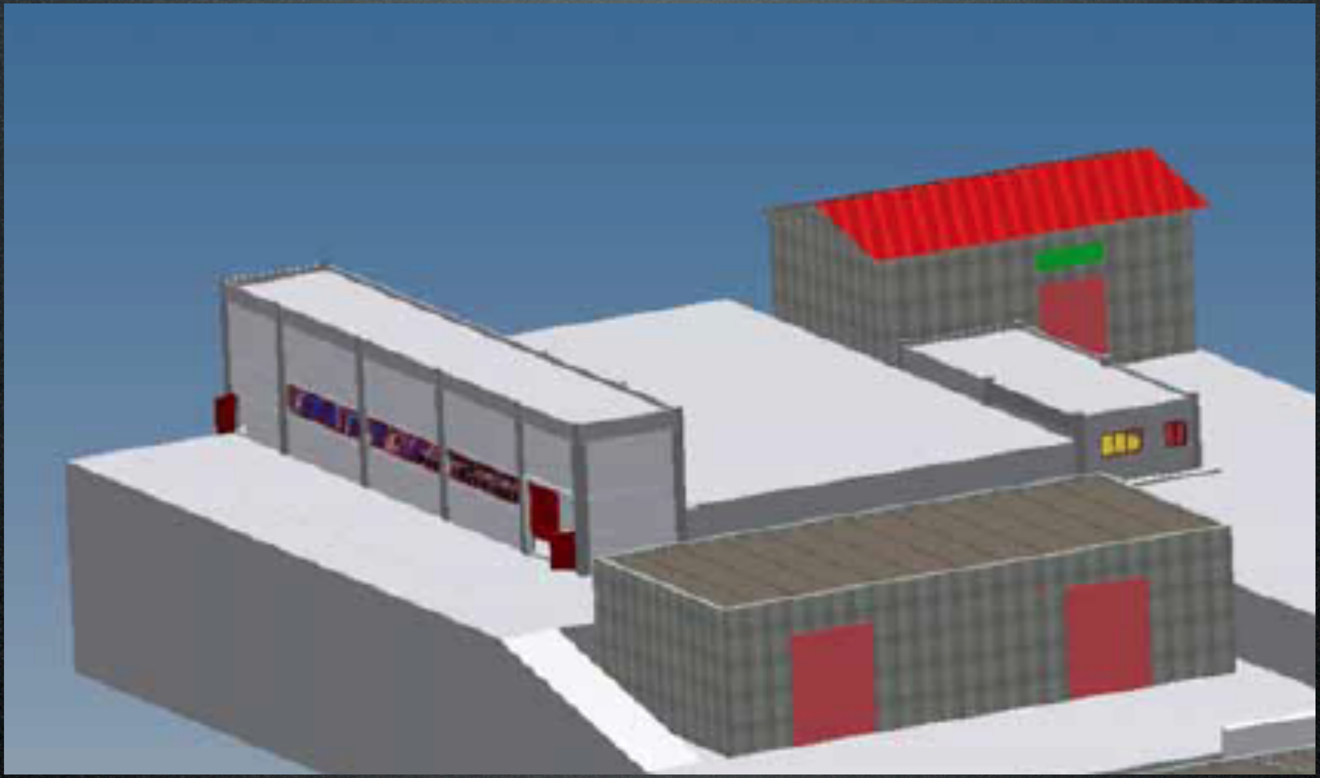
SPARC_LAB

(Sources for Plasma Accelerators and Radiation Compton with Lasers And Beams

Massimo Ferrario

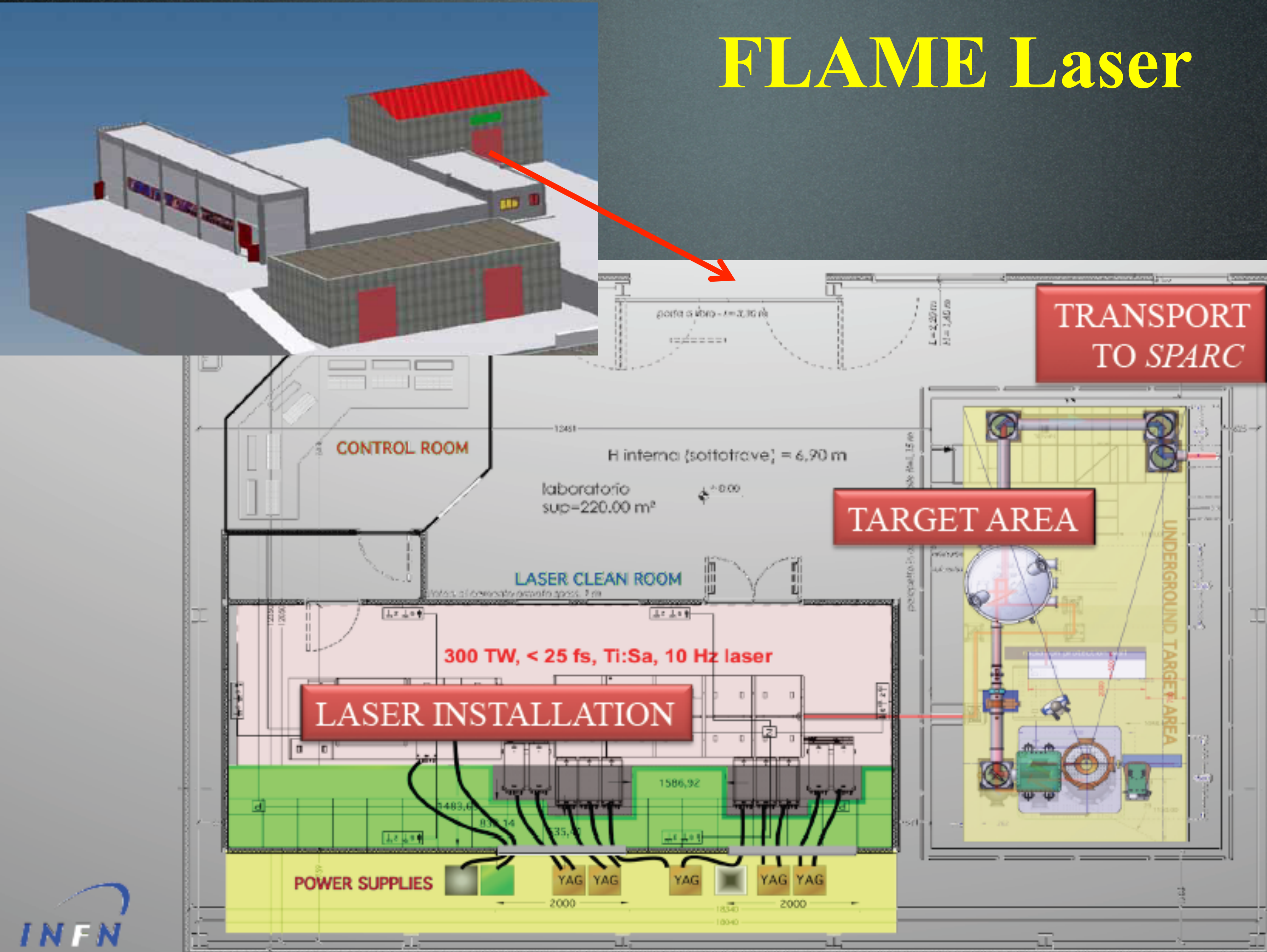


