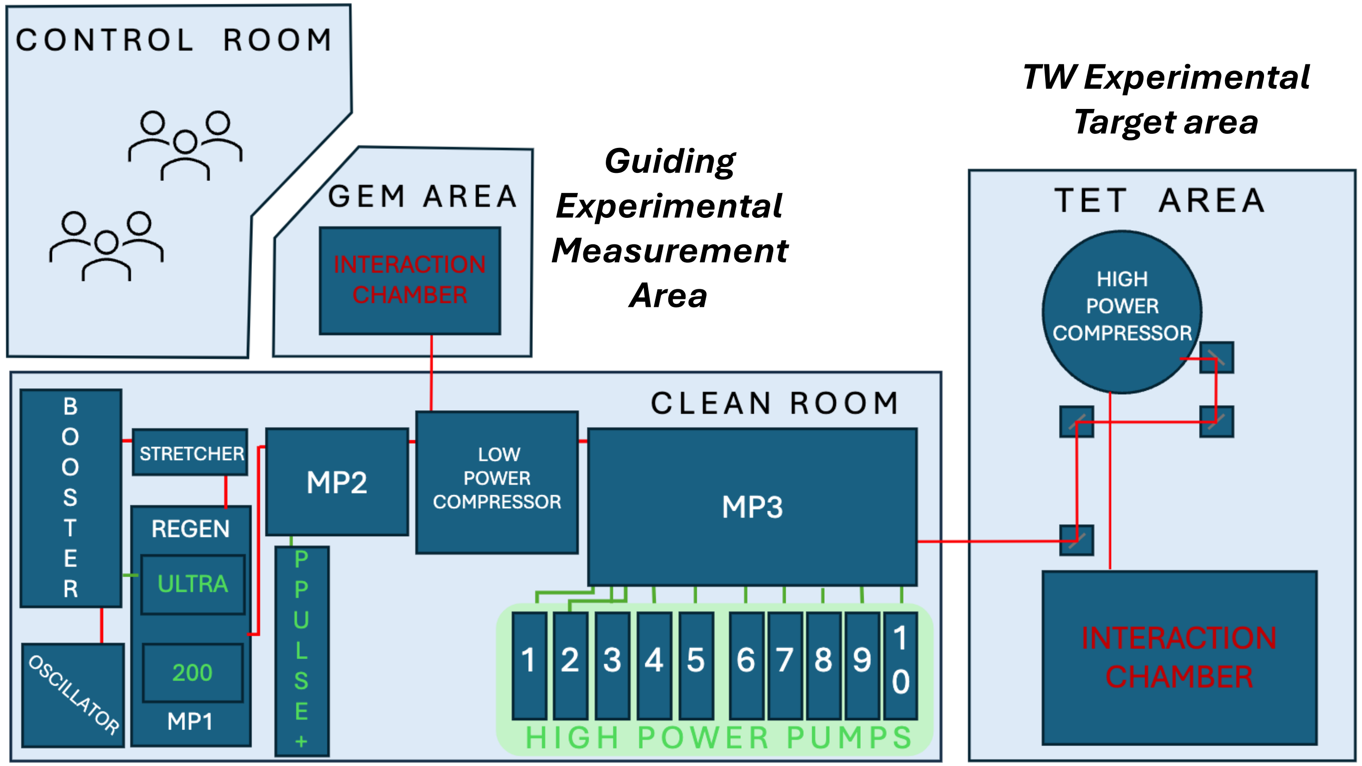

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Third high-energy multi-pass (MP3)

↓

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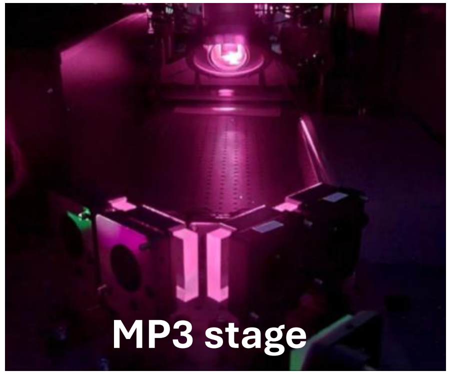
Optical high-power compressor

Temporal length of 30 fs

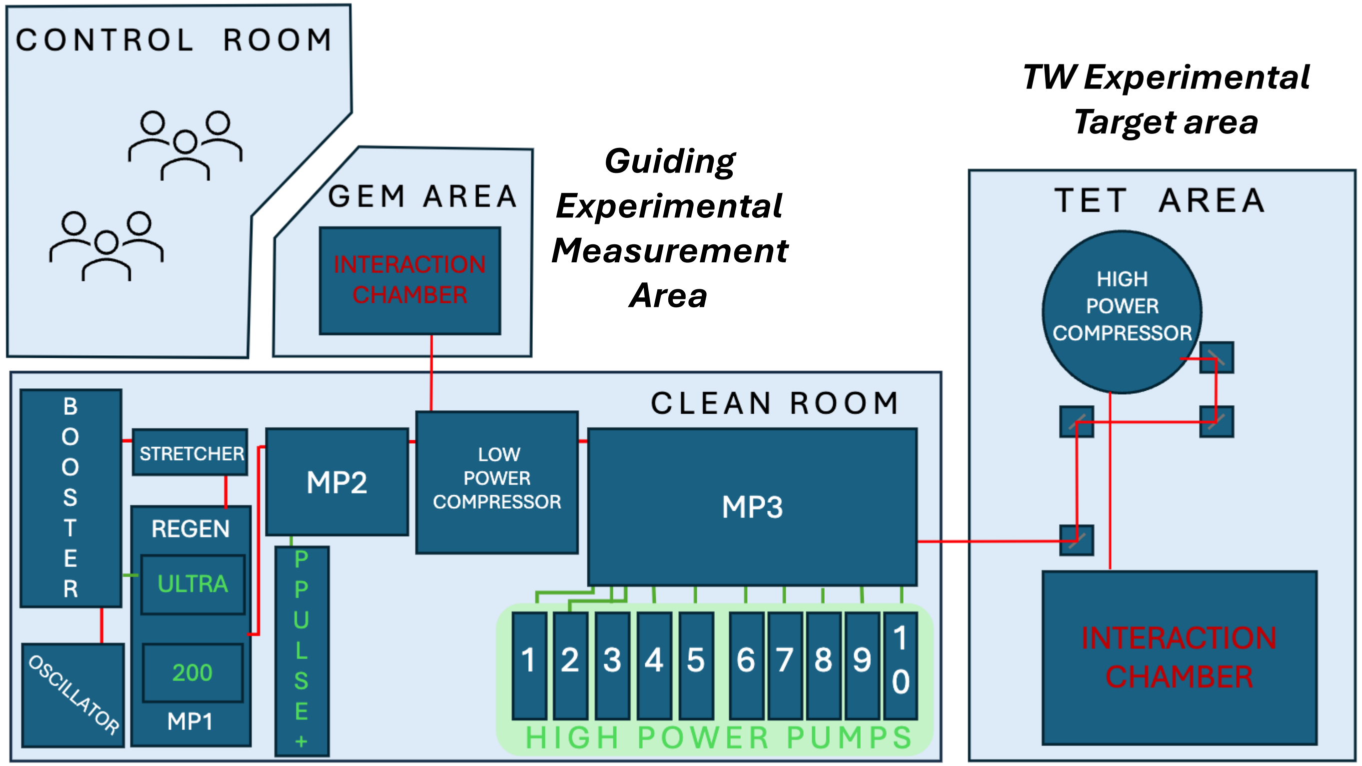
↓

The high-power and ultra-short laser beam is sent to the *TW Experimental Target Area*



