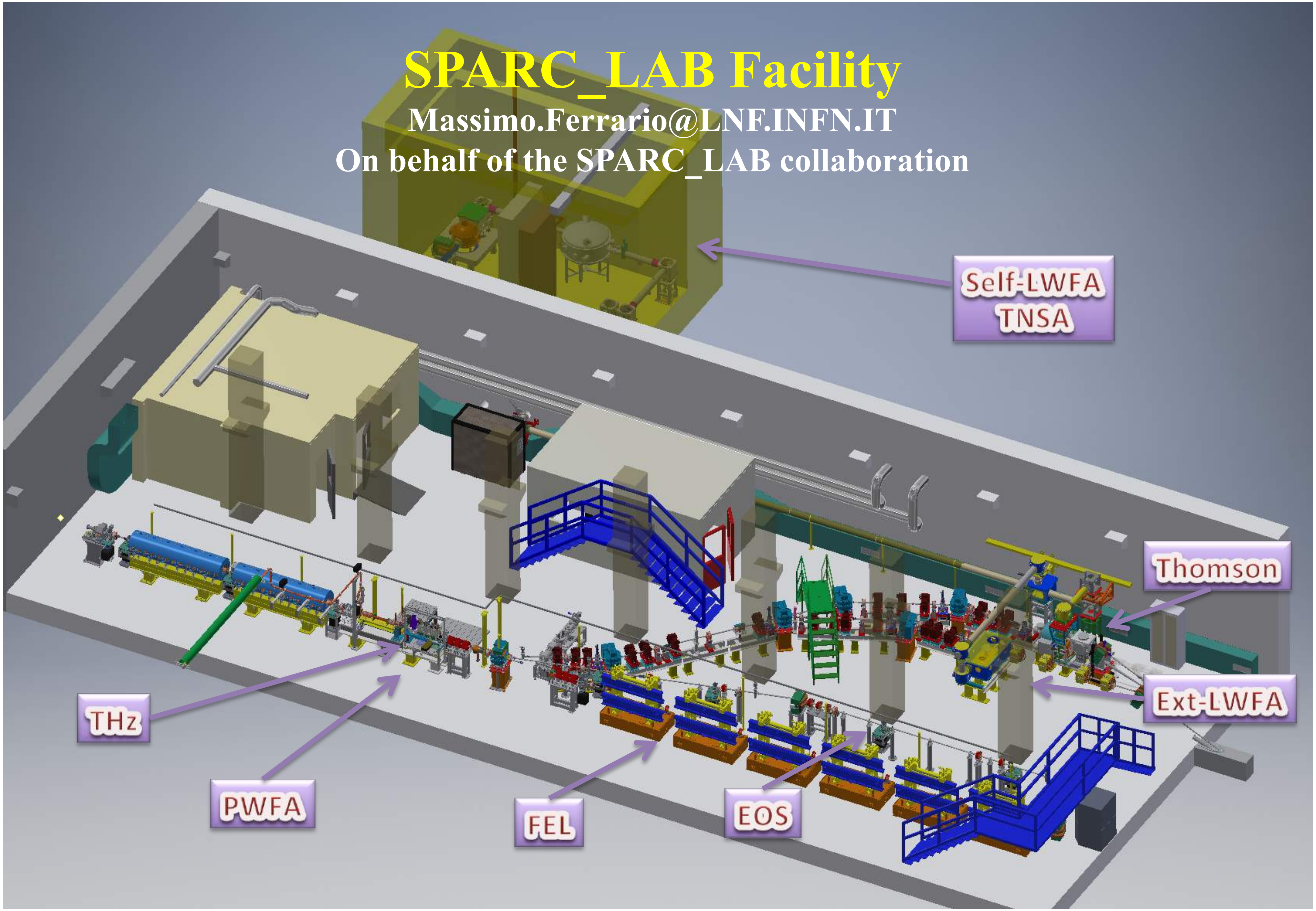
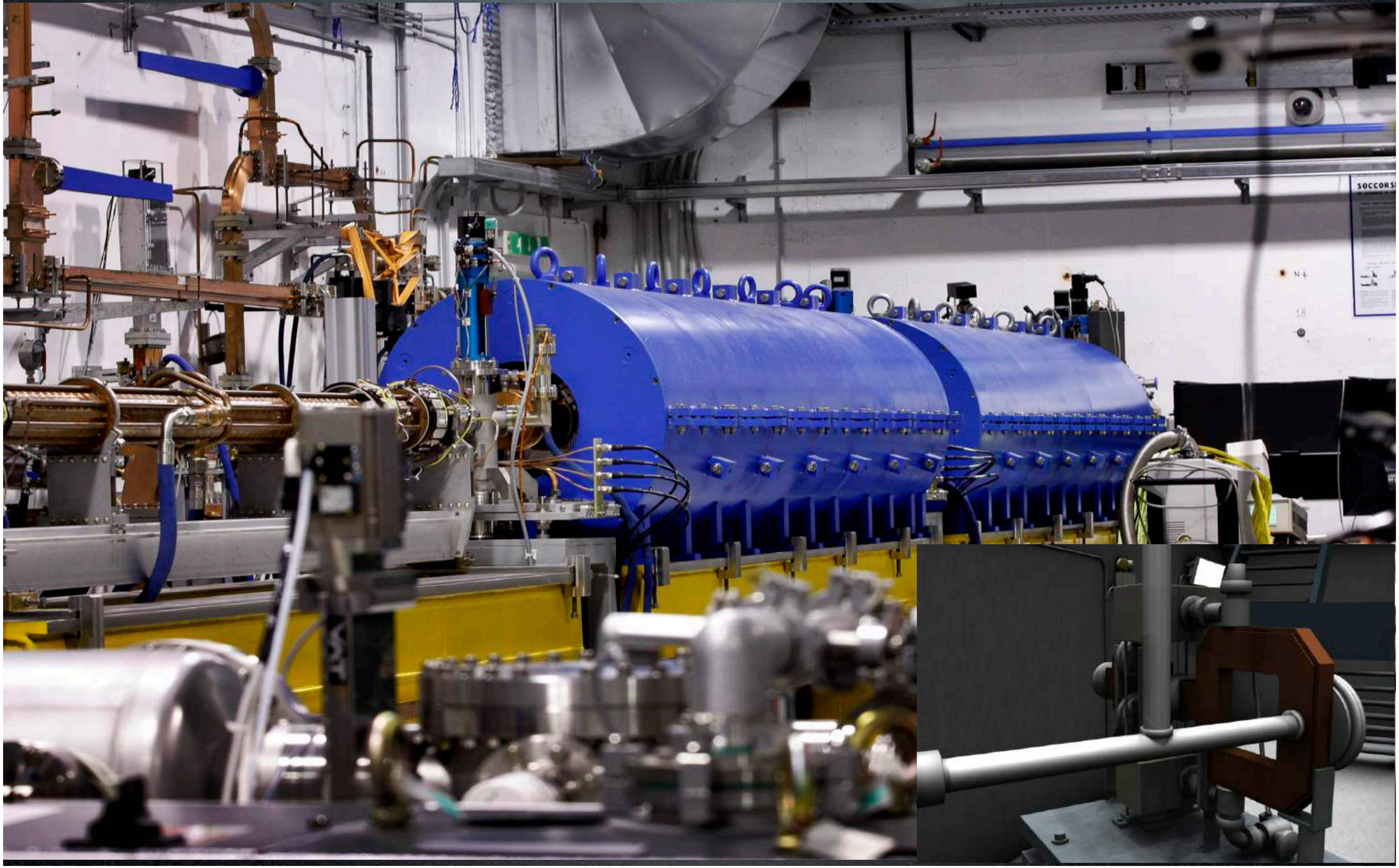
SPARC_LAB Facility

