From SPARC_LAB to EUSPARC

Massimo Ferrario and the SPARC_LAB team

EUSPARC TDR Working Groups

WG 0 – Project Management (M. Ferrario)
- 0.1 Executive summary

WG 1 – Electron beam design and optimization
- 1.1 Advanced High Brightness Photo-injector (E. Chiadroni)
- 1.2 HB Linac options, design and parameters (A. Gallo)
- 1.3 – Machine layout

WG 2 – Laser design and optimization
- 2.1 FLAME upgrade (M. P. Anania)
- 2.2 Advanced Laser systems (L. Gizzi)

WG 3 – Plasma Accelerator experiments
- 3.1 PWFA beam line (A. Cianchi)
- 3.2 LWFA beam line (A. R. Rossi)
- 3.3 Positron acceleration

WG 4 – FEL pilot applications
- 4.1 Plasma driven FEL (F. Villa)
- 4.2 Advanced FEL schemes (G. Dattoli)
- 4.3 FEL user applications (M. Benfattoi)

WG 5 – Radiation sources and user beam lines
- 5.1 Advanced dielectric THz source
- 5.2 Compton source (C. Vaccarezza)
- 5.3 User beam lines

WG 6 – Low Energy Particle Physics
- 6.1 Advanced positron sources (A. Variola)
- 6.2 Fundamental physics experiments , Labasatro (C. Gatti)
- 6.3 Plasma driven photon collider

WG 7 – Infrastructure
- 7.1 Civil Engineering and conventional plants (U. Rotundo)
- 7.2 Control system (G. Di Pirro)
- 7.3 Radiation Safety (A. Esposito)

To do list

- Identificare una strategia adatta per poterci candidare ad ospitare EUPRAXIA a LNF (piano A)

- Avviare un upgrade delle infrastutture esistenti compatibile con un funzionamemto anche come user facility (piano B)

    - Qualificarci scientificamente con risultati sperimentali di rilievo (LWFA e PWFA) a SPARC_LAB

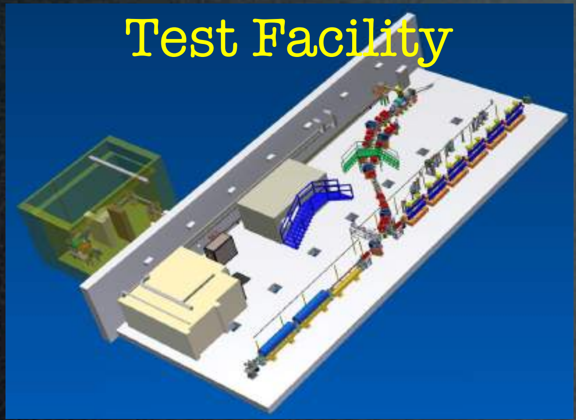
    - Esplorare le infrastrutture disponibili o edificabili a LNF

    - Aggiornare rapidamente la proposal da inviare alla Giunta (entro Gennaio 2016?)

    - *Chiarire l'entita' del possibile finanziamento INFN e delle necessita' di personale.........*

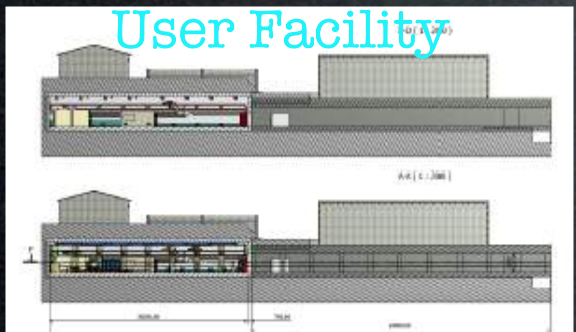
    - Produrre un Technical Design Report (entro Dicembre 2016)

Future SPARC_LAB scenarios



Consolidation: on going, ~3 years

- FLAME maintenance
- Injector upgrade (C-band, X-band)
- THz user beam line upgrade
- Thomson and Plasma beam lines final commissioning
- FEL new short period undulator



Upgrade: proposed, ~5 years

- Infrastructure extension
- Linac upgrade <1 GeV (L-S-C-X-band, multi-bunches)
- FLAME upgrade towards 1 PW
- Plasma, dielectric and high frequency acceleration
- Positron production and acceleration with plasma
- Advanced FEL schemes (oscillator, optical,QFEL?)
- THz, Compton and FEL user beam lines
- AND RELIABILITY !!!!