FLAME laser system

Both beamlines can be sent to the *Sparc bunker* for EuAPS project (more details in the next talk)



Auxiliary beamline

Small portion ($\sim 10\%$) of the beam

Low-power compressor

↓

Temporal length of 40 fs
Pulse peak power of 10 TW

FLAME laser system

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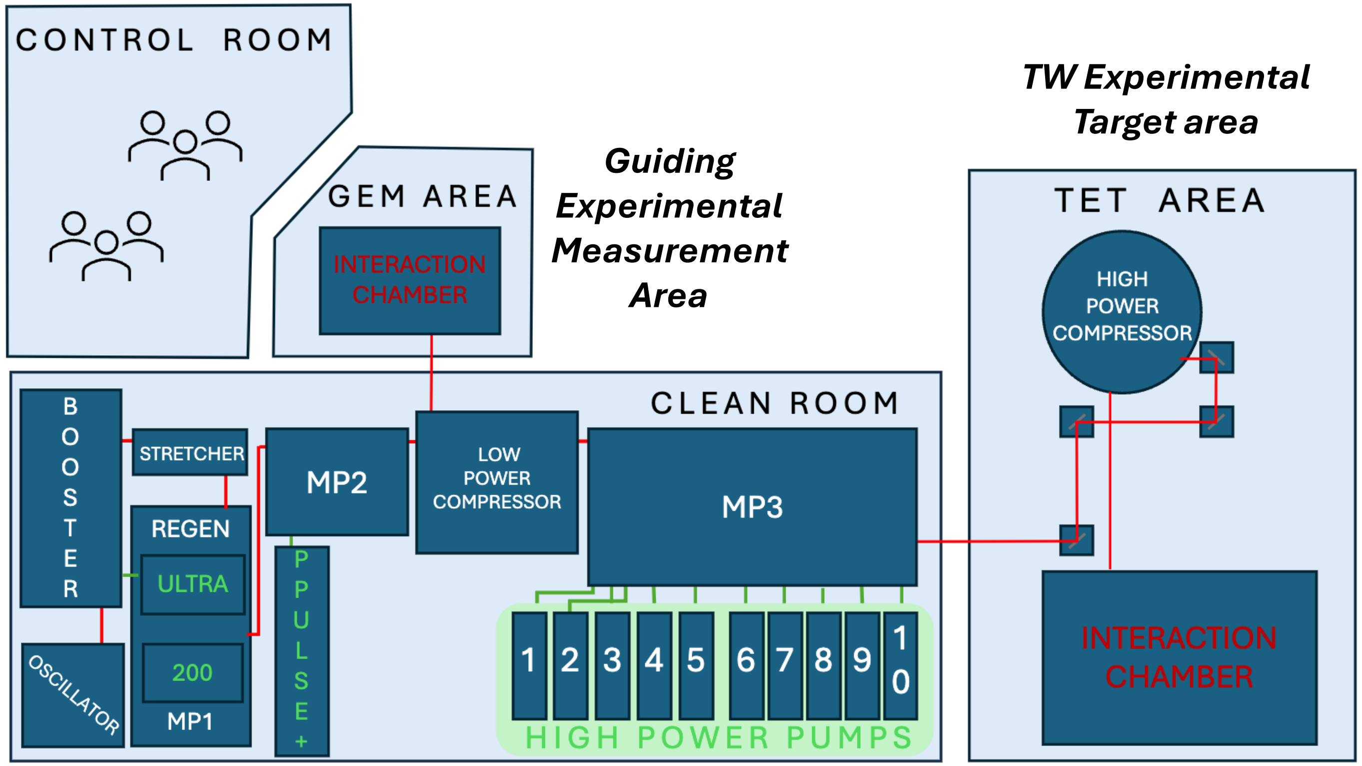

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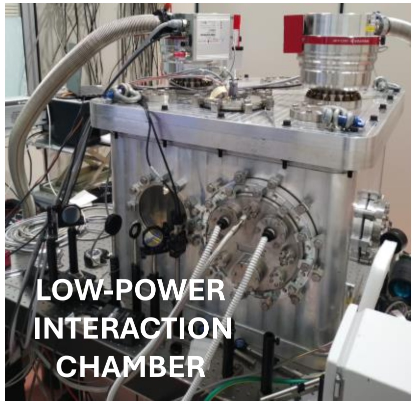
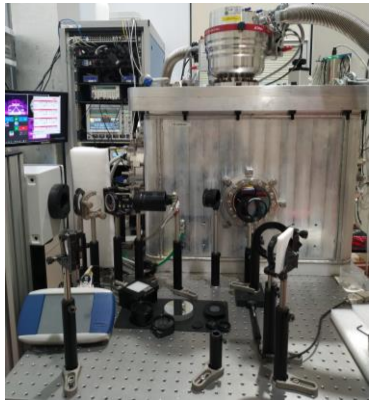




Guiding Experimental Measurement Area

Small interaction chamber in vacuum.
Max. intensity: $10^{17} W/cm^2$

The low-power laser beam can be transported to the *TW Experimental Target Area* as probe beam

Outline

- ➢ FLAME laser system
- ✓ FLAME experimental activity
- ➢ Laser, particle and plasma diagnostics
- ➢ Outlook

FLAME experimental activity

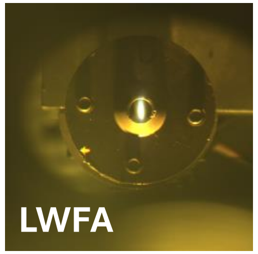
Main beamline in TET area

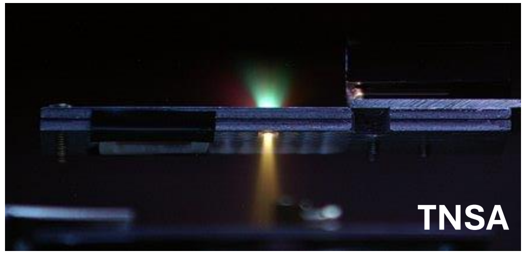
Gas-like target:

- Electron acceleration through Laser WakeField Acceleration (LWFA) in a gaseous target in self-injection or ionization injection scheme;
- production of secondary radiation, as betatron radiation.

Solid-state like target:

- Generation of fast electron and light ion bunches from interactions with solid targets in Target Normal Sheath Acceleration (TNSA) mechanism.





Implementation of single-shot diagnostic techniques

FLAME experimental activity

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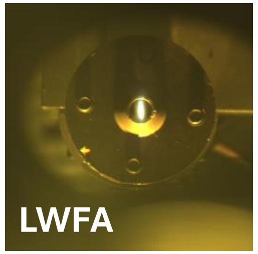
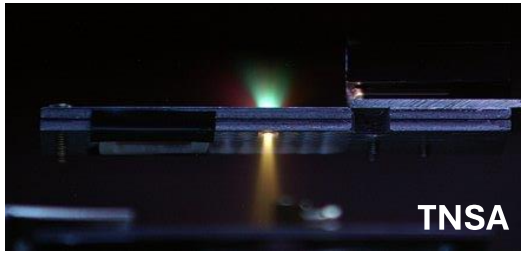


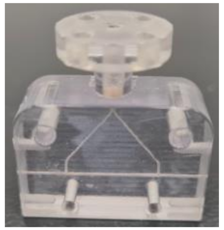


Implementation of single-shot diagnostic techniques

Auxiliary beamline in GEM area

Laser-target interaction between low-intensity pulses and different targets:

- Neutral gas for ionization tests inside the capillary;
- pre-formed plasma for laser guiding experiments.