Massimo.Ferrario@LNF.INFN.IT
On behalf of the SPARC_LAB collaboration

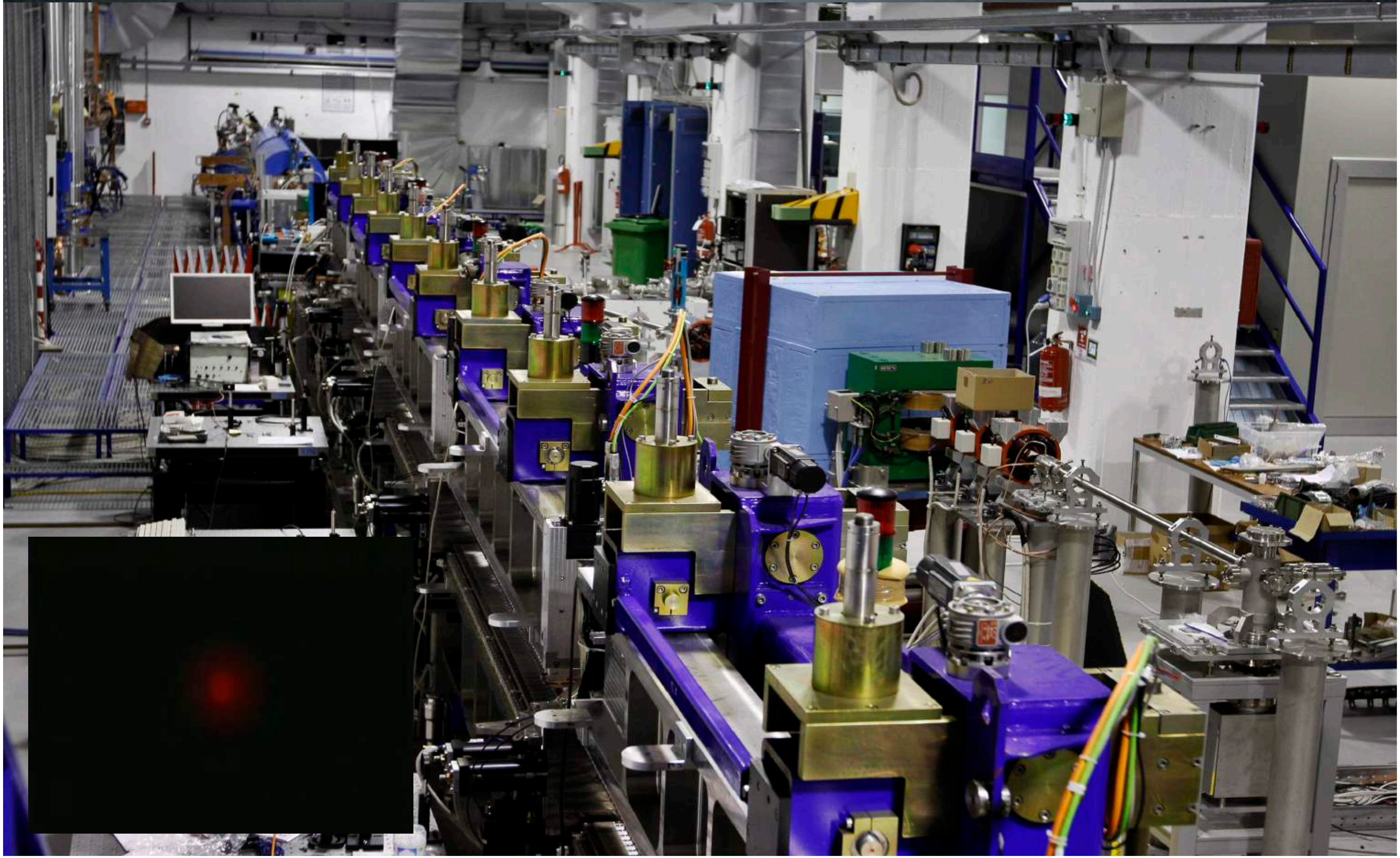



High harmonics in a single pass seeded FEL amplifier

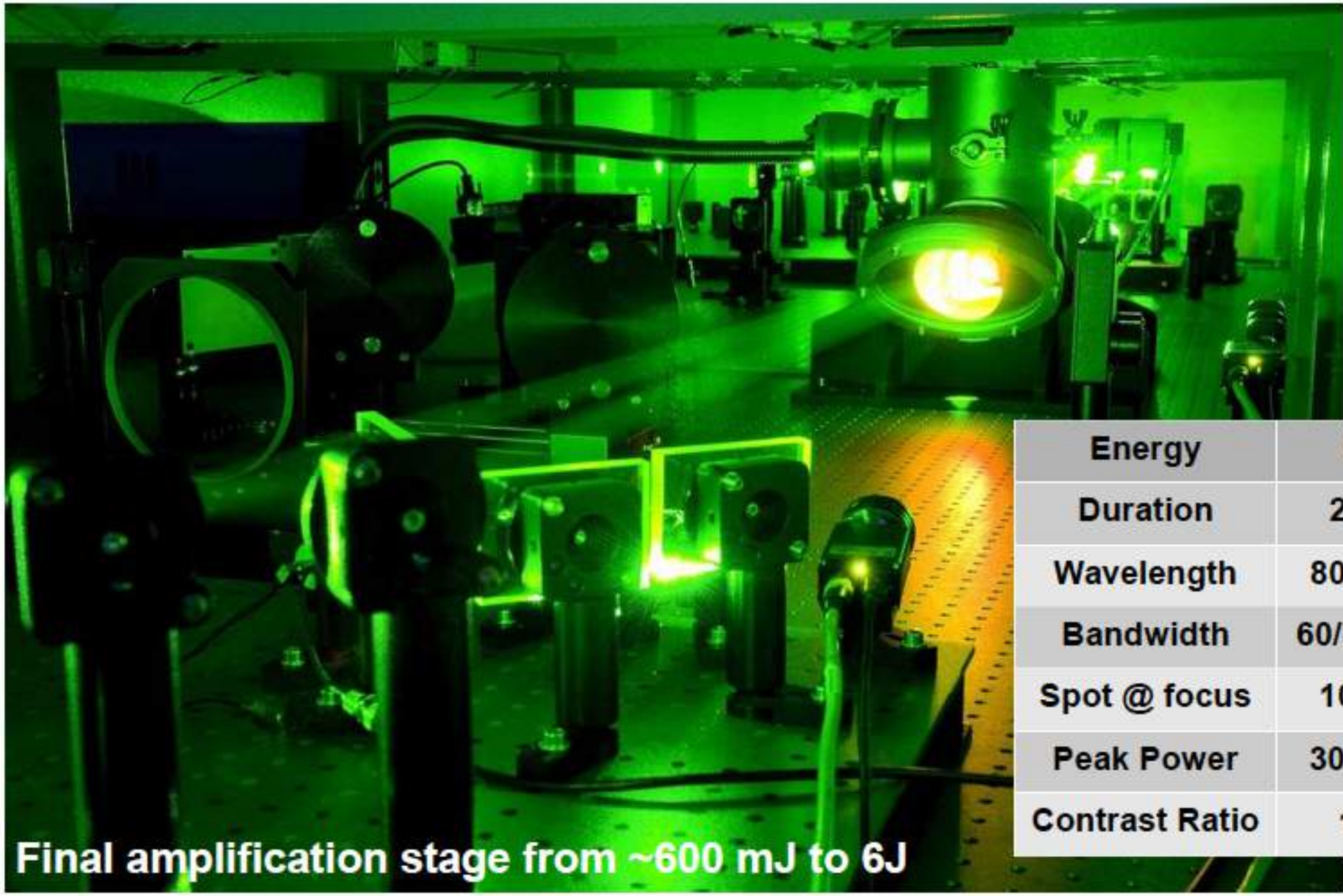
High Brightness Photo-injector with Velocity Bunching



Free Electron Laser



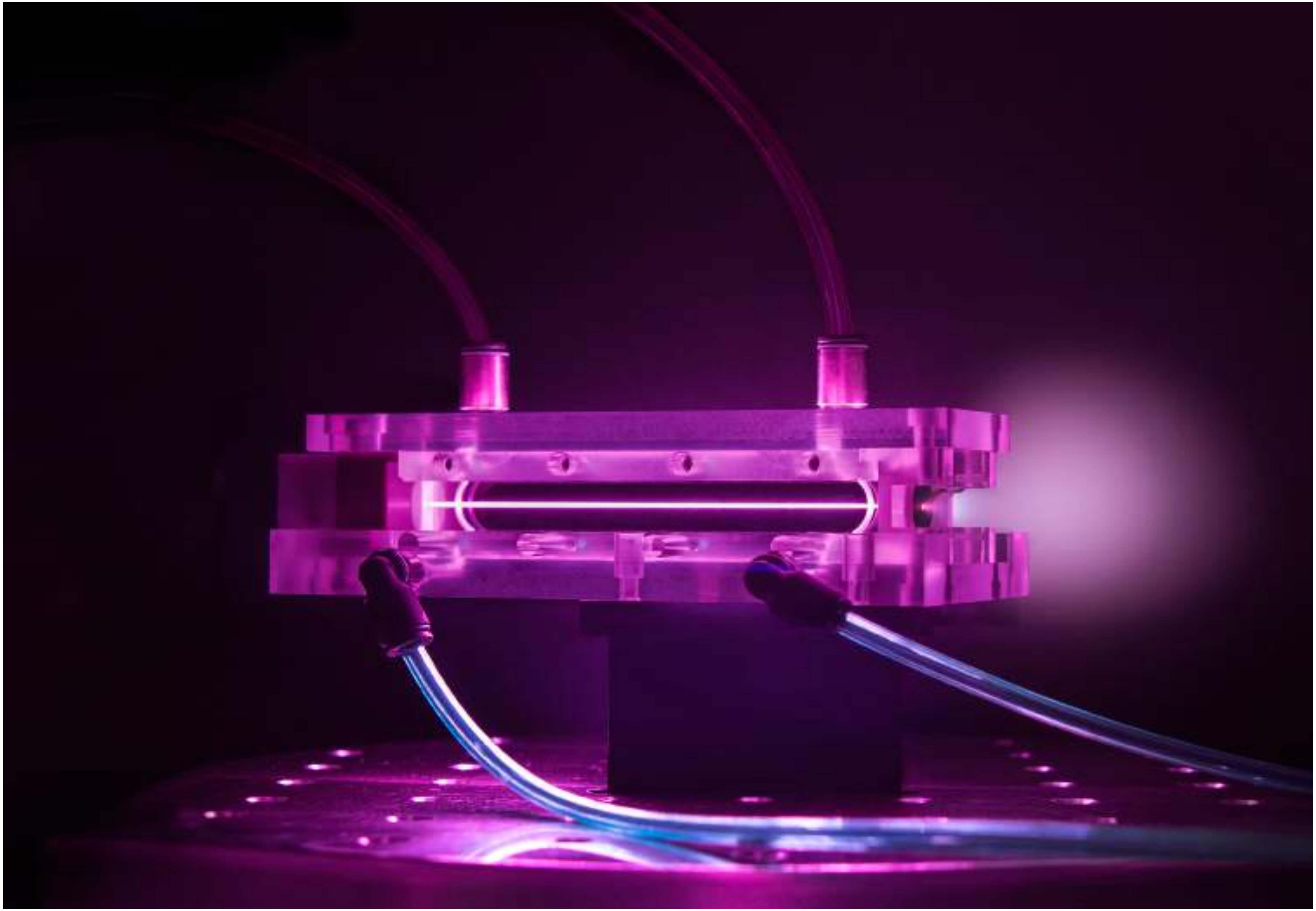
Ti:Sa FLAME laser

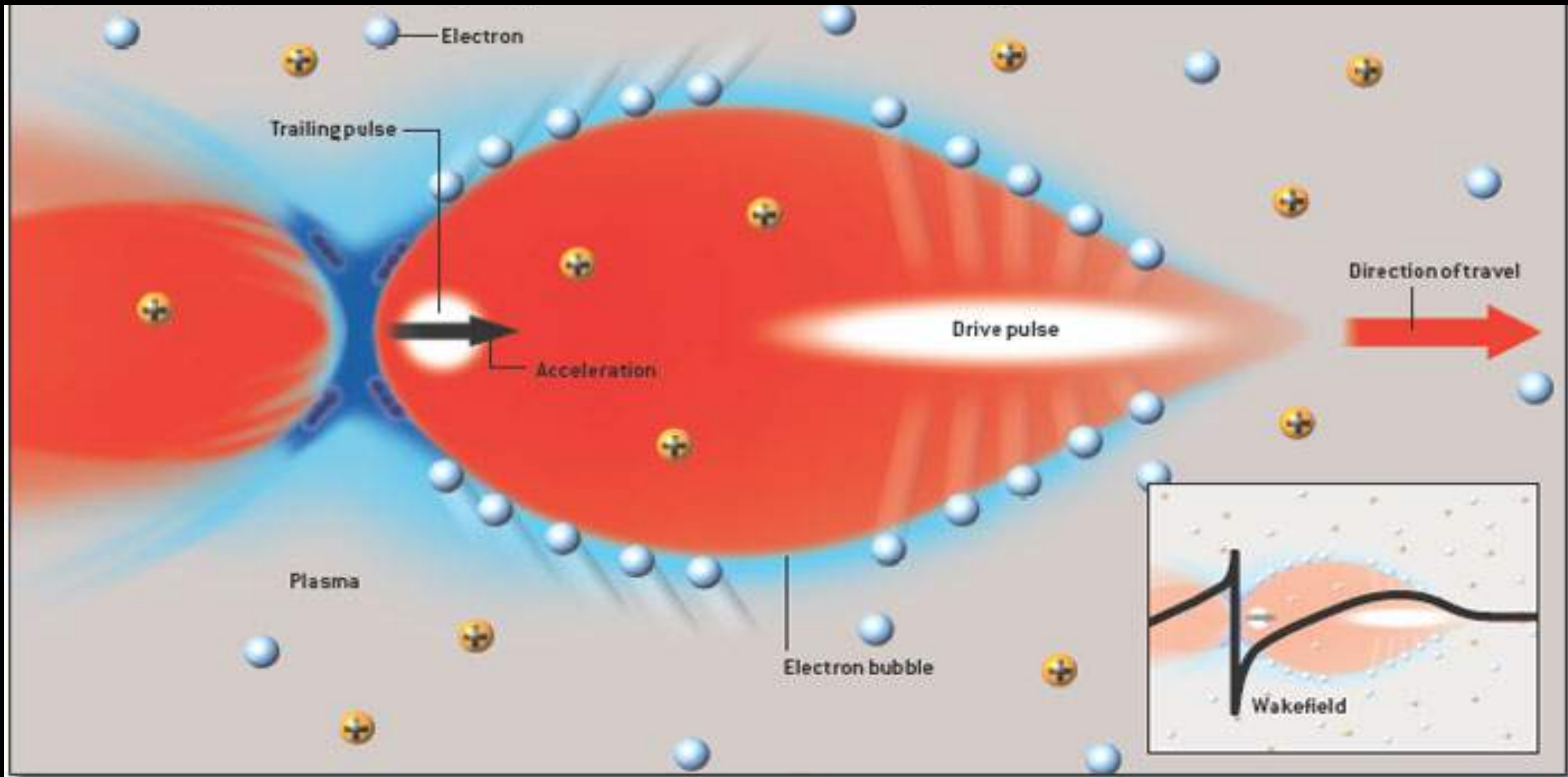


Final amplification stage from ~600 mJ to 6J

Energy	6 J
Duration	23 fs
Wavelength	800 nm
Bandwidth	60/80 nm
Spot @ focus	10 µm
Peak Power	300 TW
Contrast Ratio	10^{10}