43 LNF Scientific Committee Meeting - January 19, 2012

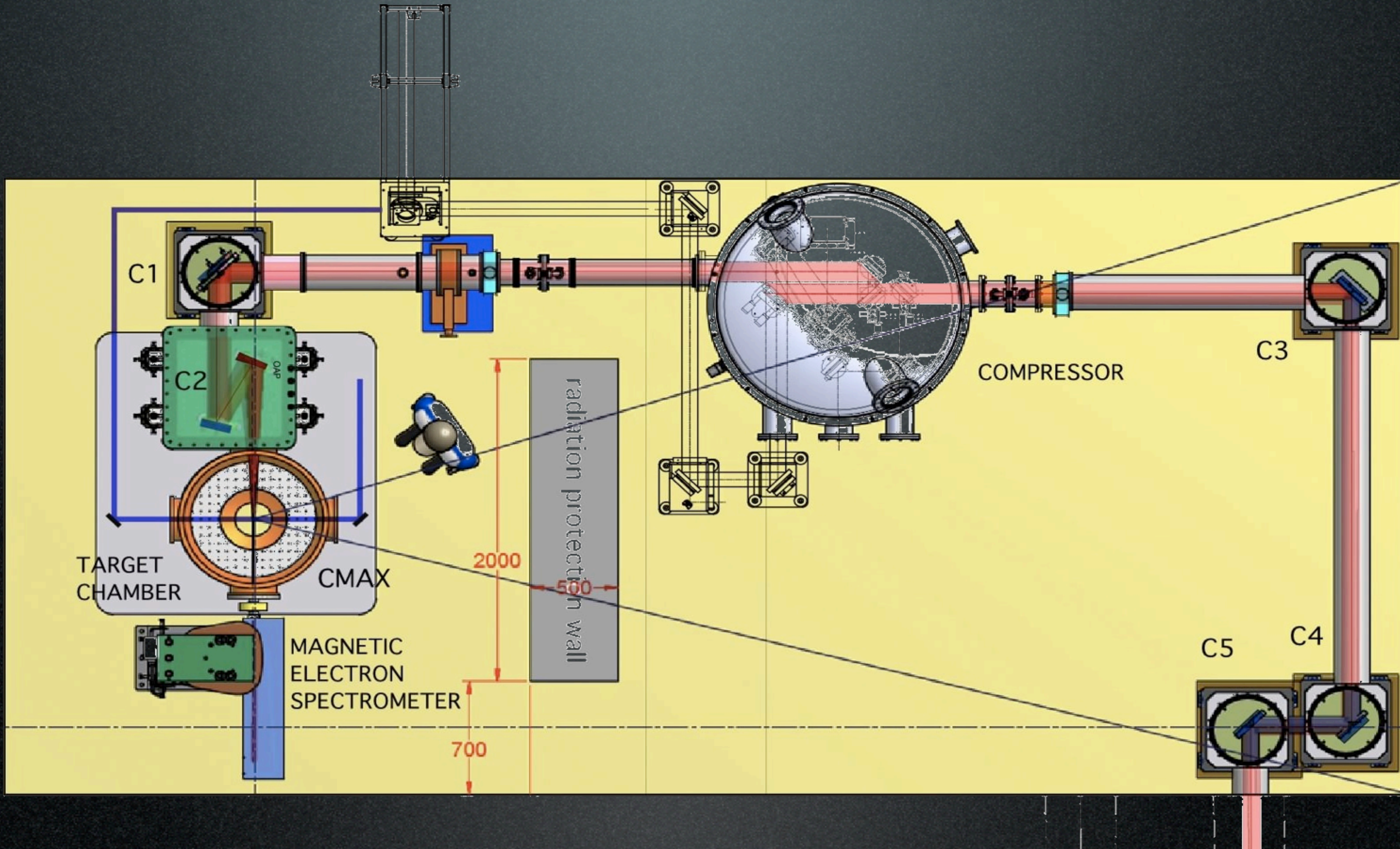
SPARC_LAB Mission

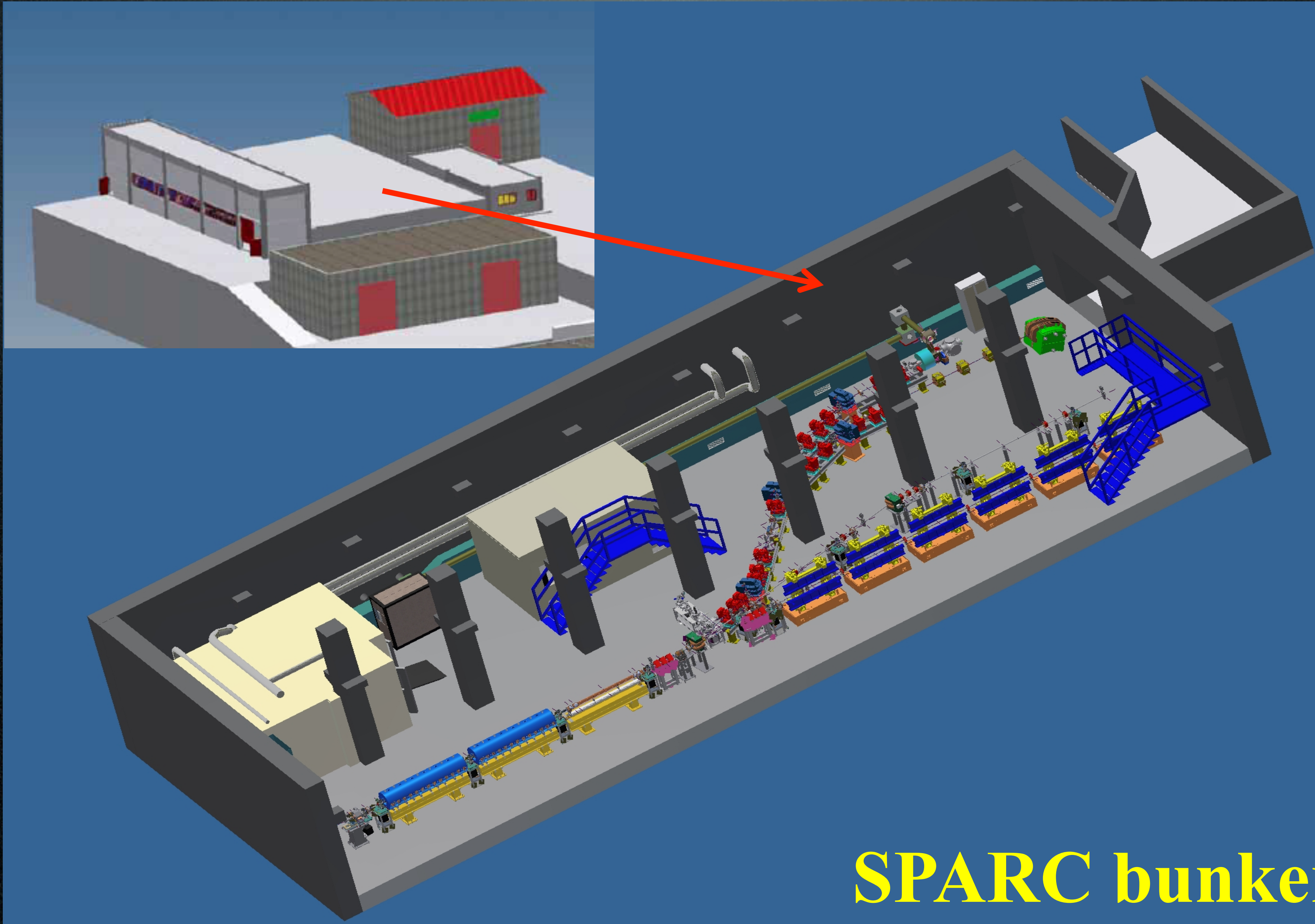
Mission of SPARC_LAB is primarily to integrate and harmonize all the existing activities at the test-facility, coordinate commissioning, operation and upgrade of the experiments, stimulate research and development and submissions of proposals for experiments to be performed at the SPARC_LAB test-facility.