FLAME experimental activity

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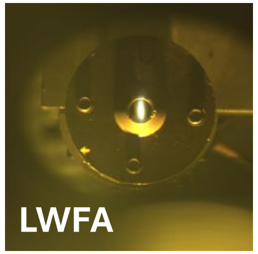

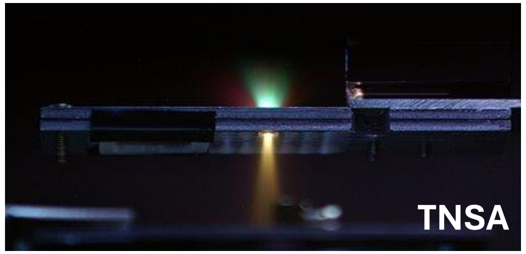

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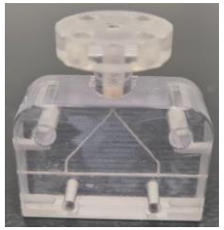
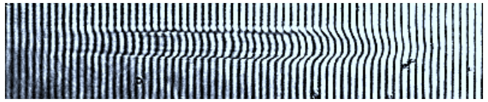


Auxiliary beamline in TET area

A delay line synchronizes the beamline with the main one for **pump-and-probe experiments**:

- Interferometry diagnostics to measure plasma density in LWFA;

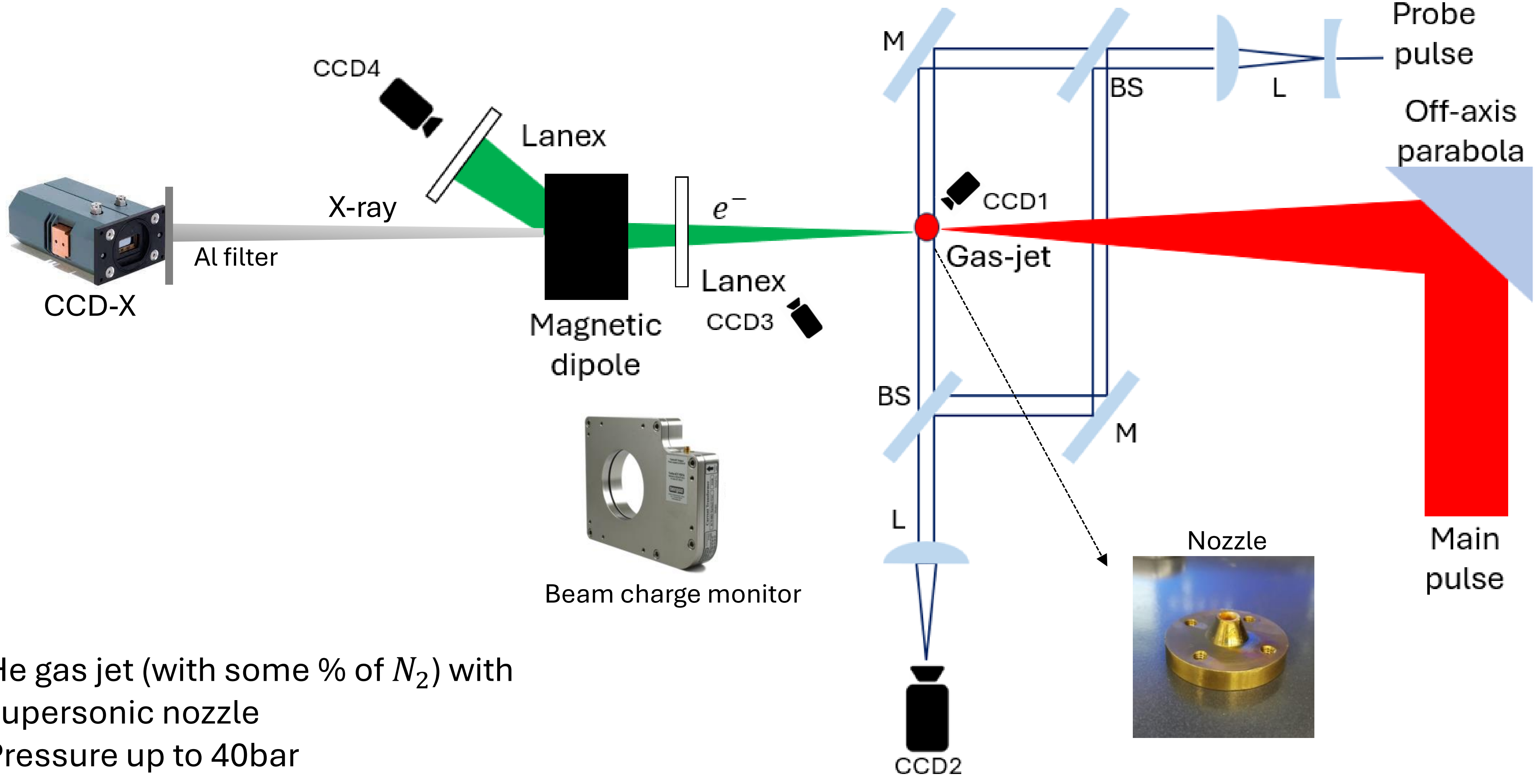


- Electron diagnostics in TNSA experiments

Outline

- FLAME laser system
- FLAME experimental activity
- ✓ Laser, particle and plasma diagnostics
- Outlook

Acceleration setup via LWFA



- He gas jet (with some % of N_2) with supersonic nozzle
- Pressure up to 40bar

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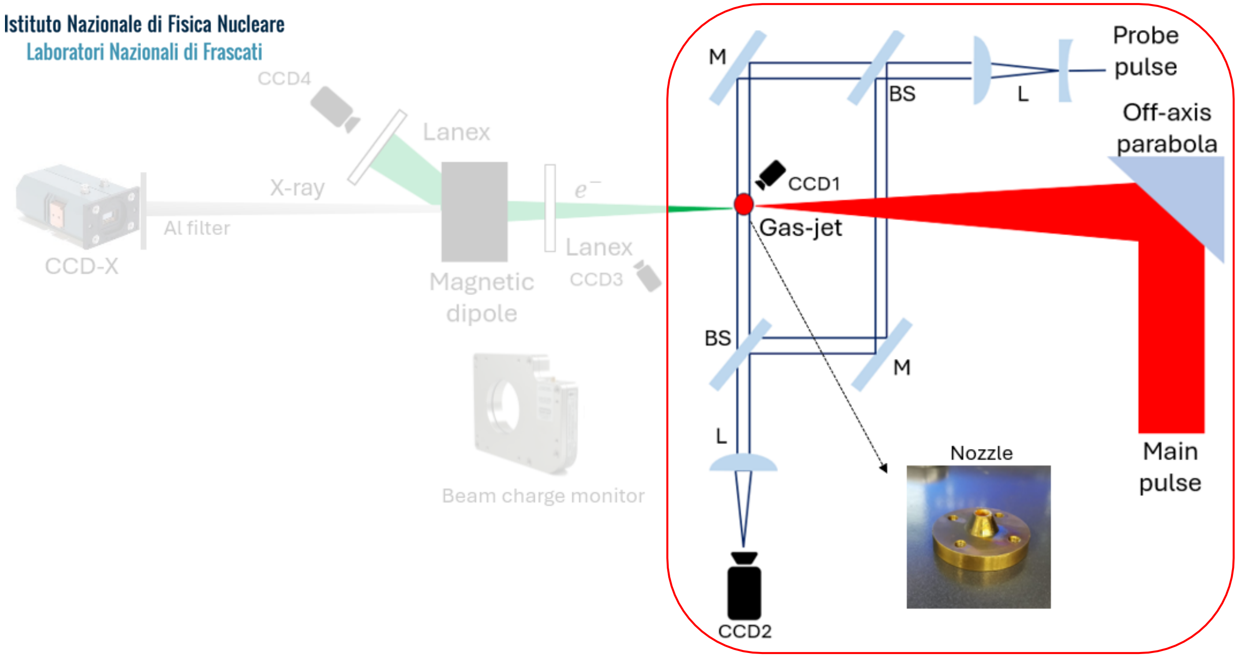
Acceleration setup via LWFA