Plasma Wake Field Acceleration



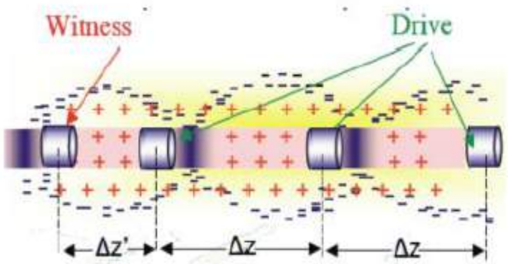


Breakdown limit?

$$E_0 = \frac{m_e c \omega_p}{e} \approx 100[\frac{GeV}{m}] \cdot \sqrt{n_0[10^{18} cm^{-3}]}$$

Plasma Wake Field Acceleration

resonant-PWFA



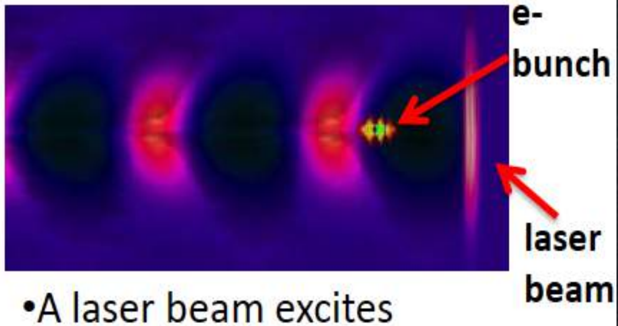
•A train of three electron bunches (driver bunches) is sent through a capillary discharge

•A resonant plasma wave is then excited in plasma

•A fourth electron beam (witness beam) uses this wave to be accelerated

n_e = 2x10^{16} cm^{-3}
λ_p = 300µm
Capillary 1mm
Hydrogen

external injection LWFA

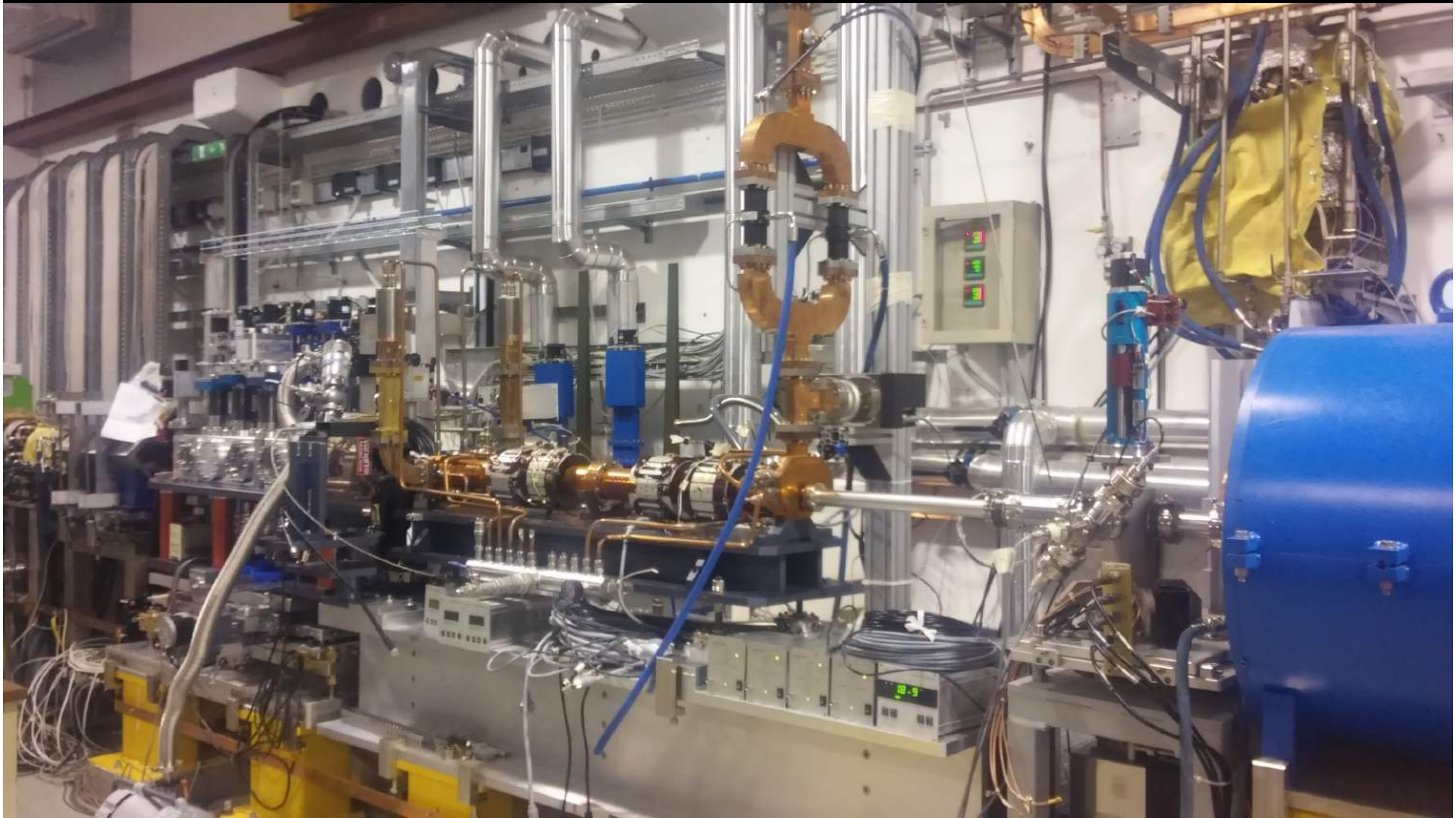


•A laser beam excites plasma waves in a capillary filled with gas

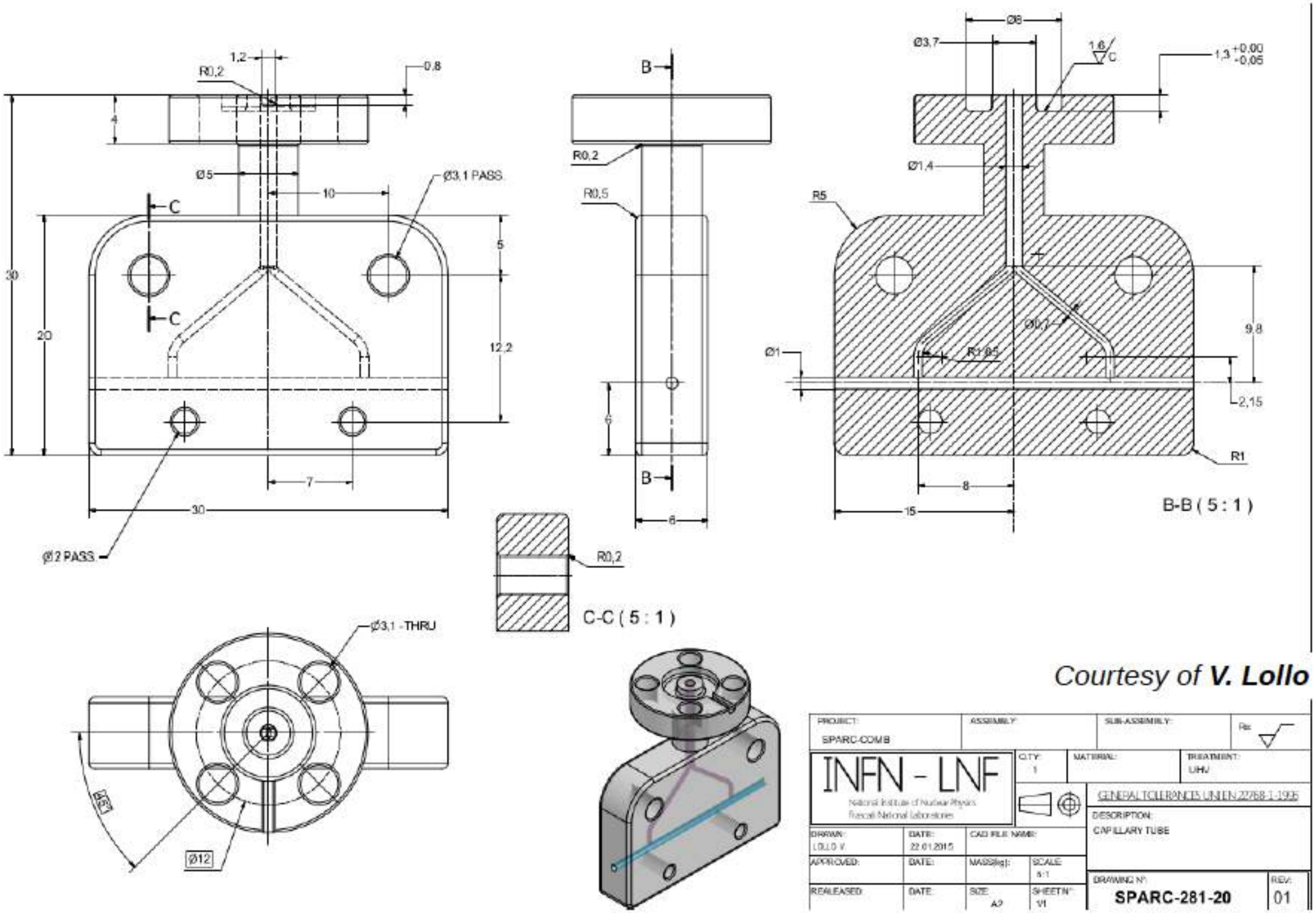
•A high brightness electron beam uses this wave to be accelerated