European Facility, ~10 years, ~200 M€

- Plasma based FEL Pilot User Facility
- Plasma based HEP beam line

June 25, 2016

Report on the EUSPARC design study at LNF

(European Source for Plasma Accelerators and Radiation user Communities)

Massimo.Ferrario@LNF.INFN.IT
on behalf of the SPARC_LAB - EUSPARC collaboration

1 - INTRODUCTION

It is widely accepted by the international scientific community that a fundamental milestone towards the realization of a plasma driven future Linear Collider (LC) will be the integration of the new high gradient accelerating plasma modules in a short wavelength Free Electron Laser (FEL) user facility. The capability of producing the required high quality beams and the operational reliability of the accelerator modules will be certainly certified when such an advanced radiation source will be able to drive external user experiments, with the added value of unique photon beam characteristics (ultra-short photon pulses).

EuPRAXIA ("European Plasma Research Accelerator with eXcellence In Applications"), the approved Horizon 2020 European Design Study, is supposed to be a Large Research Infrastructure certainly beyond the capabilities of a single lab. As stated in the EuPRAXIA proposal (INFRADEV-1-2014): "It is supposed to bring together for the first time *novel acceleration schemes, modern lasers, the latest correction/feedback technologies and large-scale user areas*. It is of significant size, but significantly more compact than a conventional 5 GeV beam user facility. If the design study will be successful, EuPRAXIA could be constructed in the early 2020's. It would be the required intermediate step between proof-of-principle experiments and ultra-compact accelerators for science, industry, medicine or the energy frontier ("plasma linear collider"). Such a research infrastructure would achieve the required quantum leap in accelerator technology towards more compact and more cost-effective accelerators, opening new horizons for applications and research.

The EuPRAXIA design study will cover three major aspects:

- The technical focus is on designing accelerator and laser systems for improving the quality of plasma-accelerated beams.
- The scientific focus is on developing beam parameters, two user areas and the use cases for a femto-second FEL and High Energy Physics (HEP) detector science.
- The managerial focus is on developing an implementation model for a common European plasma accelerator. *This includes a comparative study of possible sites in Europe, a cost estimate and a model for distributed construction in Europe and installation at one central site.*"

If the proposed SPARC_LAB upgrade, named EUSPARC and discussed in the following paragraphs, will be completed within the next 6 years, we believe it will be possible to strongly candidate LNF to host the EuPRAXIA European Facility.

In order to meet the EuPRAXIA requirements some important preparatory steps must be set up at LNF:

- Consolidating the existing infrastructure in order to qualify SPARC_LAB with significant experimental results in the field of plasma accelerators and FEL.
- Consolidating in the very short term the existing expertise with staff positions for at least: 3 accelerator researchers (Plasma, Diagnostics and FEL Physics), 2 high power laser experts and 2 laser technicians.
- Investigating the availability of a large infrastructure at LNF or build a new experimental hall able to host the EUSPARC facility.
- Provide within one year a Conceptual Design Report with a scientifically exciting program for EUSPARC itself.

A number of significant improvements of the existing SPARC_LAB facility are underway, mainly funded by MIUR via the EUROFEL_MIUR and "Premiale" contracts with an additional INFN contribution:

- FLAME maintenance and consolidation up to the nominal 300 TW power,
- Injector upgrade for ultra-high brightness beams with a new RF gun,
- THz user beam line installation in the upper aisle,
- Thomson and External injection plasma beam lines final commissioning and operation,
- FEL short period undulator test and R&D on RF and optical alternatives including Quantum FEL studies.