SPARC LAB

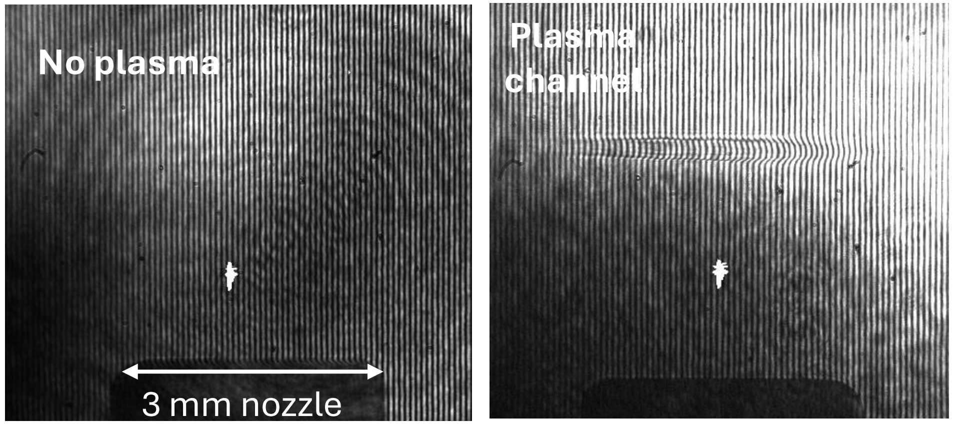


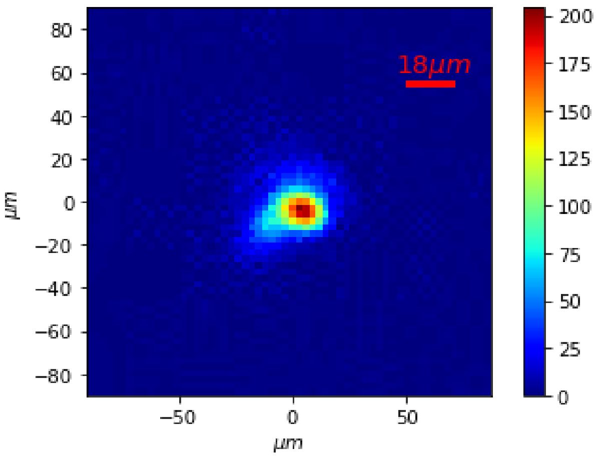
Laser diagnostics in the interaction chamber:

- A gold-coated, 15-degree OAP mirror ($f = 1\,m$) focuses the main pulse at the target (gas-jet) position;
- a CCD camera is used to measure the spot;

Plasma diagnostics in the interaction chamber:

- a Mach-Zehnder interferometer coupled with the probe beam to measure the plasma density;
- a CCD camera detects the resulting interference fringes





Laser spot size @$1/e^2$: **18 µm**

Laser intensity: $\mathbf{I} \sim \mathbf{10^{19}} \boldsymbol{W/cm^2}$

Plasma density: $\boldsymbol{n_e} \sim \mathbf{10^{19}}\ \boldsymbol{cm^{-3}}$

Acceleration length : **1mm**

M. Galletti, F. Stocchi, et al. Appl.Sci 2024, 14, 8619

Acceleration setup via LWFA

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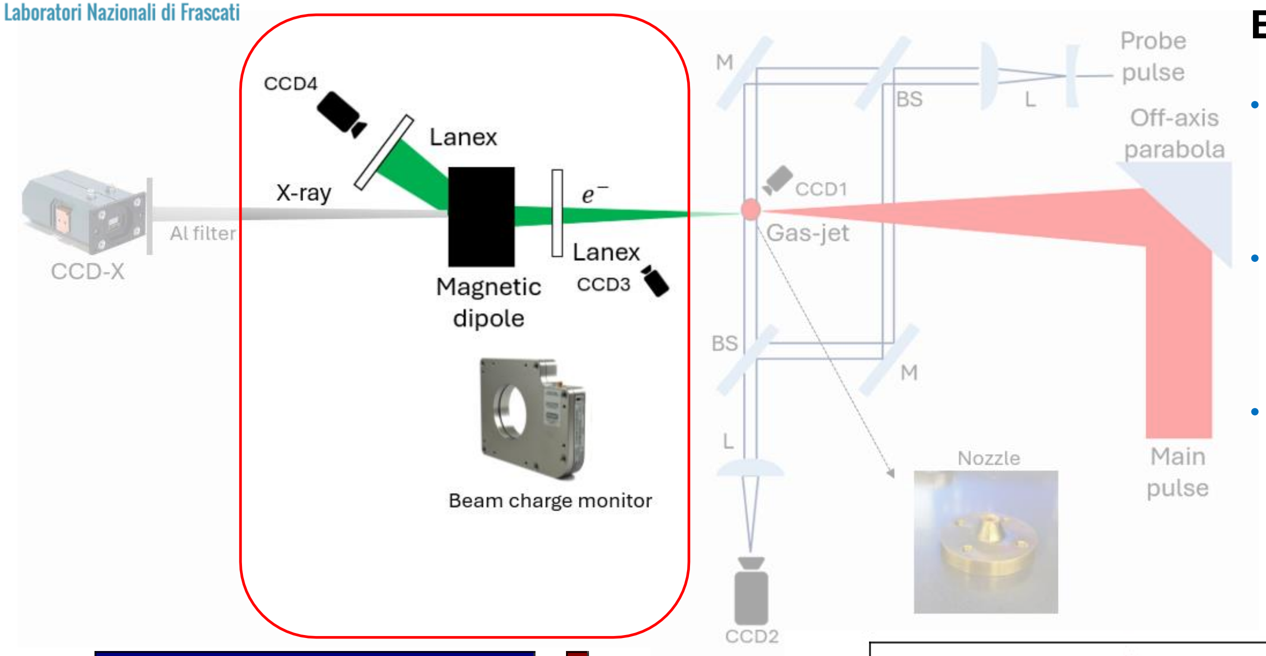
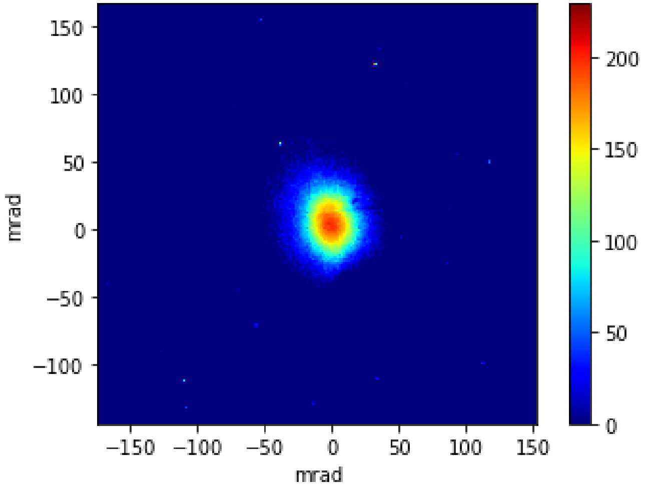
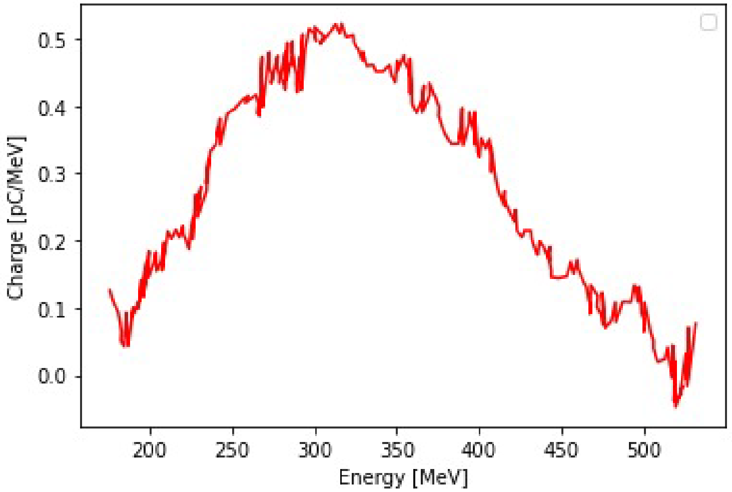