n_e = 1x10^{17} cm^{-3}
λ_p = 100µm
Capillary 100 µm
Hydrogen

C-Band accelerating structure and PWFA chamber

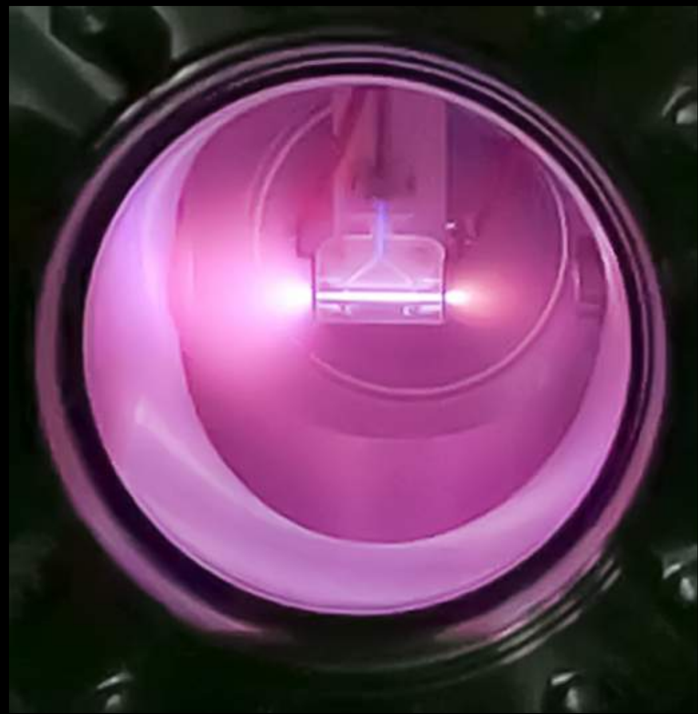


Plasma capillary

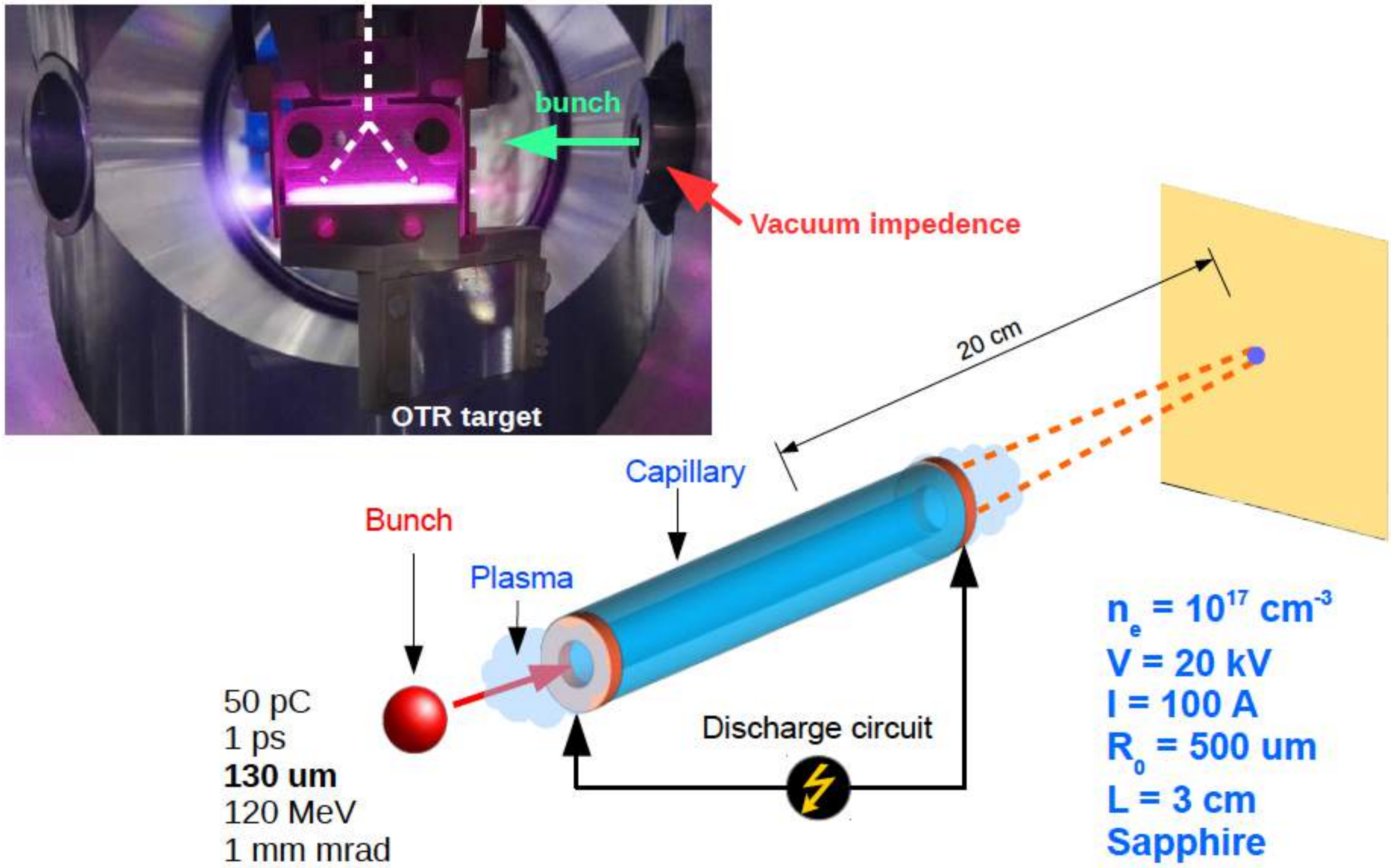


Courtesy of ***V. Lollo***

First Capillary Discharge (Oct. 23 - 2015)



Experimental layout

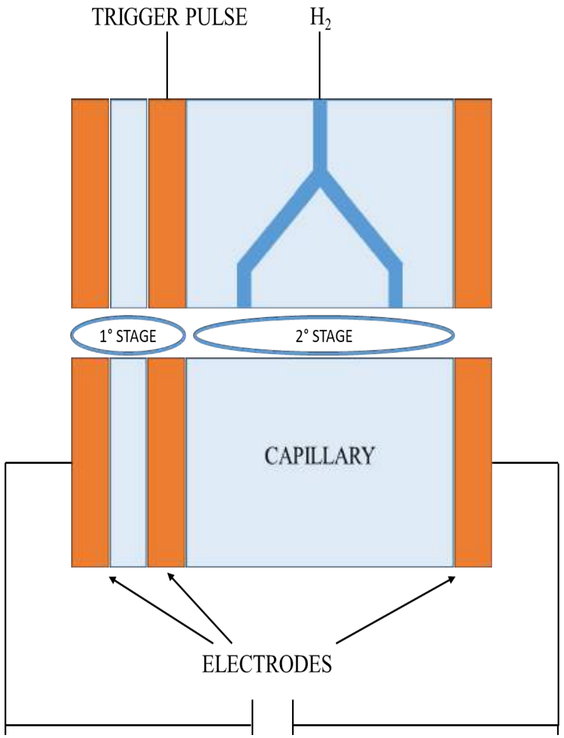


Beam Manipulation

Plasma source

We preionize the capillary with a preformed plasma prior the main discharge. The initial plasma is formed in a short primary capillary by a high voltage pulse discharge. Part of this plasma and free electrons expanding into a long capillary that is connected to a high voltage capacitor. Since the discharge process follows the Paschen law, the breakdown threshold of the long capillary is lowered and the discharge can develop.

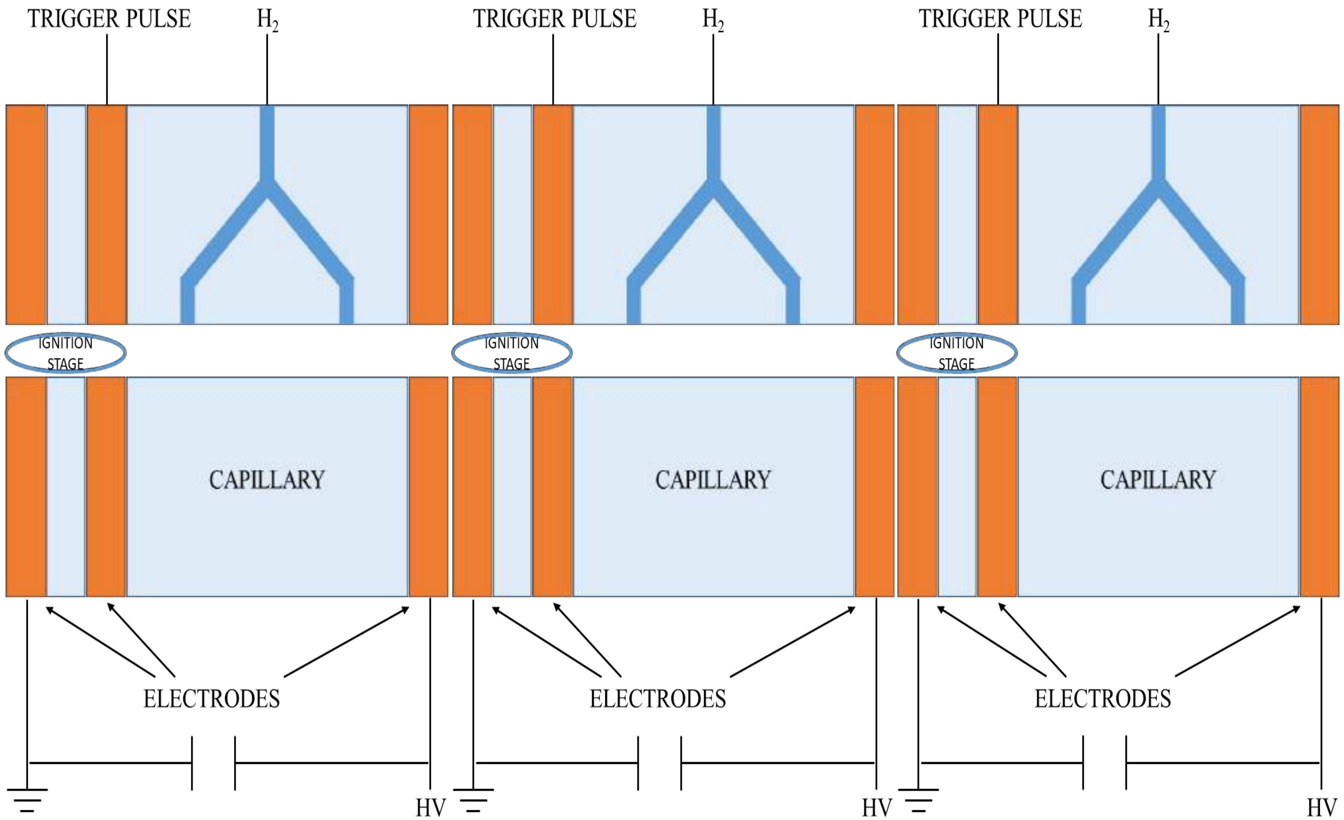
This strategy allow to ionize long capillaries with reasonable applied voltage in controlled and homogeneous way.



F. Filippi, "Gas-filled capillary discharge for tens-centimetre long plasma channel", Poster, Today

Plasma source

This scheme can be reproduced for tens-of-centimetre capillaries. This single unit can be integrated simply by adding more units obtaining up to tens of centimetre capillaries homogenously ionized and controlled independently one to each other, leading to the desired length of plasma (almost 30 cm) with the proper density (10^{17} cm^{-3}) required for this project.

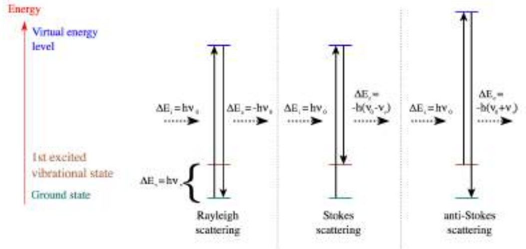


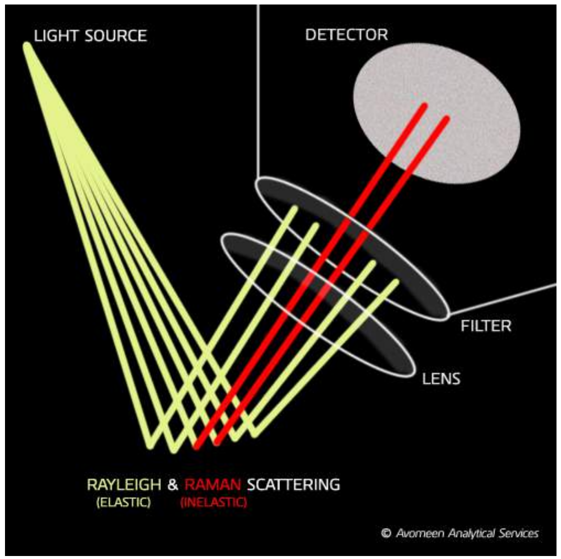
F. Filippi, “Gas-filled capillary discharge for tens-centimetre long plasma channel”, Poster, Today

In laboratorio / offline

Supervisor: Francesco Filippi

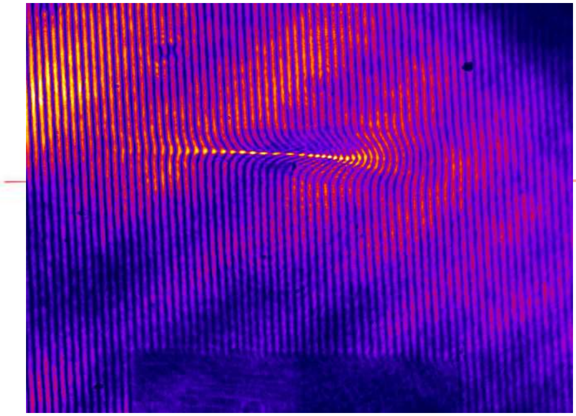
- “*Studio di flussi di gas neutro in un capillare con la tecnica del Raman scattering*”
  - simulazioni idrodinamiche con OpenFOAM
  - parte sperimentale col Raman
- Cosa si impara?
  - Codice idrodinamico OpenFOAM
  - interazione laser-plasma
- Cosa si deve conoscere
  - Basi di fisica del plasma