FLAME Laser

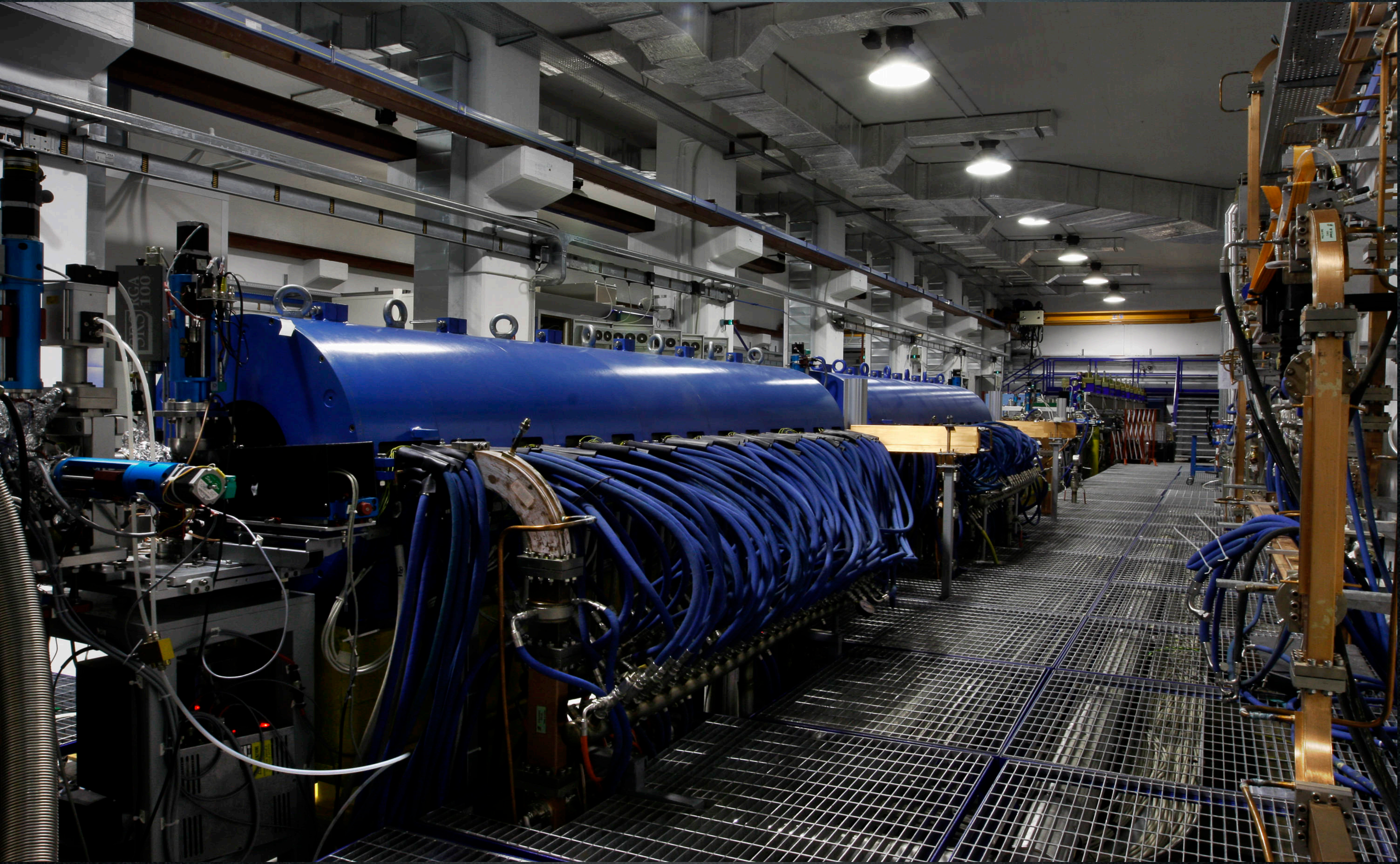

TRANSPORT TO SPARC
CONTROL ROOM
H interna (sottotrave) = 6,90 m
laboratorio sup=220.00 m²
TARGET AREA
LASER CLEAN ROOM
300 TW, < 25 fs, Ti:Sa, 10 Hz laser
LASER INSTALLATION
UNDERGROUND TARGET AREA
POWER SUPPLIES
YAG
YAG
YAG
YAG
YAG
2000
2000