In parallel to the facility consolidation actions listed above, a number of significant experiments are foreseen with the existing SPARC_LAB facility, focused in achieving some of the fundamental requirements enabling the EuPRAXIA program. Within the next 5 years the SPARC_LAB Work Program foresees:

WP_1 - Adiabatic plasma lenses

WP_2 - Energy spread de-chirper

WP_3 - Plasma driven UV FEL test experiment

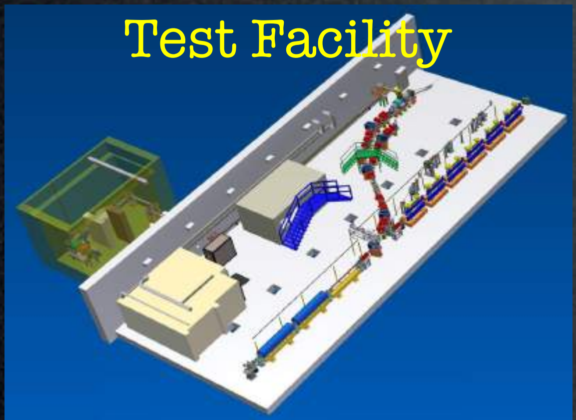
WP_4 - Laser Plasma Acceleration with external inj.

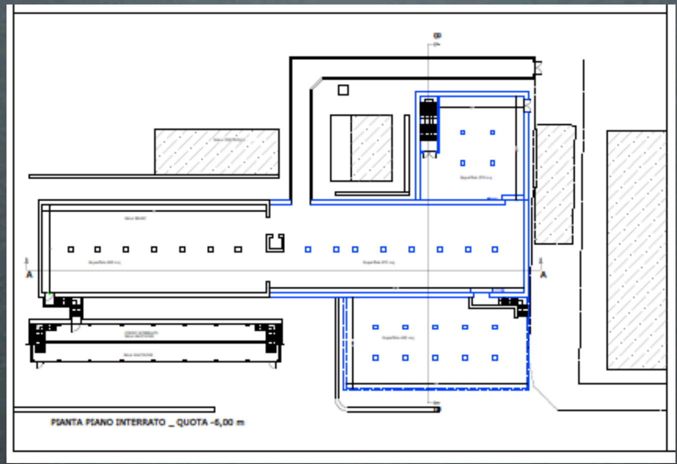
WP_4b - Laser Plasma Acceleration with self- injection

WP_5 - Laser Plasma Acceleration staging

WP_6 – Optimization of plasma channels

Civil Engineering options





4 - EUSPARC SCIENTIFIC PROGRAM

The EUSPARC scientific program has three main directions:

- High gradient acceleration techniques for the next FEL and e+e- collider generations.
- Advanced radiation sources for photon science (FEL, Betatron, Compton, Channeling).
- Physics of high field interactions with matter.

The main required actions enabling the accomplishment of such a program are:

- The FLAME laser upgrade up to 1 PW
- The RF Linac upgrade up to 1 GeV

FLAME at present

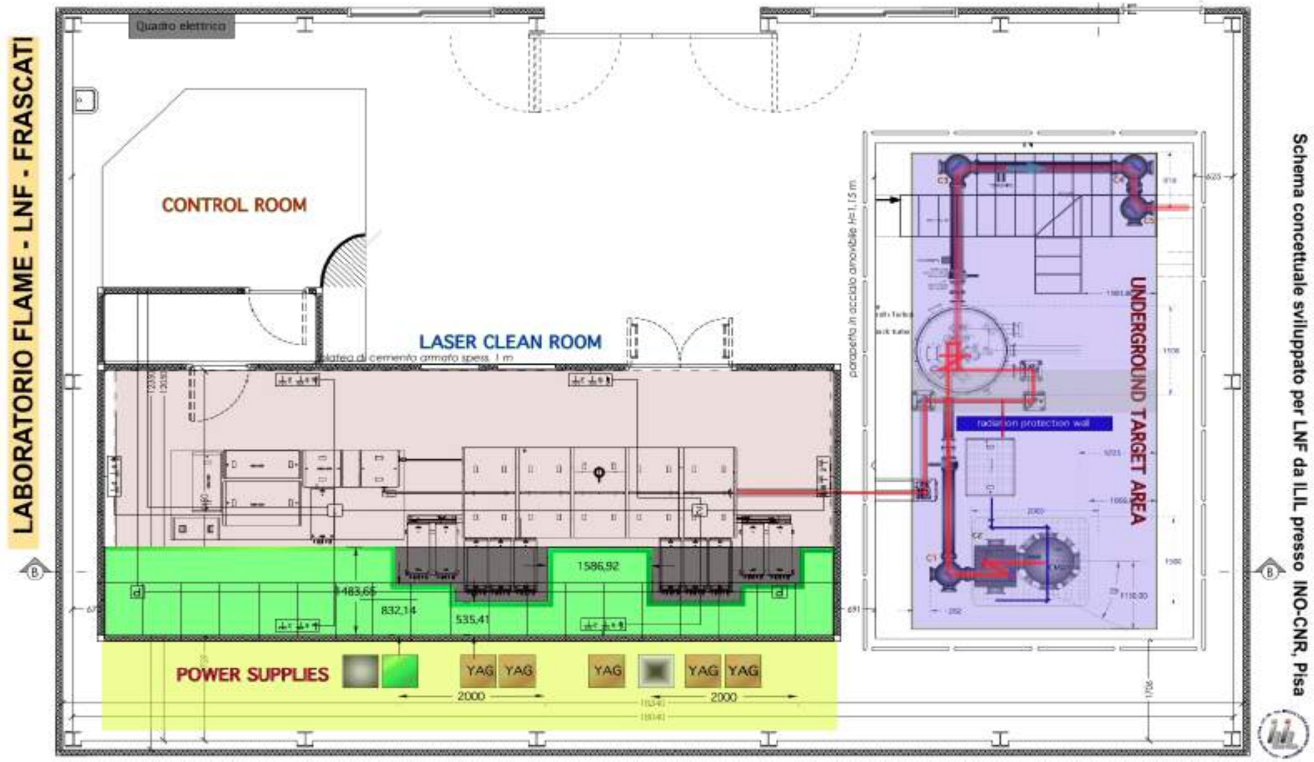


Figure 1: Current Layout of the Flame building showing the Laser, underground target area and the transport line to the Sparc bunker.