L. Schaper et al., NIM A ***740****, 208–211 (2014)*

enrica.chiadroni@lnf.infn.it



In laboratorio / offline

Supervisor: Francesco Filippi

- "*Misure di interferometria per studiare la distribuzione di densità di plasma in un capillare*"
  - implementazione di un interferometro Mach-Zehnder nella nuova cameretta per misurare la densità di plasma e la sua distribuzione trasversa"

    *A. J. Gonsalves et al., PRL **98**, 025002 (2007)*
  - programma di acquisizione e analisi in Labview
- "*Implementazione di un sistema online di misura di densità di plasma con Stark broadening*"
  - programma di analisi con Labview: cross-check con spettri simulati

    *F. Filippi et al., JINST **11**, C09015 (2016)*

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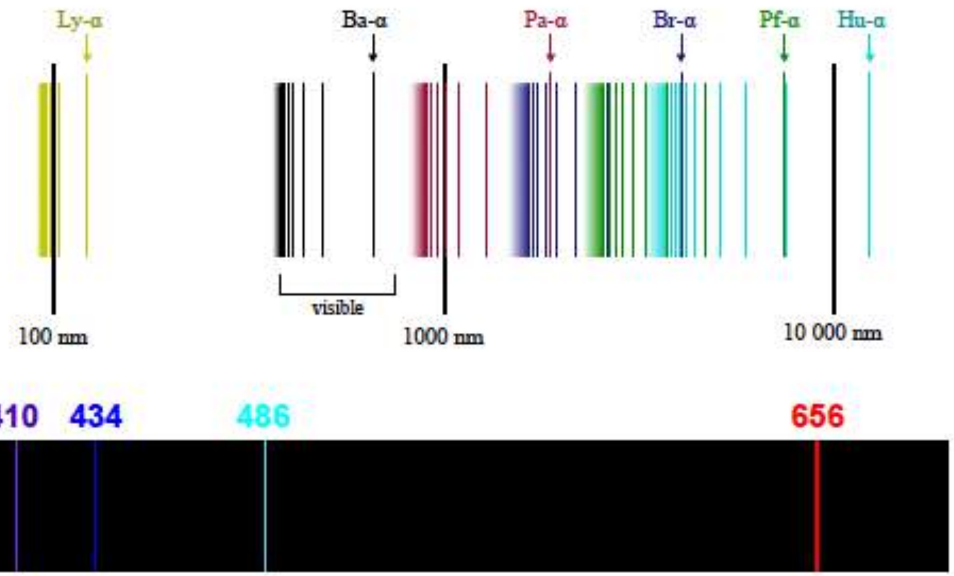
Stark broadening diagnostics

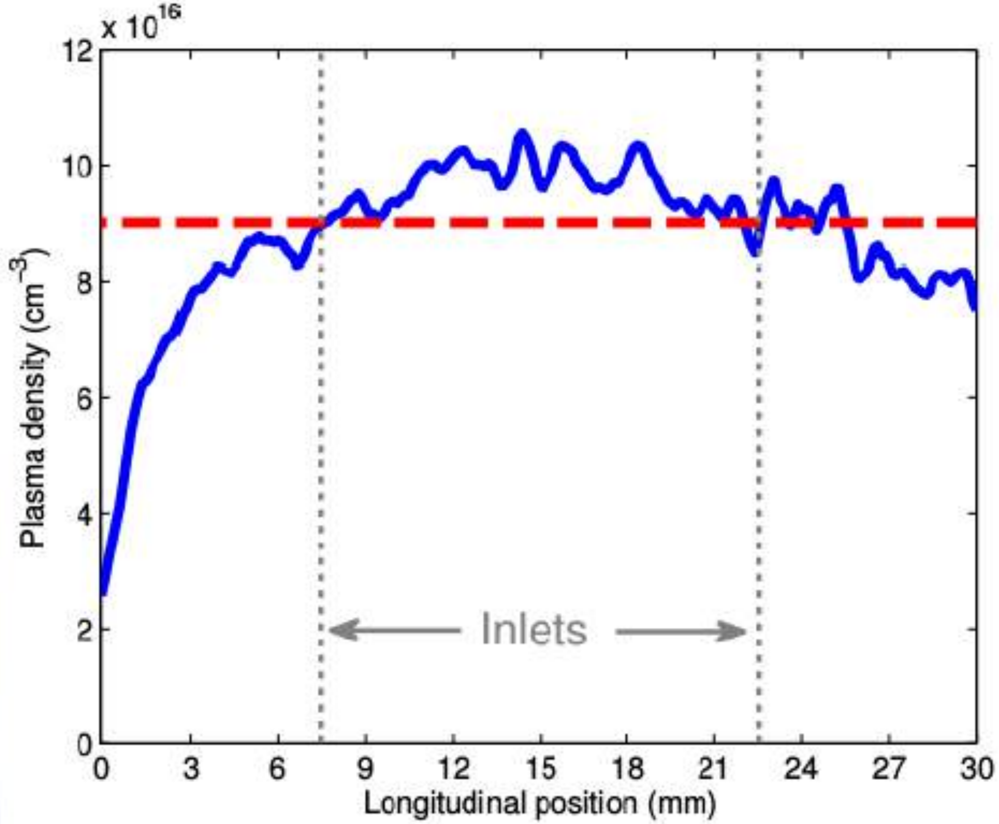


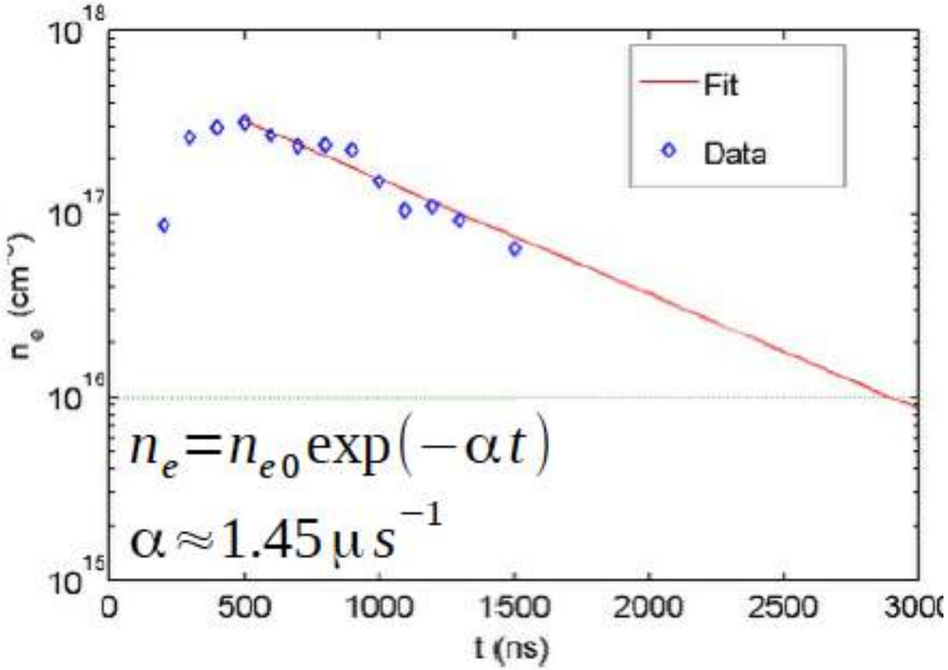
Hydrogen emission spectrum lines in the Balmer series

- Based on the **light emitted by plasmas** → measure of **electron plasma density**
- Plasma density can be determined by means of **Stark broadening effect**
  - *Spectral lines of Hydrogen are broadened as a result of the emitter interaction with the electric field produced by nearby ions.*
- The line-width is directly related to the plasma density → $\Delta\lambda \propto \alpha(T)\, n_0^{2/3}$
  - For Hydrogen, the H_β line (486 nm) is usually used → **α** is *less temperature dependent*.

Plasma characterization in capillary

Plasma density measurement from H_β Stark broadening



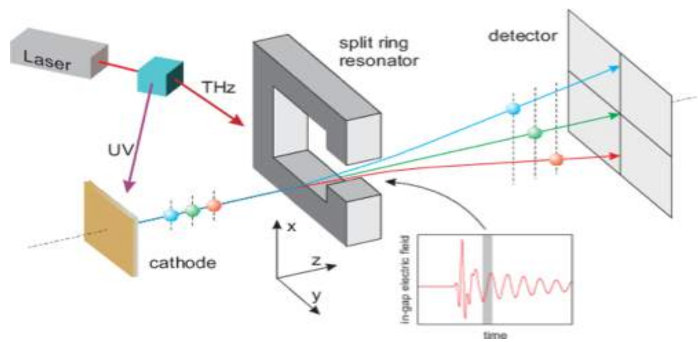


The plasma density is controlled through the delay after the discharge

Simulazioni

Proposer: Enrica Chiadroni

- "*Bunch length measurement with a fs resolution THz streaker at SPARC_LAB*"
  - Review of the state-of-the-art of laser-based THz generation
  - Study and set-up of the THz generation scheme with the SPARC_LAB photo-cathode laser to drive
  - Design of the structure (split ring resonator), suitable for SPARC_LAB case
  - Start-to-end simulations to the define the working point (charge, energy, energy spread, …) to optimize the temporal resolution preserving the beam quality and guiding the experiments
    - Implementation in the SPARC linac and experimental tests with the beam
- Cosa si impara?
  - Generazione THz da laser
  - Dinamica dei fasci di elettroni di alta brillanza
  - Codici di simulazione (ad es. General Particle Tracer)
- Cosa si deve conoscere?
  - Basi di fisica degli acceleratori



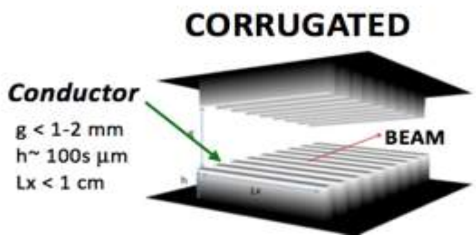
J. Fabianska et al., Scientific Reports **4**, *5645 (2014)*

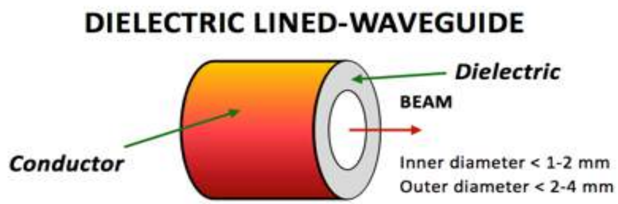
enrica.chiadroni@lnf.infn.it

Teoria / Simulazioni

Proposer: Andrea Mostacci

- *"Bunch length measurement with passive streaking at SPARC_LAB"*
  - review the pricniple of corrugated beam pipe and the dielectric lined (**wakefields**) dechirping or streaking
    - 3D design (**CST or HFSS**) of a device capable to streak the plasma accelerated beam at SPARC_LAB
      - practical implementation issues (vacuum, high precision movements, thermal budget control, …)
    - in the framework of assessed beam dynamics simulation tools (e.g. **TSTEP, ELEGANT or GPT**), perform "virtual measurements" to evaluate the achievable resolution and verify the sub-fs resolution) expected in literature





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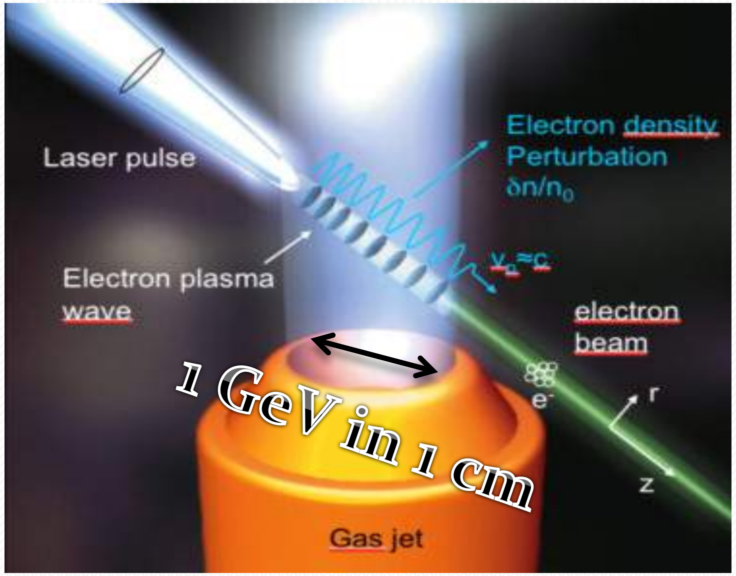
Self-injection with FLAME

Laser wakefield accelerators (LWFA) are a novel type of accelerators capable to produce accelerating field up to 100 GV/m. This feature gives the possibility to have very compact accelerators able to accelerate electrons to GeV energies in few **centimetres**.