Target Area

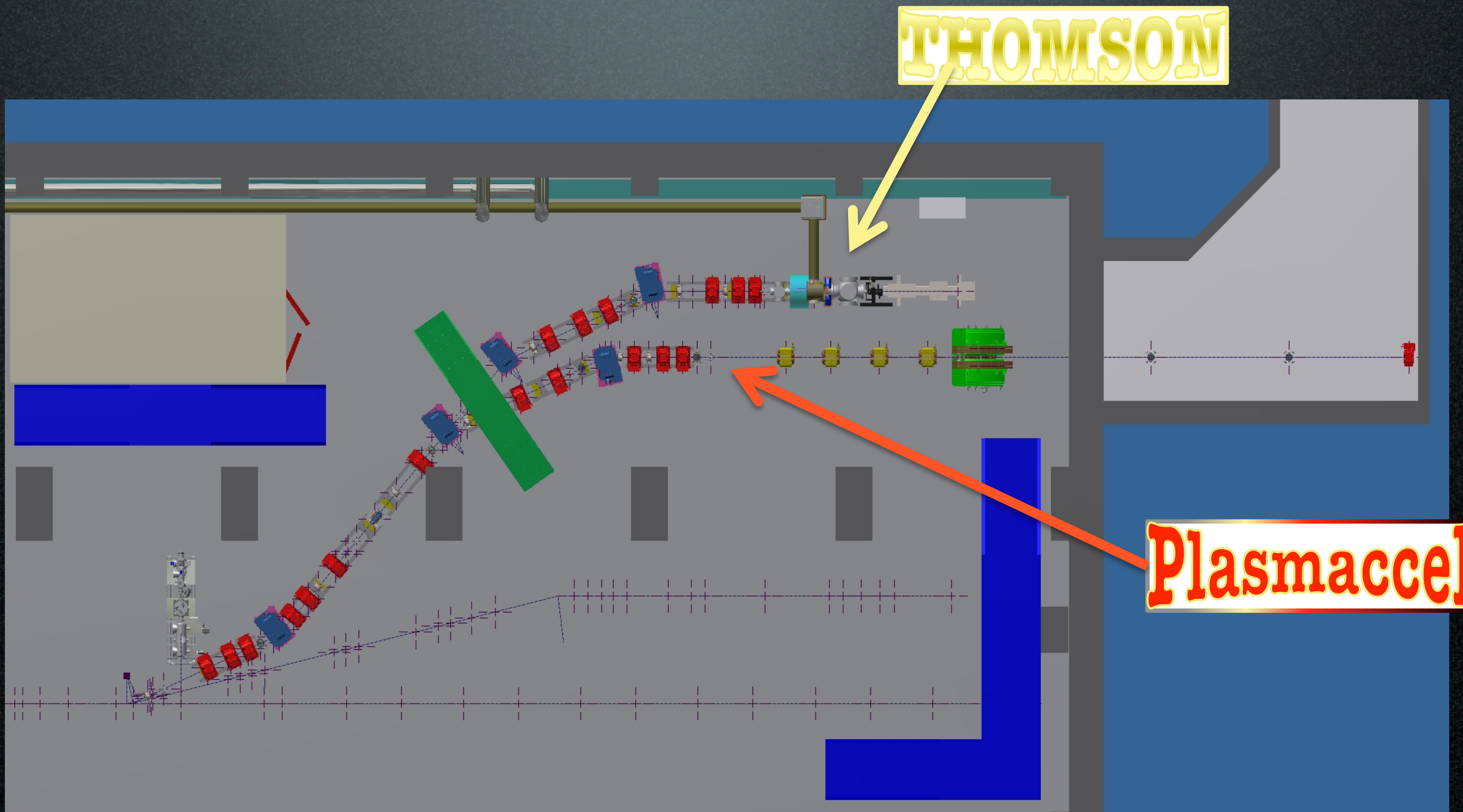

C1
C2
OAP
TARGET
CHAMBER
CMAX
2000
radiation protection wall
500
700
MAGNETIC
ELECTRON
SPECTROMETER
COMPRESSOR
C3
C4
C5



SPARC bunker



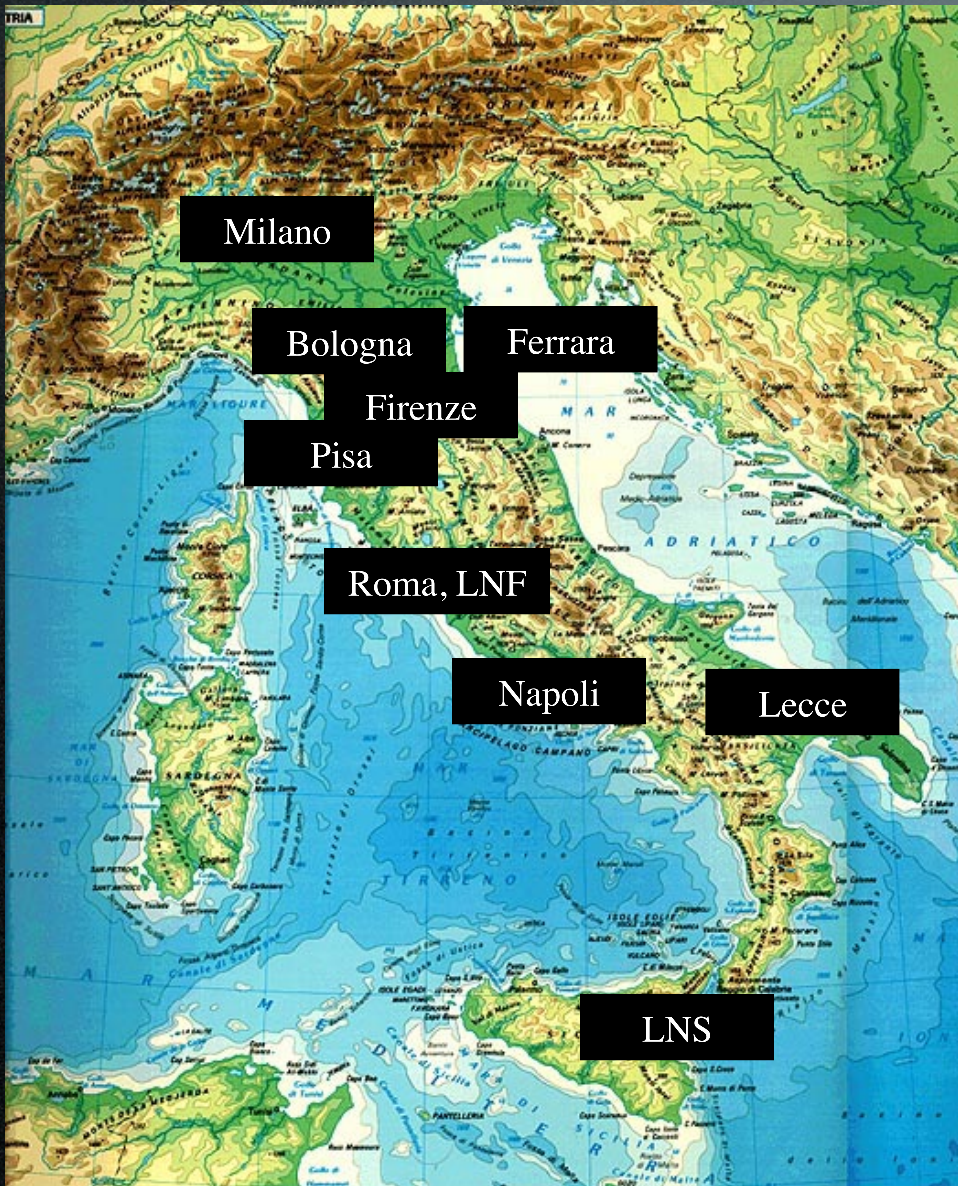
New installations



SPARC_LAB Activities

- *High gradient acceleration* (COMB, PLASMONX, SITE)
- *FEL physics and applications (SPARC, SASE, SEEDING, HHG, COMB)*
- *Advanced radiation sources and applications (PLASMONX, BEATS2, TERASPARC, γ-RESIST, ELI_NP)*
- *Advanced beam physics and accelerator technology (SPARC, COMB, ELI_NP)*
- *Fundamental physics (γ-RESIST)*
- *Positron source (POSSO)*
- *Laser/Plasma physics (γ-RESIST, PLASMONX)*
- *Promote Spin-off of previous activities (SPARC, ELI_NP)*
- *Laser/Plasma based ion sources (LILIA)*