Electron beam diagnostics in the interaction chamber:

- Scintillator lanex screen coupled with a CCD camera to measure the electron beam size;
- Integrating Current Transformer (ICT) with a Beam Charge Monitor (BCM) for the bunch charge measurements;
- Energy spectrometer: magnetic dipole (B=1T) coupled with a scintillator lanex screen and a CCD.





Electron divergence (FWHM): **20-30 mrad**

Mean energy: **320 MeV**

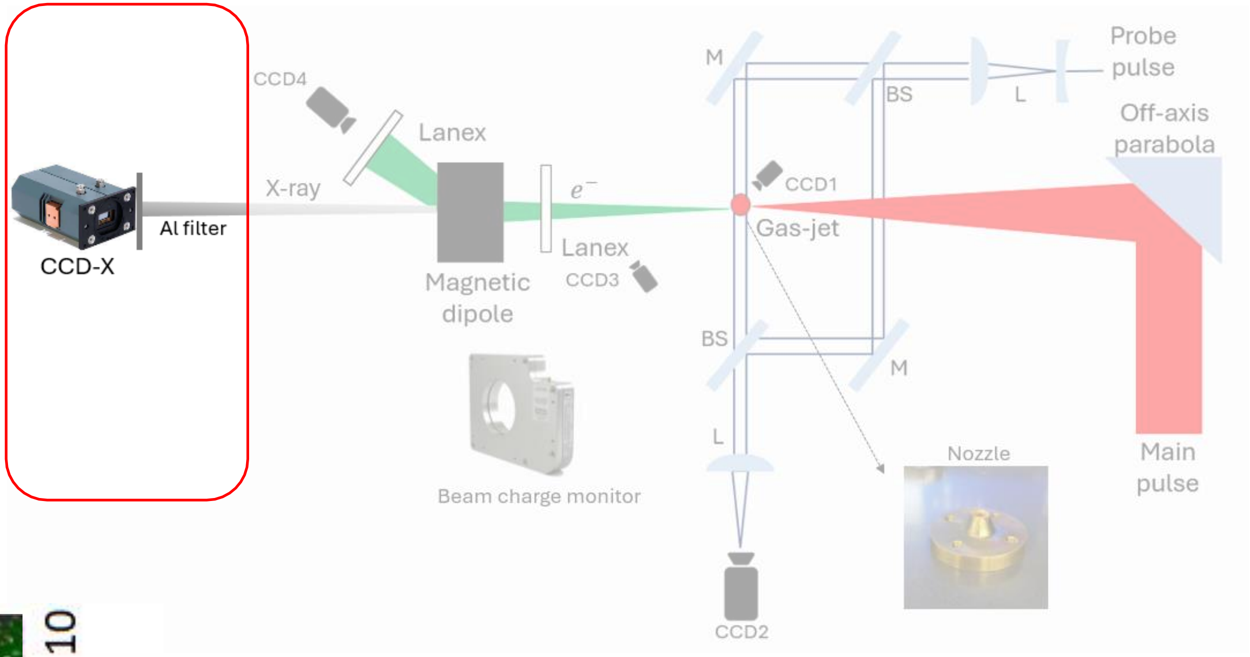
Energy spread: **20%**

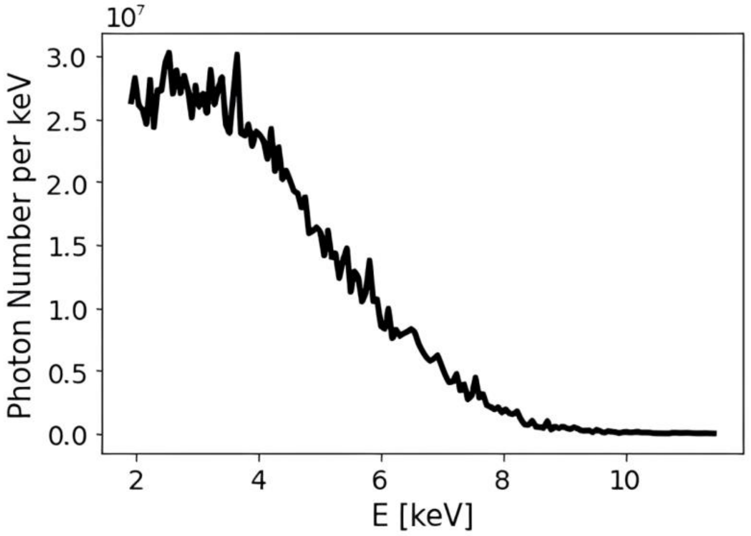
M. Galletti, F. Stocchi, et al. Appl.Sci 2024, 14, 8619

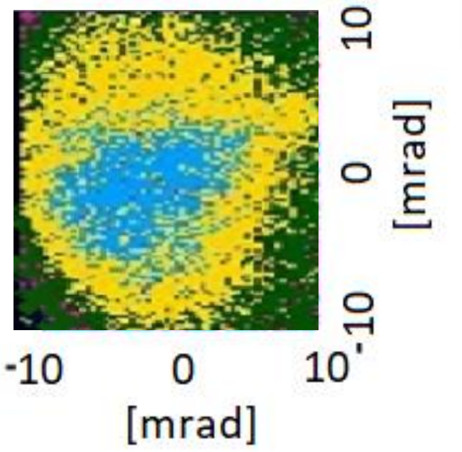
Acceleration setup via LWFA

Betatron radiation diagnostics in the interaction chamber:

- CCD-X camera for the radiation spectra;
- X-ray scintillator to measure the beam angular distribution