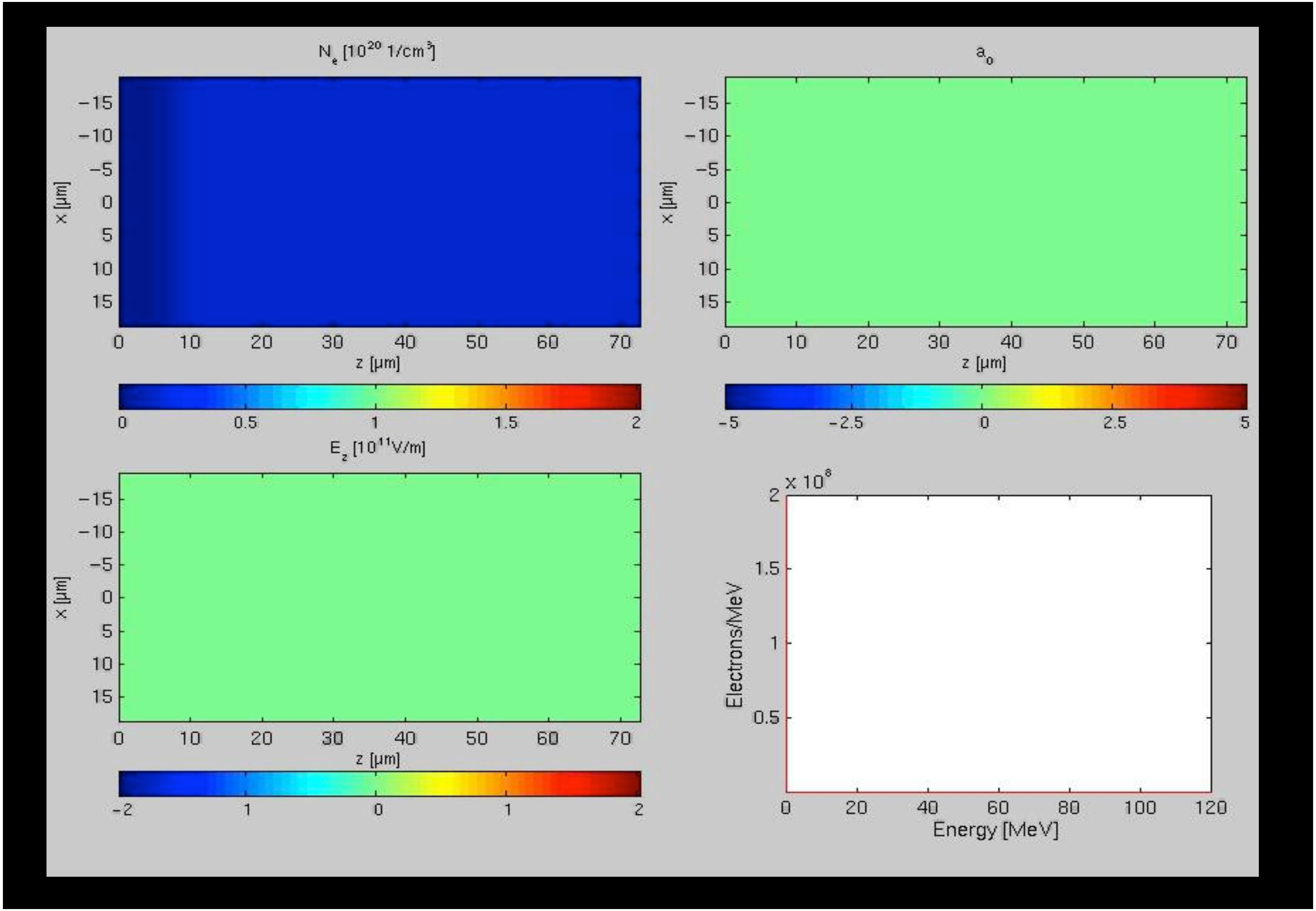


PROS:

1. Costs of the facilities;
2. Compactness: key-word is TABLE TOP!

CONS:

1. Instability of the electron bunches → necessary to study new accelerating structures to control the beam (PWFA?);
2. Quality of the electron bunched are not comparable to that of conventional accelerators → research undergoing.



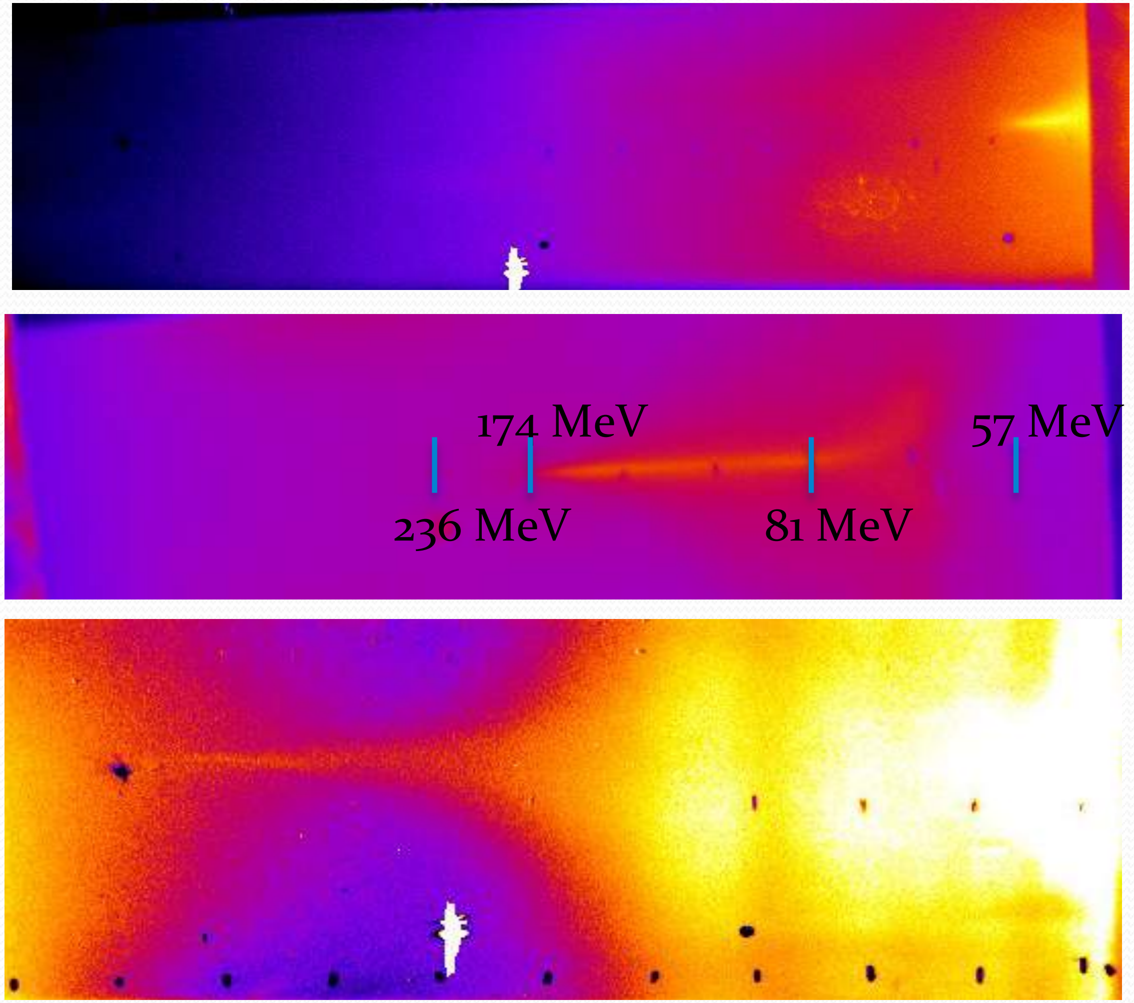
N_e [10^20 1/cm^3]
a_0
x [μm]
z [μm]
E_z [10^11V/m]
Electrons/MeV
x 10^8
Energy [MeV]

Self-injection experiments with FLAME

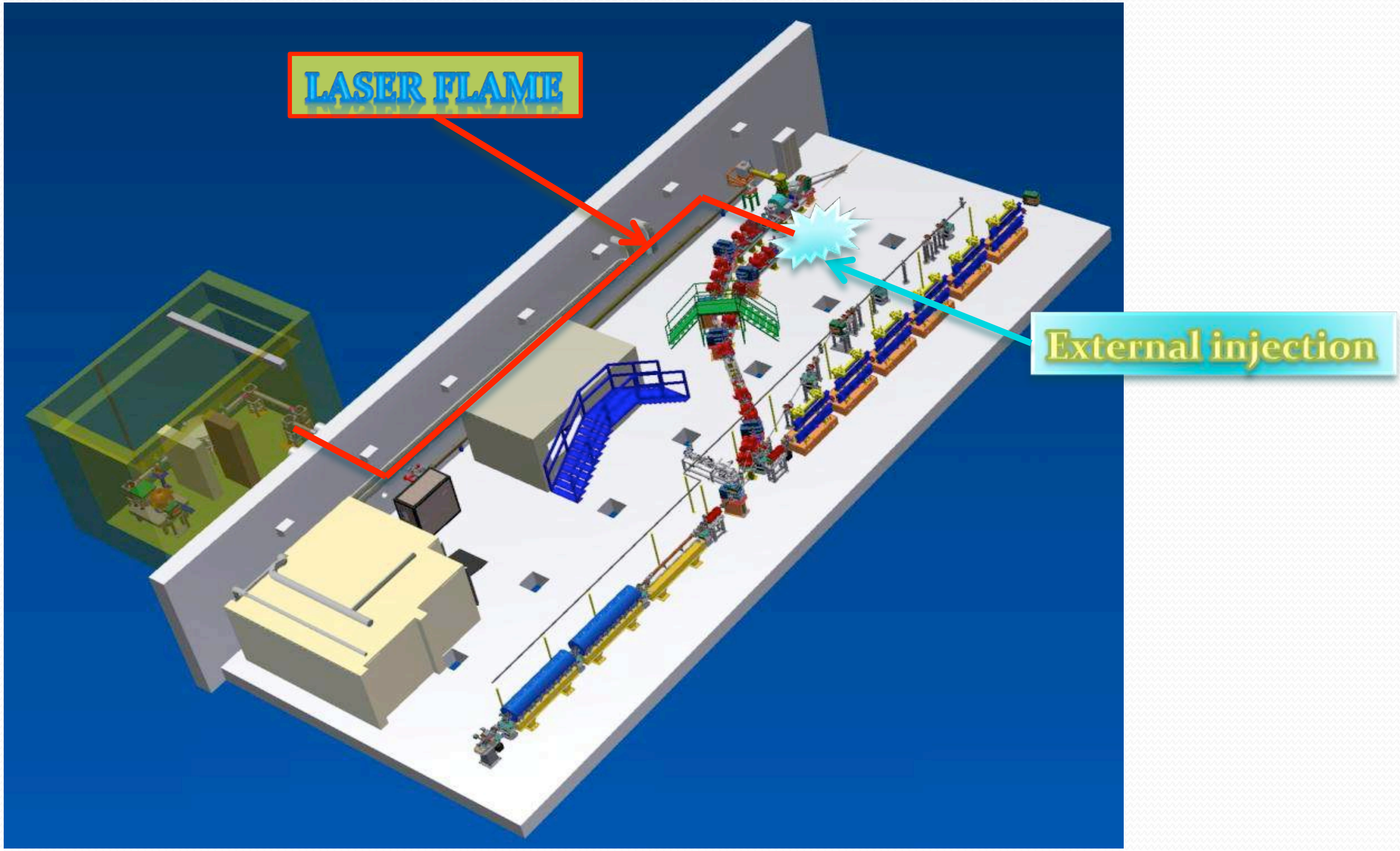
Source optimization and parametric study of the laser and plasma parameters is undergoing.