SPARC_LAB related INFN units



Laboratori Nazionali di Frascati
D. Alesini, M. Anania, P. Antici, M. Bellaveglia, R. Boni, M. Boscolo, P. Calvani, M. Castellano, E. Chiadroni, A. Clozza, G. Di Pirro, U. Dosselli, A. Drago, M. Ferrario, A. Gallo, C. Gatti, G. Gatti, A. Ghigo, C. Marcelli, M. Migliorati, A. Mostacci, E. Pace, A. Rossi, C. Sanelli, B. Spataro, C. Vaccarezza.

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Sezione di Roma 1
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Sezione di Roma 2
A. Cianchi, L. Catani

Sezione di Ferrara
M. Gambaccini, Cardareli, Marziani, Mucollari.

Sezione di Lecce
W. Perrone, A. Lo Russo, Buccolieri, Castellano, Di Giulio, Nassisi, Palama', Tepore.

Sezione di Bologna
Sgattoni, Bazzani, Londrillo, Turchetti.

Sezione di Firenze
Adriani, Bonechi, M. Calvetti, Graziani, Passaleva, A. Tricomi

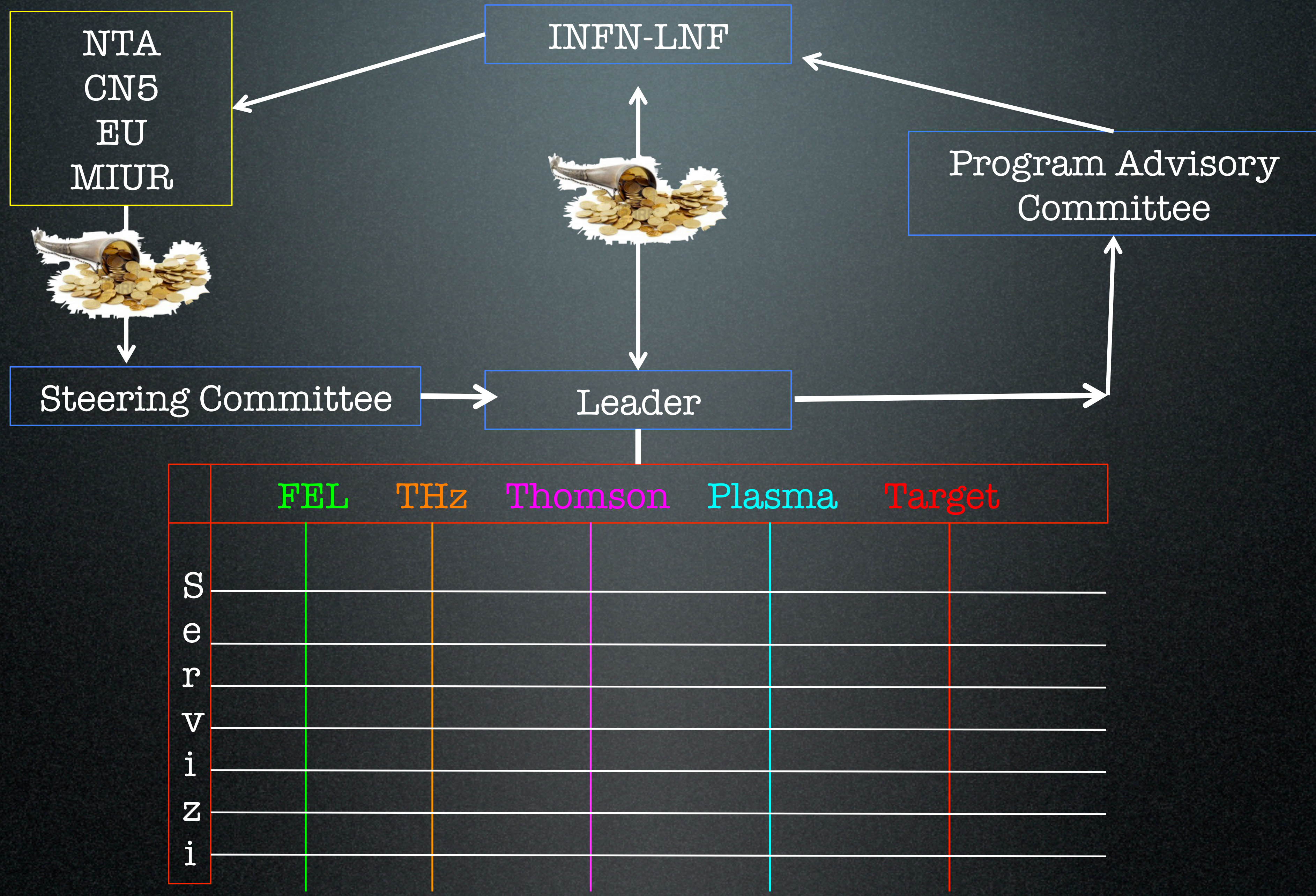
Sezione di Napoli
R. Fedele, De Angelis, Di Leva, Gialanella, Masullo, Tanjia.

Laboratori Nazionali del Sud
Cirrone, Torrisi, Re, Raffaele.