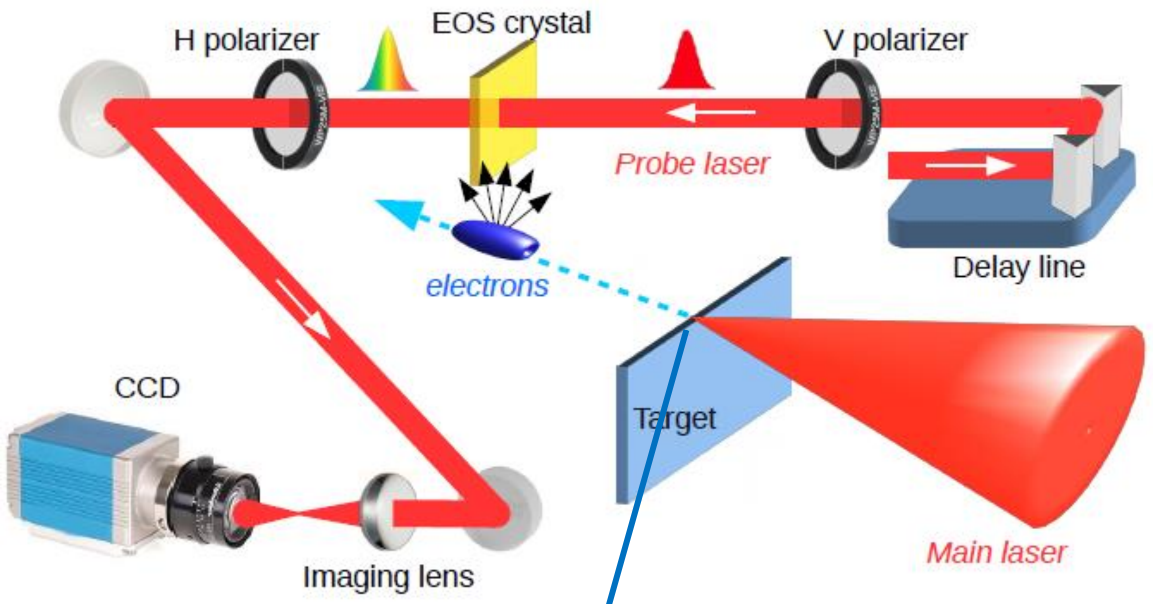
X-rays beam divergence (FWHM): ~ **7 mrad**

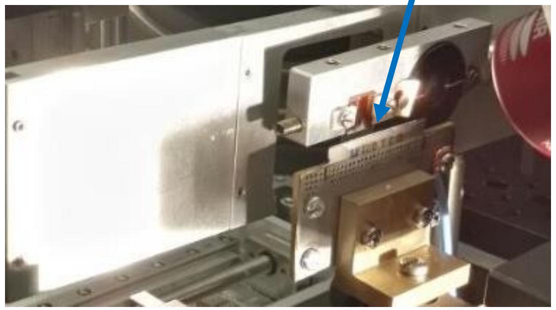
Photon number: ~$\mathbf{10^8}$ **per pulse**

Critical energy: ~**4 keV**

M. Galletti, F. Stocchi, et al. Appl.Sci 2024, 14, 8619
A. Curcio et al., Phys. Rev. Accel. Beams vol. 20 (2017) 012801

Experimental setup for laser-solid target interaction





Direct time-resolved measurements of relativistic electrons produced from solid targets by the interaction with an ultra-short and high-intensity laser pulse.

- Laser : $60\ \mu m$ of spot size @$1/e^2$ and 4J after the compressor;
- laser beam focused on different target ;
- Single-shot and non-destructive measurements for electron longitudinal profile.

Electron bunches **up to 7 nC charge, ps duration and a mean energy of 12 MeV**

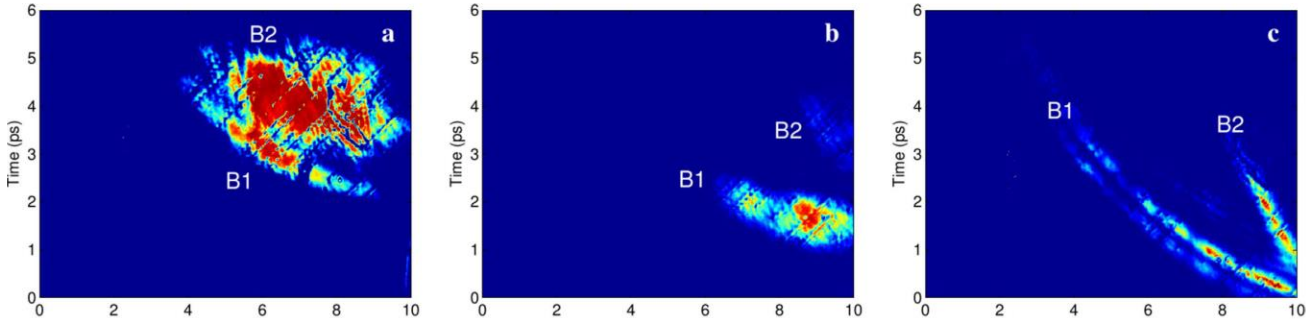


Figure 2. Snapshots with different target shapes. Signatures of the escaping electrons from (a) planar, (b) wedged and (c) tipped targets. The emitted charges are, respectively, (a) 1.2 nC (B1) and 3 nC (B2); (b) 2 nC (B1) and 0.3 nC (B2); (c) 7 nC (B1) and 3 nC (B2)

Pompili, R. et al. Sci Rep 6, 35000 (2016).

Outline

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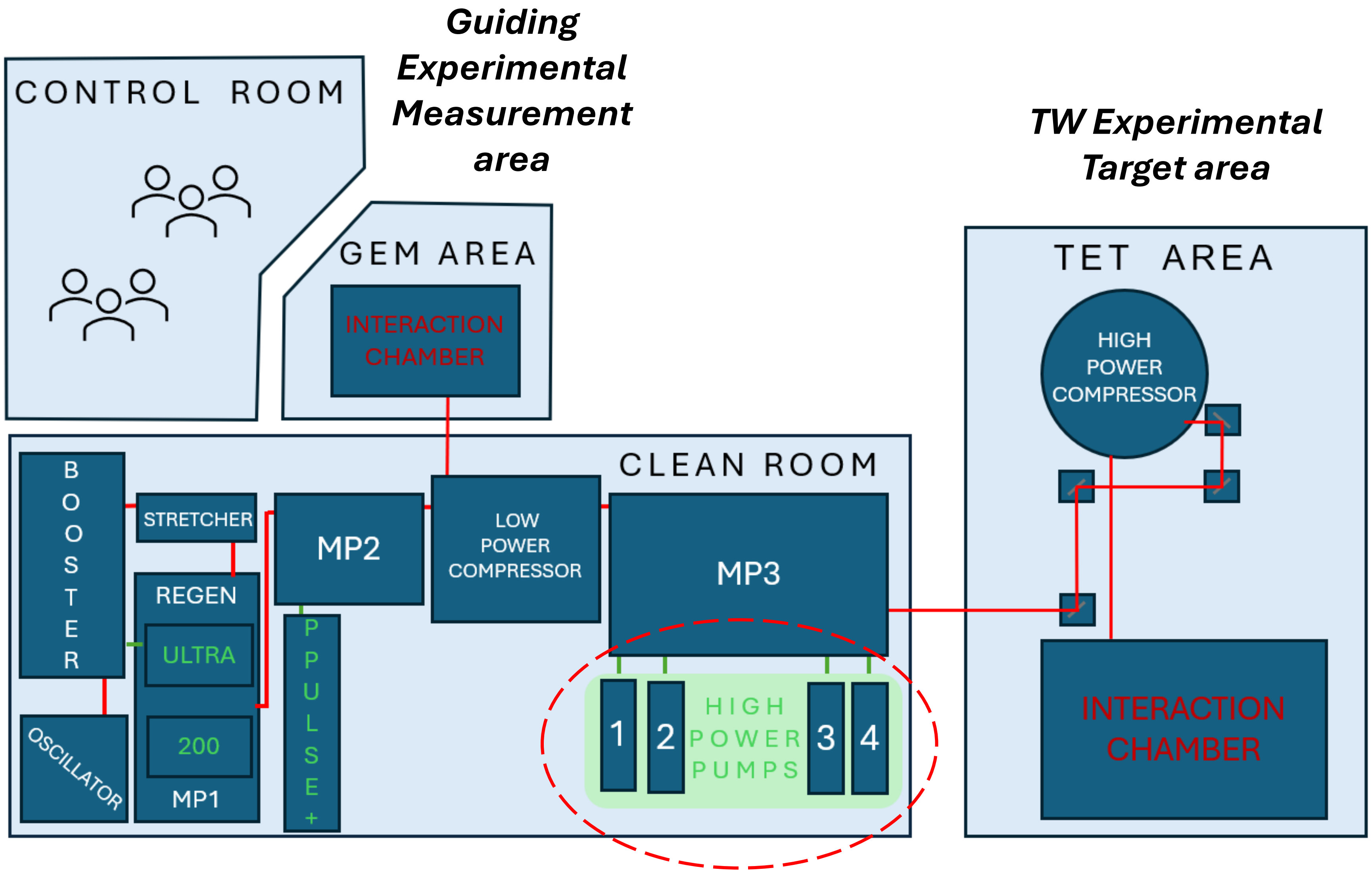
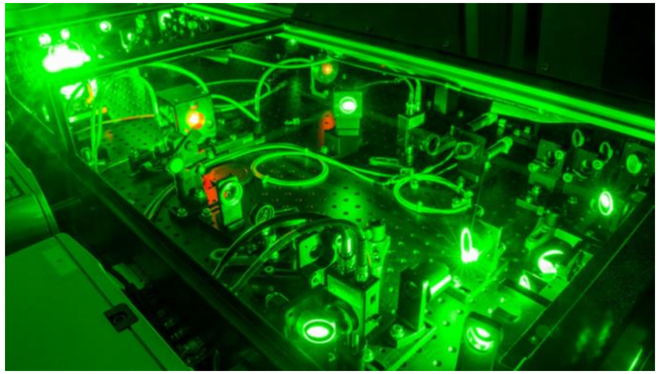
New FLAME laser system