So for example by scanning the plasma density, electron energy has been varied from 50 MeV, to 175 MeV and up to 300 MeV.

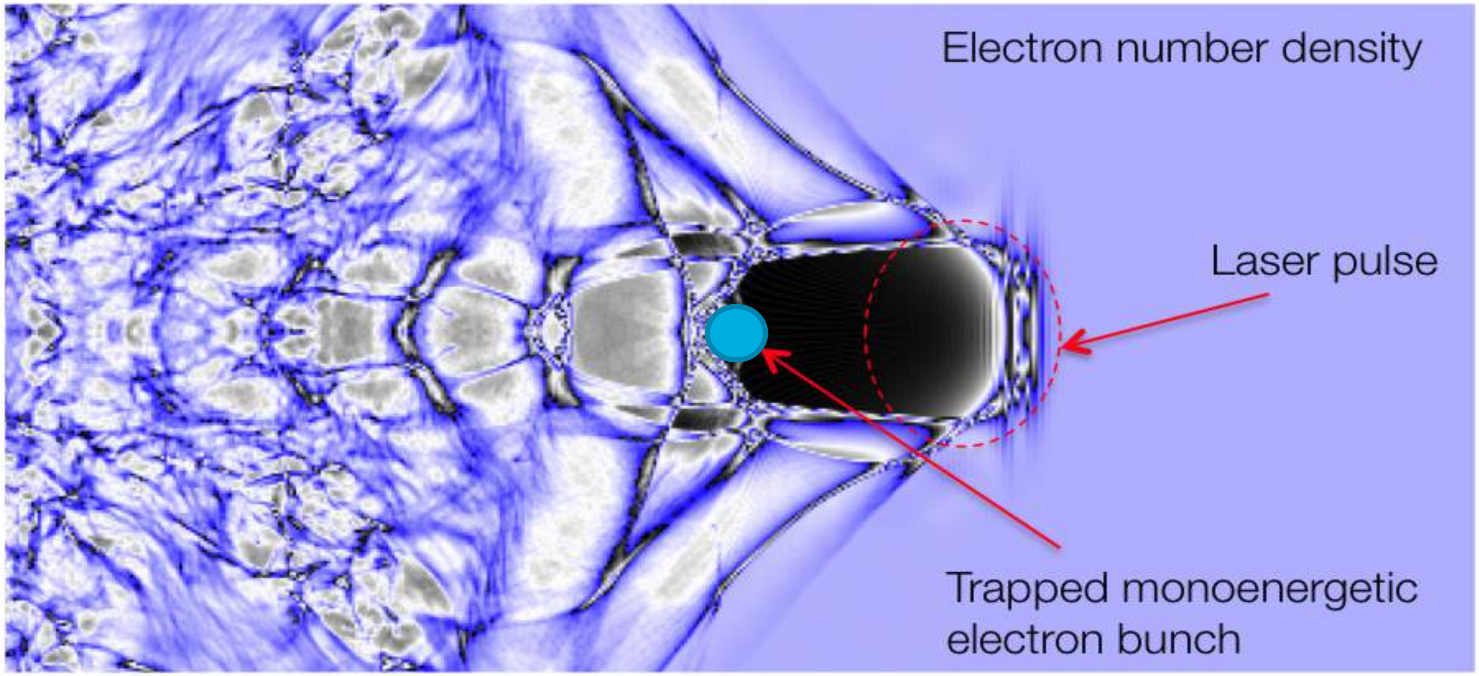
Also by tuning plasma density, energy spread has been reduced from 100% to 20%.



External injection



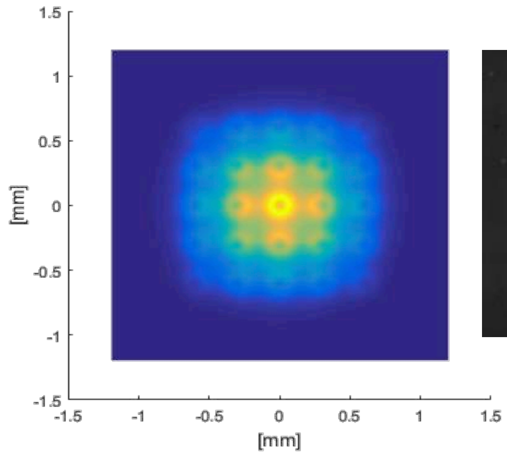
External injection

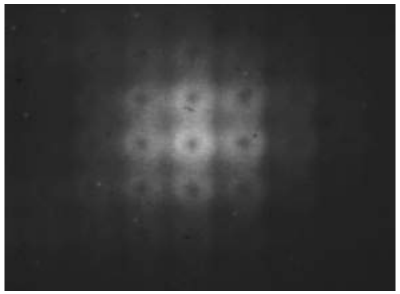


Electrons accelerated by the linac injected with the right phase on the creast of the wakefield to be further accelerated.

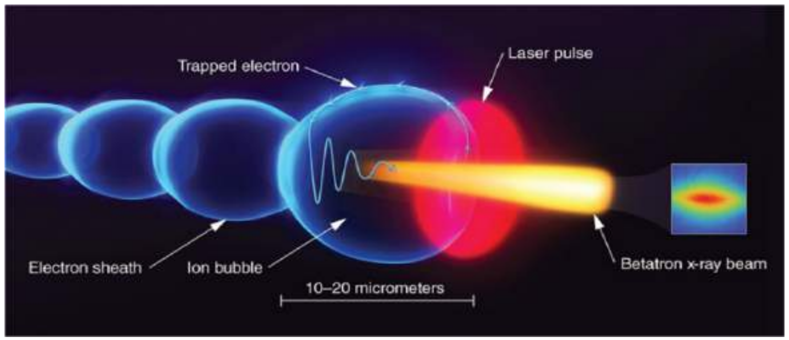
Expected electrons at the plasma exit with a higher energy and a quality comparable to that of incoming electron beam.

Developing diagnostics for plasma accelerators

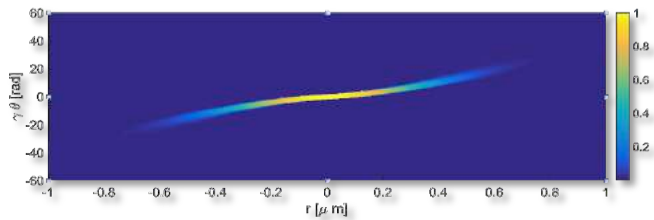




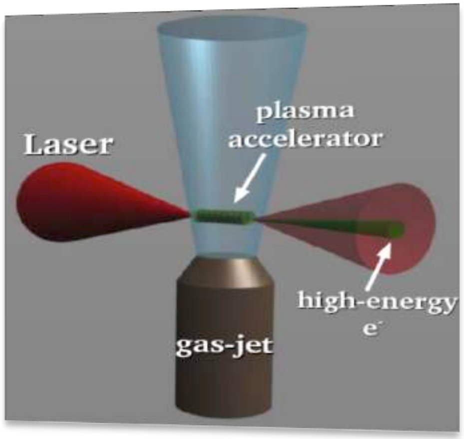
Mapping the transverse phase space by means of microlens array to measure the emittance in single shot



Measuring the Betatron radiation spectrum and electron spectrum to reconstruct the beam phase space inside the plasma bubble



Compact neutron source by laser self injection



$$N \sim 2.5 \cdot 10^9 \frac{\lambda_0 [\mu m]}{0.8} \sqrt{\frac{P[TW]}{100}}$$

Electron scaling law in case of single gas

Electrons generated by self injection can be driven on a high atomic number material in order to produce fast neutrons
Achievable flux comparable to compact accelerated neutron source but dimension on cm scale!!

Great interest in developing this source in a place where are radiation sources are already available, like FEL, Compton, THz, etc.
Foreseen application in cultural heritage studies.

EuPRAXIA

EUROPEAN PLASMA RESEARCH ACCELERATOR WITH EXCELLENCE IN APPLICATIONS

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 653782.

EuPRAXIA@SPARC_LAB

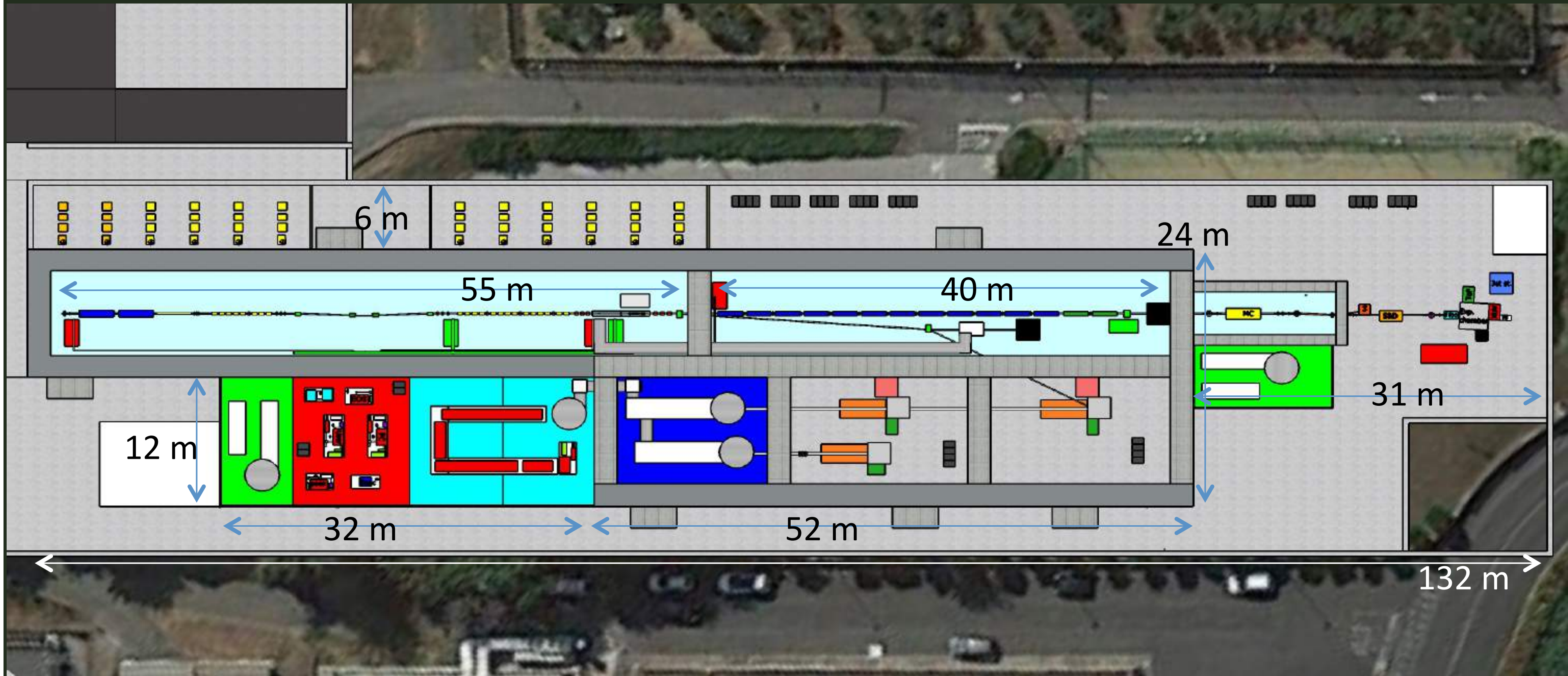
design study towards a new compact FEL facility at LNF