CNR
L. Gizzi, L. Labate , De Nicola, V. Rossi Albertini, J.V. Rau.

ENEA
L. Giannesi , C. Ronsivalle, M. Artioli, G. Dattoli, E. Di Palma, A. Petralia, M. Quattromini, E. Sabia, I. Spassovsky, V. Surrenti.

UCLA
J. B. Rosenzweig, P. Musumeci


NTA
CN5
EU
MIUR
INFN-LNF
Program Advisory Committee
Steering Committee
Leader
FEL
THz
Thomson
Plasma
Target
Servizi

FLAME Status

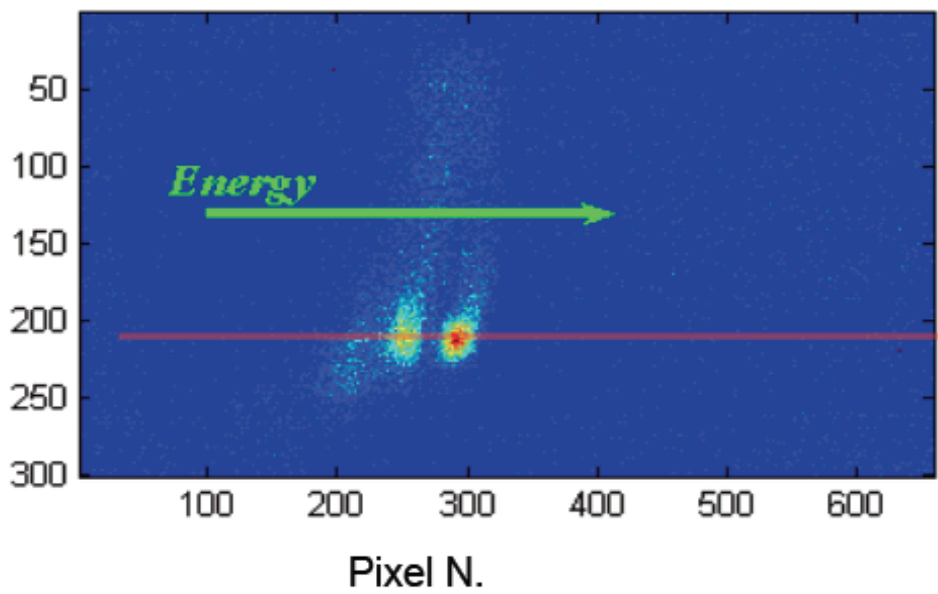
- **June 2011**. All FLAME amplifiers working. Phase measurements at full energy: problems detected with Ti:Sa cristal cooling.
- **Settembre 2011**. Radioprotection final permission close to be cleared: full authorization for full energy operation of FLAME and Target Area by end of November
- **Ottobre 2011**. Acquisition procedure for Adaptive Optics
- **November 2011**. Implementation of new Ti:Sa cristal cooling set-up
- **December 2011.** Test at full power (200-250 TW)
- **January 2012.** Self-Injection Acceleration at full power
- **March 2012.** Installation of Adaptive Optics, to reach 10^{21} W/cm^2

Self Injection:
spectrum of the accelerated electrons

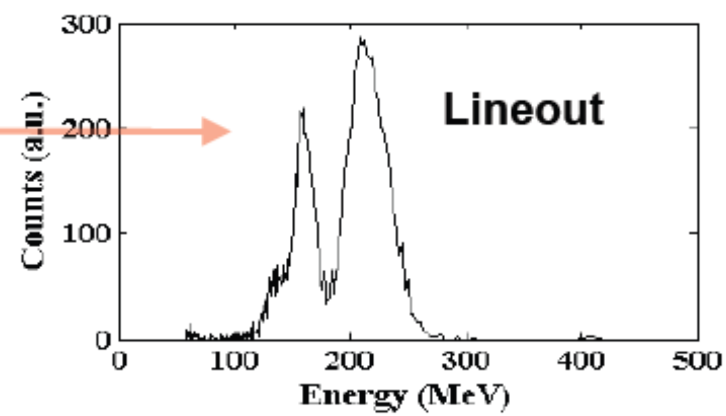
Recent spectra acquired at 1 J laser energy on gas-jet target and 35 fs: expected intensity at focus: 7E18 W/cm2