Energy	**7 J**
Duration (FWHM)	30 fs
Wavelength	800 nm
Repetition rate	**5 Hz**
Peak power	**230 TW**
Max. Intensity	$10^{19}\ W/cm^2$

Outlook

- Laser system upgrade (7 J with a repetition rate of 5 Hz, peak power of 230 TW)
- Study of different configurations for the LWFA process
- Development of analysis techniques to optimize the particles and radiation production
- Testing ground for experimental configuration for radiation production
- First betatron source for user-oriented applications (EuAPS project)

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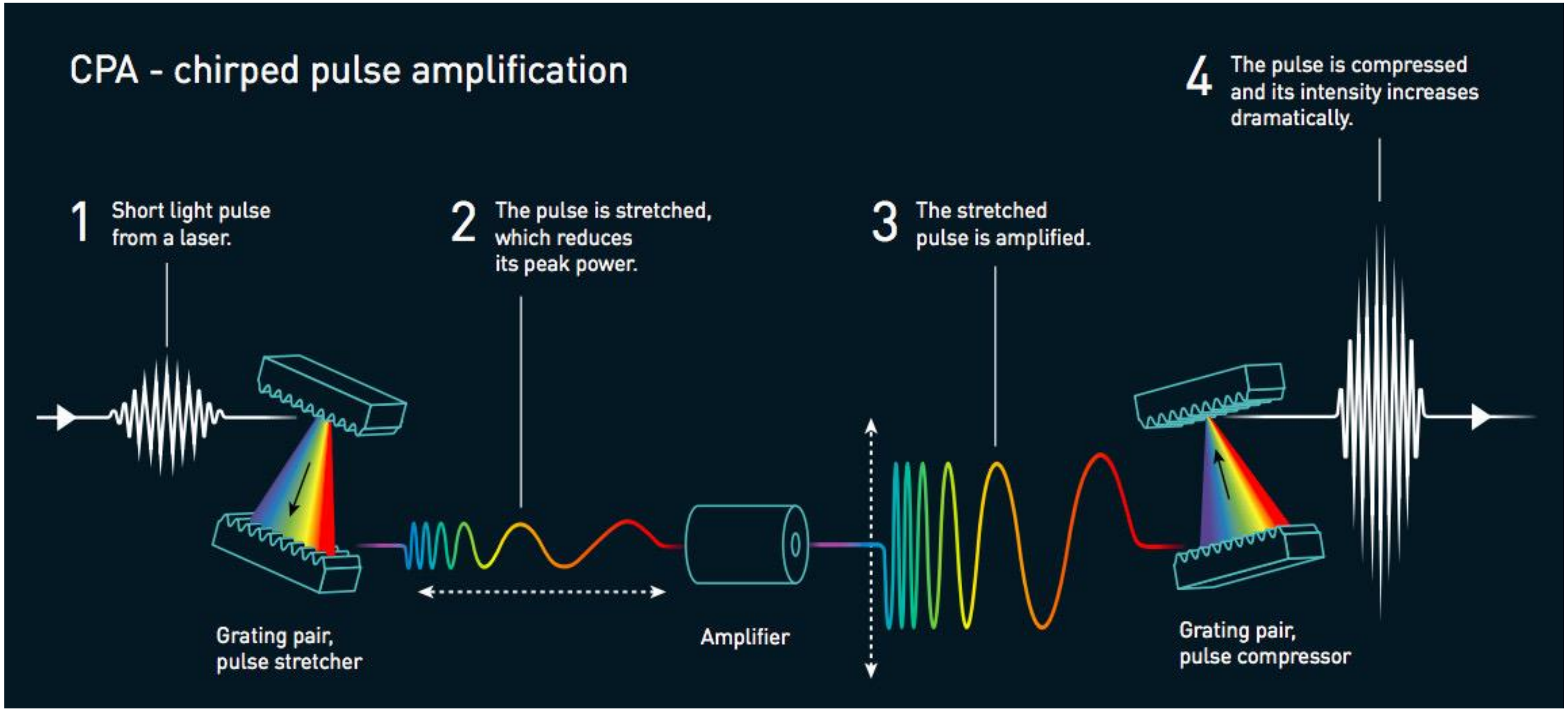
Thank you for your attention!