FLAME Upgrade

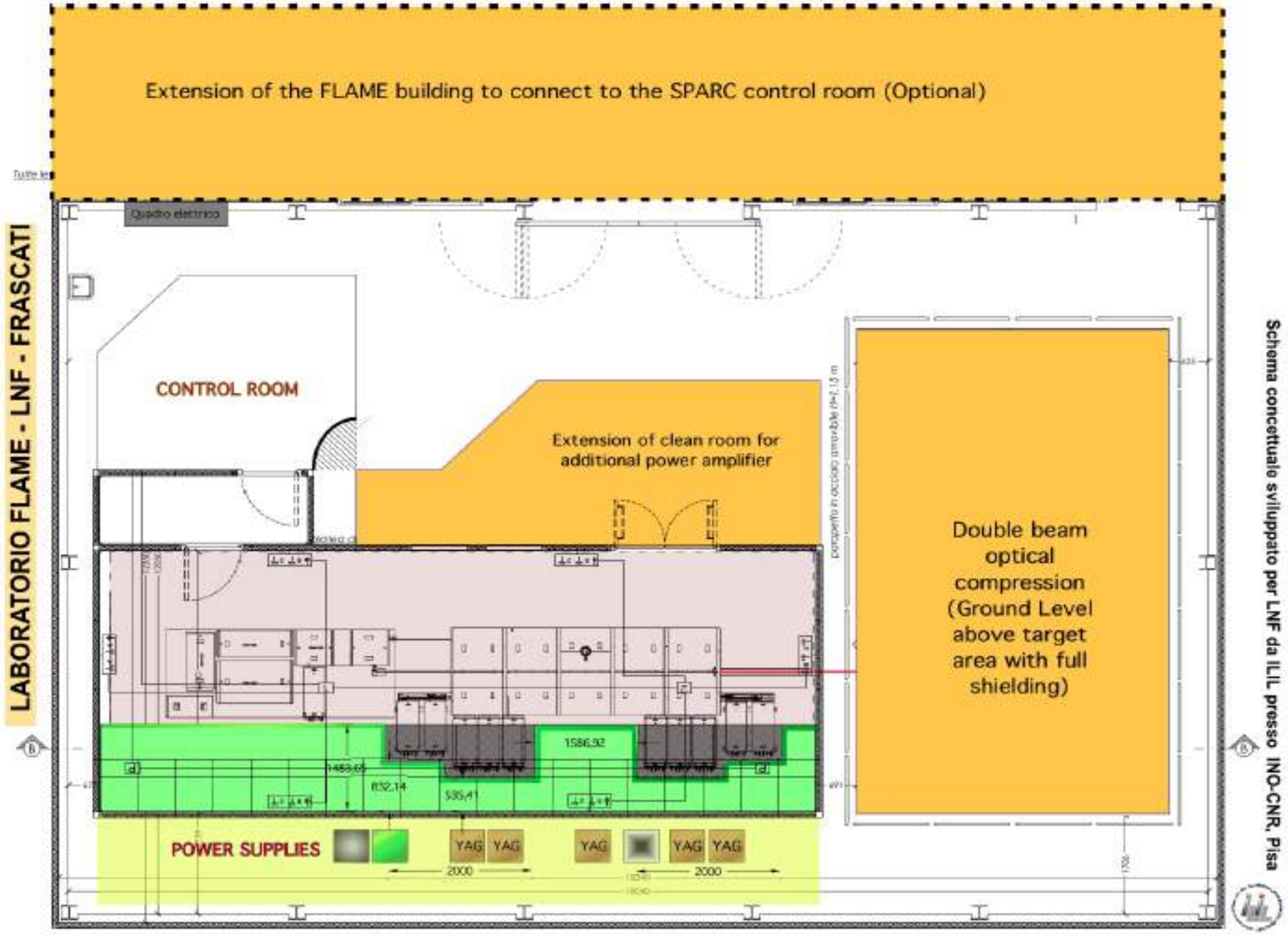


Figure 2: Layout of the upgraded Flame building, with the ground floor layout including the extension of the clean room and the dual compressor room. An optional extension of the Flame building is also planned to allow a better connection with the present Sparc control room building.

LINAC Upgrade

SPARC (10 m)

Linac (25 m)

Plasma (5 m)

Ondulatori (25 m)

Ottica (20 m)

Utenti (20 m)

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2021
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SPARC_LAB Consolidation
FLAME maintenance and consolidation up to 300 TW
LWFA staging tests at FLAME
Thomson beam line final commissioning
Exin beam line final commissioning and operation
LWFA with external injection
LWFA staging tests with external injection
RF injector upgrade
THz user beam line upgrade
Plasma Lens
High quality Beam acceleration PWFA
Beam transport to FEL
Plasma driven FEL studies
Advanced undulators studies
SPARC_LAB users operation
EUSPARC
Machine Conceptual Design Report
Machine Technical Design Report
New building design
New building authorisation requests
New building tender
New building construction
FLAME upgrade tender
FLAME upgrade installation
FLAME commissioning to 1 PW
FLAME installation in the new building
LINAC upgrade tender
LINAC RF tests
LINAC and SPARC_LAB installation in the new building
EuPRAXIA
Design Study
Preparatory Phase

FLAME Upgrade

Basic parameters of the two beams of the Flame upgrade.

Beam n.	Pulse Duration	Pulse Energy	Contrast (ps)	Rep Rate
Beam 1 (0.2PW)	17 fs	3.5J	1E12	10Hz
Beam 2 (PW)	20 fs	20J	1E13	1Hz

The following steps can be identified in the overall Flame upgrade.:

1) upgrade of the front-end (currently 0.5J) to higher energy (>1J) and short <15 fs pulse duration;
2) Upgrade of the existing main amplifier for beam 1 at ≈1 PW;
3) Installation of a new amplifier for beam 2 at 0.2 PW;
4) Upgrade (and relocation) of the new compressor for beam 1;
5) Installation of a new compressor set-up for beam 2;
6) New layout of the target area, including fully shielded ceiling and dual beam target chamber as shown in the Figure 3 below.