Massimo.Ferrario@lnf.infn.it
On behalf of the study group

Isola d'Elba, 27 September 2017

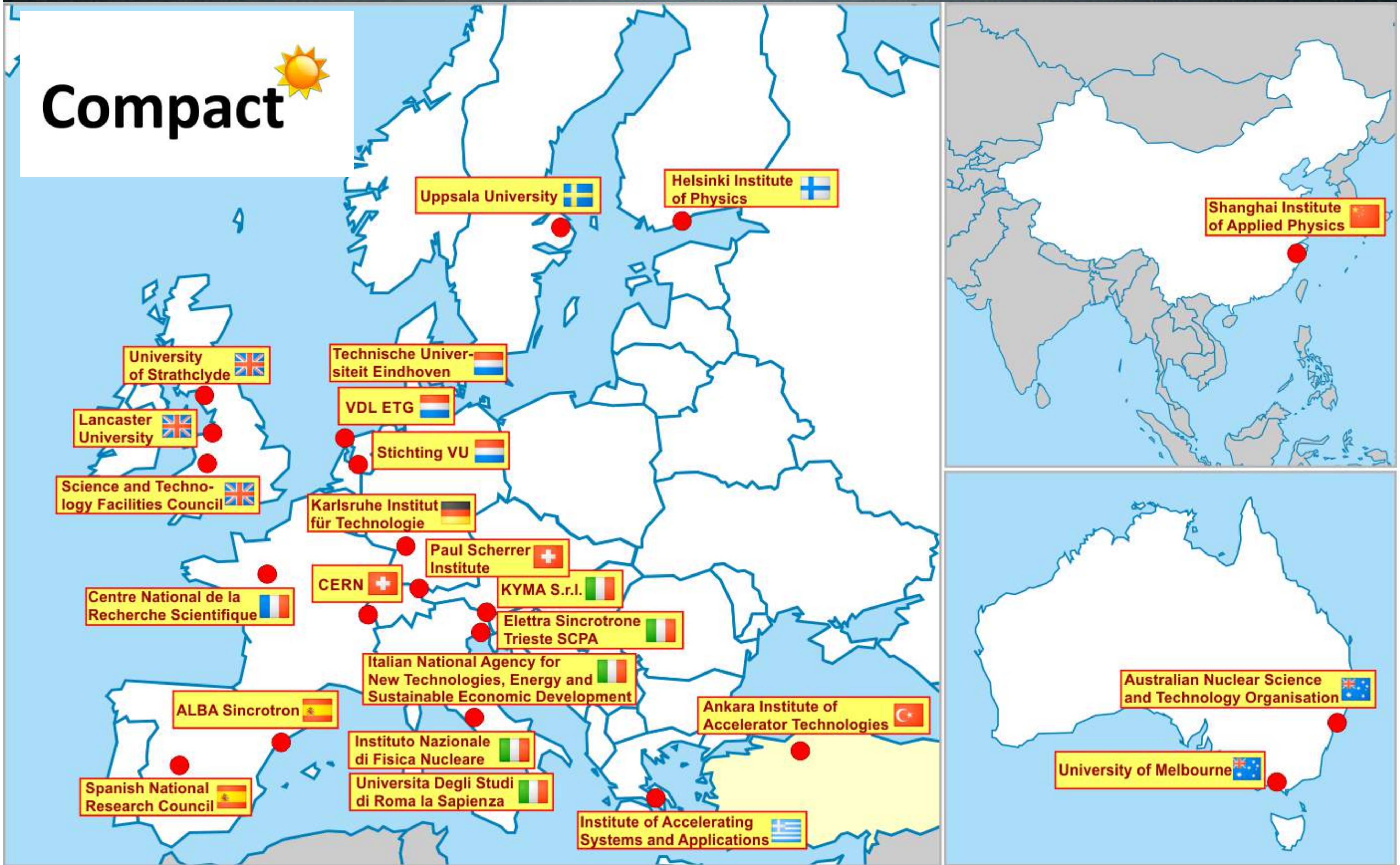
Istituto Nazionale di Fisica Nucleare

- Candidate LNF to host EuPRAXIA (1-5 GeV)
- FEL user facility (1 GeV – 3 nm)
- Advanced Accelerator Test facility (LC) + CERN



- 500 MeV by RF Linac + 500^{+} MeV by Plasma (LWFA or PWFA)
- 1 GeV by X-band RF Linac only
- Final goal compact 5 GeV accelerator

Compact


Uppsala University
Helsinki Institute of Physics
Shanghai Institute of Applied Physics
University of Strathclyde
Technische Universiteit Eindhoven
VDL ETG
Lancaster University
Stichting VU
Science and Technology Facilities Council
Karlsruhe Institut für Technologie
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CERN
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Centre National de la Recherche Scientifique
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Italian National Agency for New Technologies, Energy and Sustainable Economic Development
ALBA Sincrotron
Ankara Institute of Accelerator Technologies
Australian Nuclear Science and Technology Organisation
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Universita Degli Studi di Roma la Sapienza
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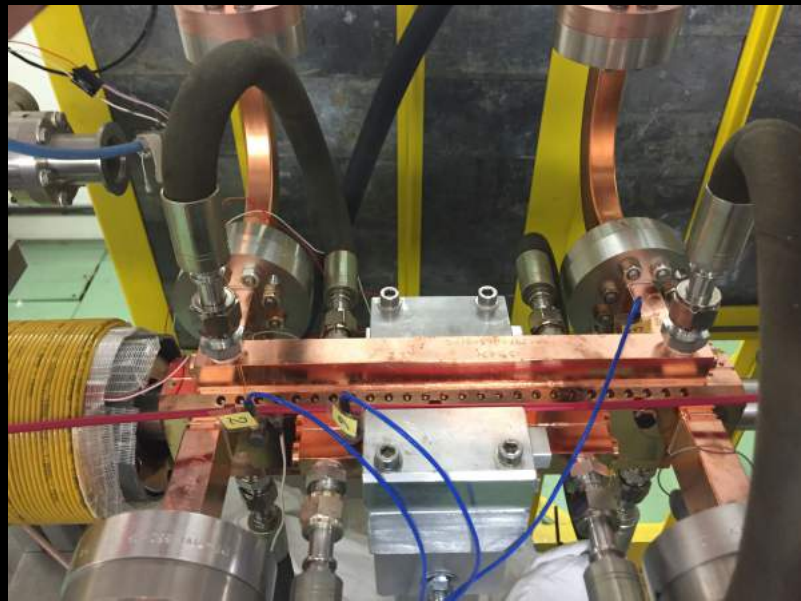
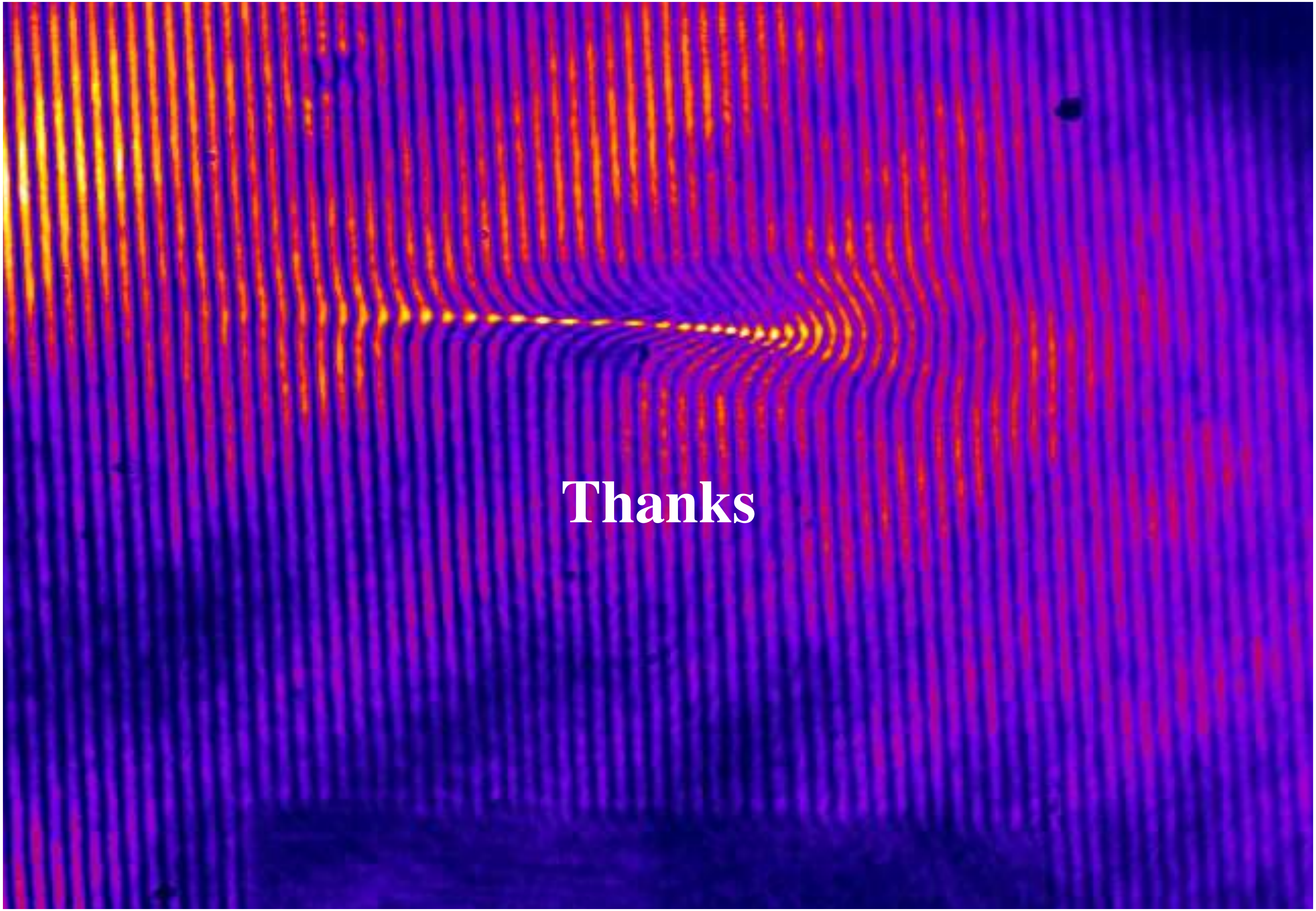
University of Melbourne
Institute of Accelerating Systems and Applications

X-band Linac



M. Diomede, “Preliminary RF design of an X-Band LINAC for the EuPRAXIA@SPARC_LAB project”, Poster, Monday

C. Vaccarezza, ”EUPRAXIA at SPARC_LAB: Beam Dynamics studies for the X-band Linac, WG4, Today


Thanks