Backup slides

Chirped Pulse Amplification technique

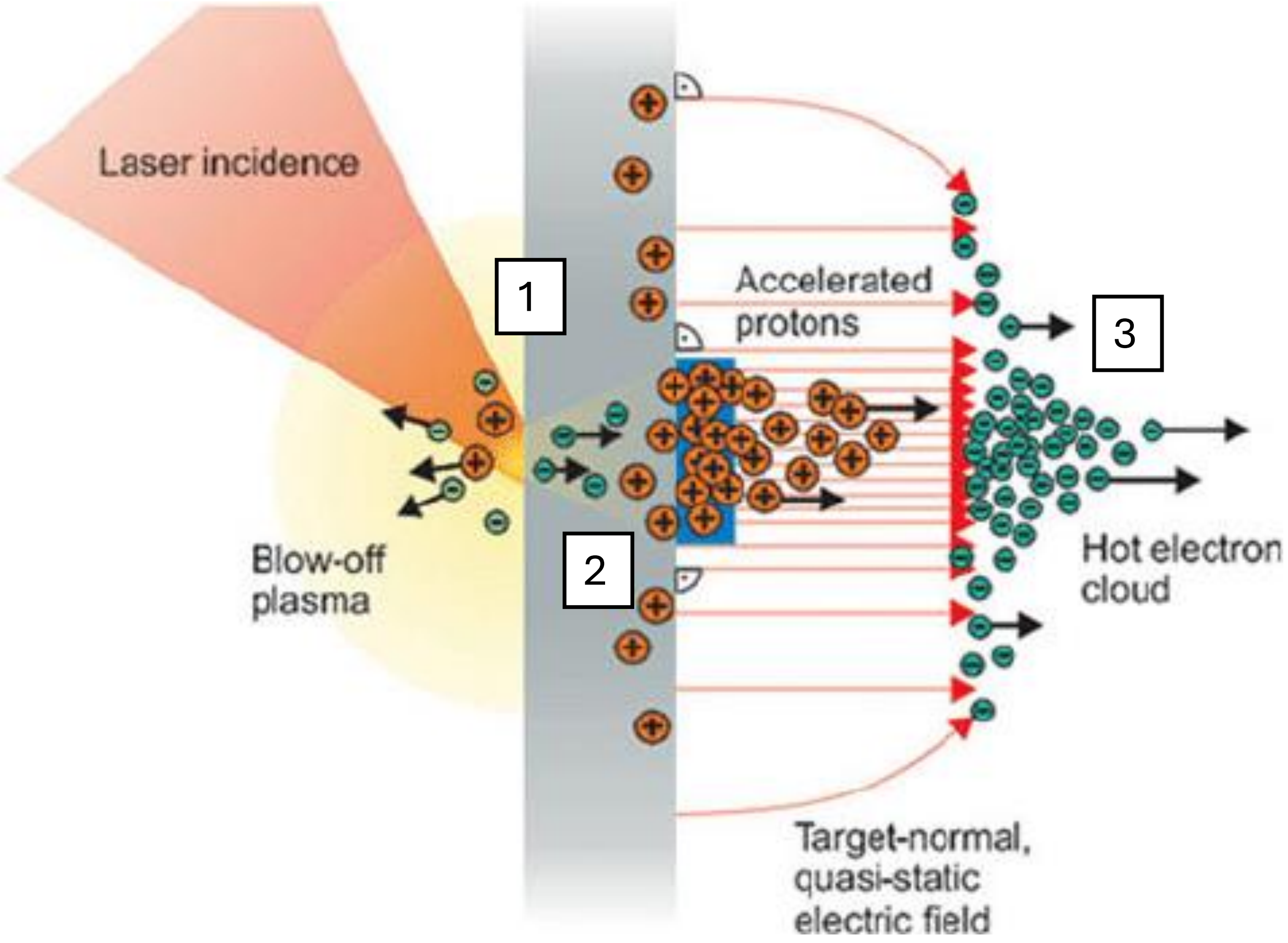
Strickland, D.; Mourou, G. Compression of amplified chirped optical pulses. Opt. Commun. 1985, 55, 447–449

Physics Nobel Prize in 2018



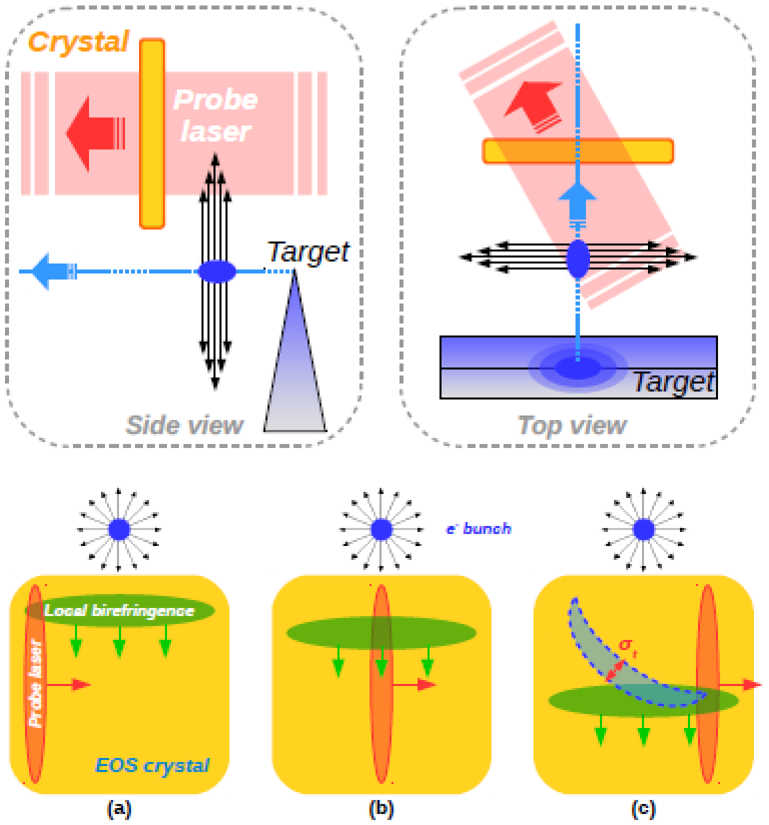
TNSA: Target Normal Sheath Acceleration

- Laser interacts with pre-formed plasma.
- Electrons are accelerated and reach the rear side of the target. Only more energetic electrons escape and a electrostatic potential is established
- Positive charge left on target are accelerated by the electric field induced by the electrons



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

EOS diagnostics for electron detection



- EOS experimental setup: the bunch emitted from the target travels normally and under the crystal surface, while the probe laser crosses the crystal with an incident angle.

a) The Coulomb field of the bunch induces the crystal birefringence;

b) the local birefringence shifts in the crystal while the electric field of the bunches propagate.

c) The final signal (blue region), detected by the CCD, is due to the temporal superposition of the local birefringence and the probe laser pulse.

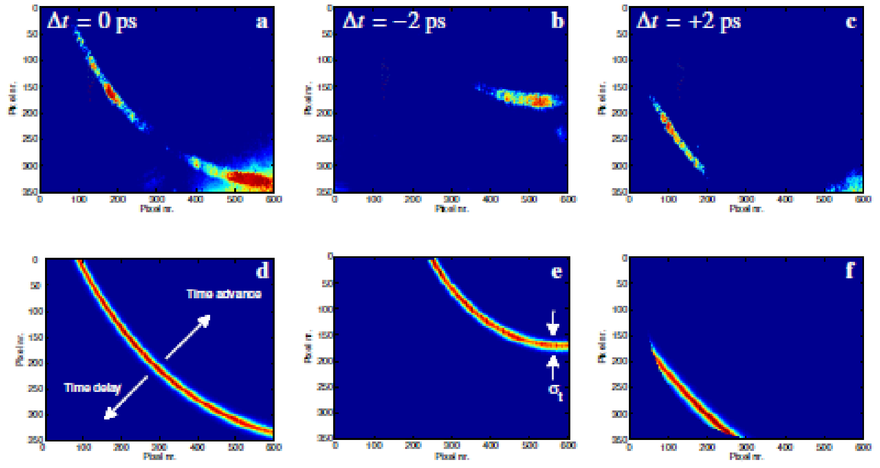


Fig. 5. (a-c) Experimentally measured EOS signals obtained by changing the probe laser delay (Δt) with respect to the main laser. For a delay (advance) of the probe laser, the resulting signals shift down (up). (d-f) Simulated EOS signals assuming the emitted electron cloud described in Sec. 4. The time direction is indicated by the white arrows in (d). The lack of uniformity in the experimental signals is mainly due to inhomogeneities both on the ZnTe crystal surface and on the transverse profile of the probe laser.

Pompili, R., et al. Opt.Exp. 24 (2016)