FLAME Upgrade

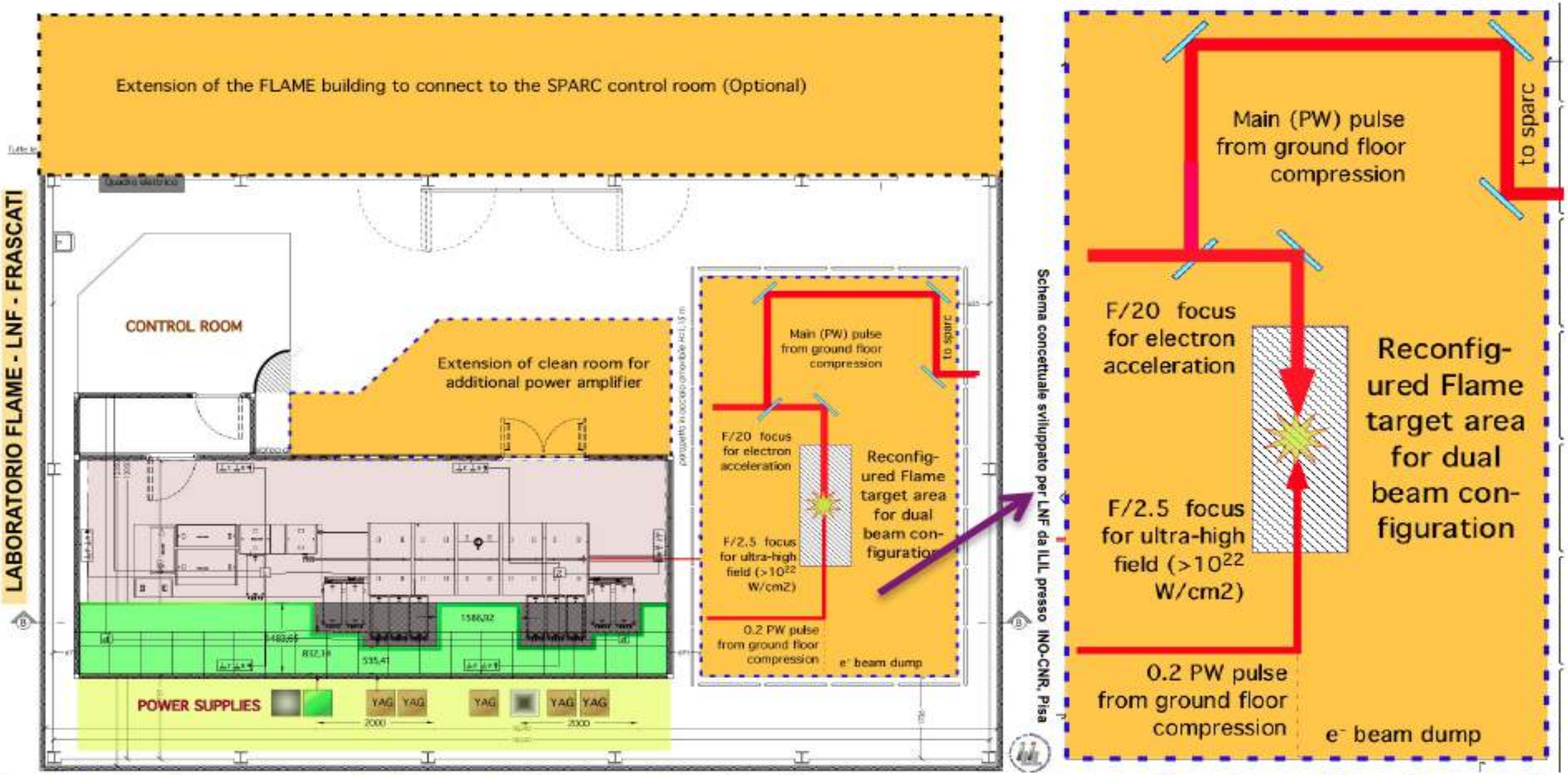

Figure 3. Layout of the **undergoround** flame target area, showing the interaction chamber after reconfiguration with the new dual-beam configuration.

In the scenario in which the EuPRAXIA facility will be built in another European country, LNF will be anyway equipped with a new infrastructure based on a combination of a high brightness GeV-range electron beam and a PW-class laser system (similar to the FACET user facility planned at SLAC). These unique features will enable new, very promising synergies between fundamental-physics-oriented research and high-social-impact applications. EUSPARC is in fact conceived as an innovative and evolutionary tool for multi-disciplinary investigations in a wide field of scientific, technological and industrial applications, it could be *progressively* extended to be a high brightness "particle beams factory". It will be able to produce a high flux of electrons, photons (from infrared to γ-rays), protons and positrons, that will be available for a wide national and international scientific community interested to take profit of advanced particle and radiation sources.

We can foresee a large number of possible activities, among them:

- Science with Free Electron Lasers (FEL),
- Nuclear photonics with Compton back-scattering γ-rays sources,
- Quantum aspects of beam physics including the Quantum-FEL development,
- Science with THz radiation sources,
- Physics with high power/intensity lasers,
- R&D on advanced accelerator concepts including plasma accelerators and polarized positron sources
- R&D in accelerator physics and industrial spin – off