Energy dispersion with a 0.9 T magnetic dipole

Electron energy spectrum



Electrons at lanex screen



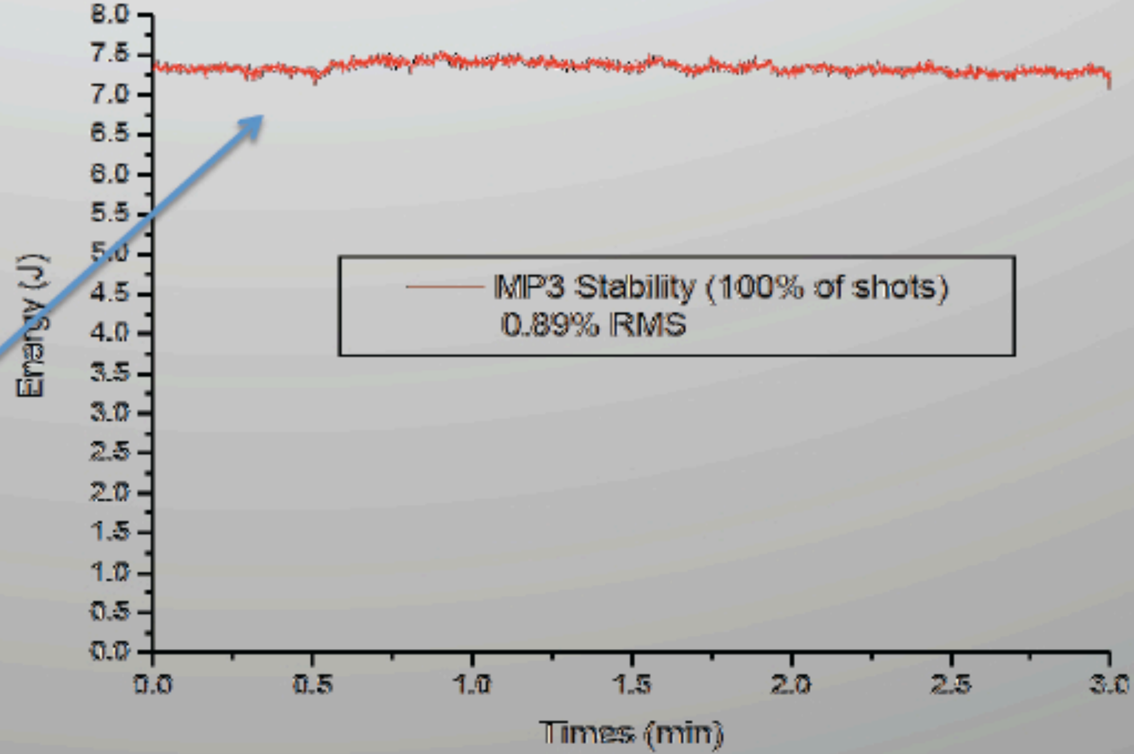
Energy of LPA electrons entering the multi 100 MeV range

T. Levato et al., EPS Conference in Plasma Physics, 2011

FINAL AMPLIFIER: FULL ENERGY

Final amplifier operational with all YAG pump lasers

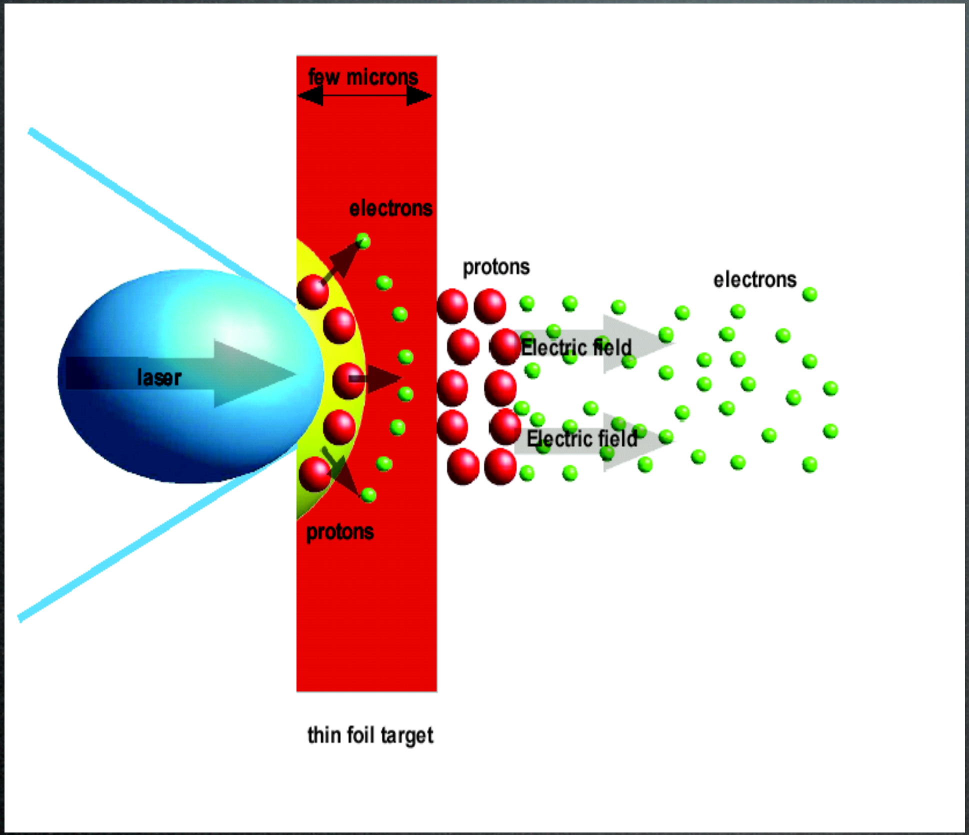
Pulse energy: 7.34 J (before compression)

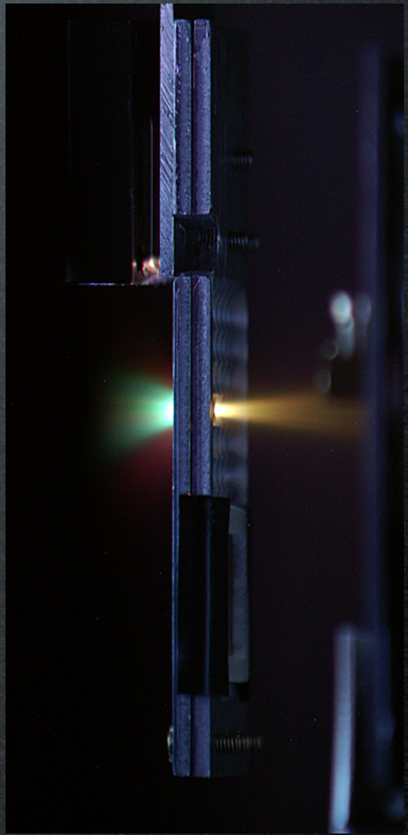


Summary of performance (to date)

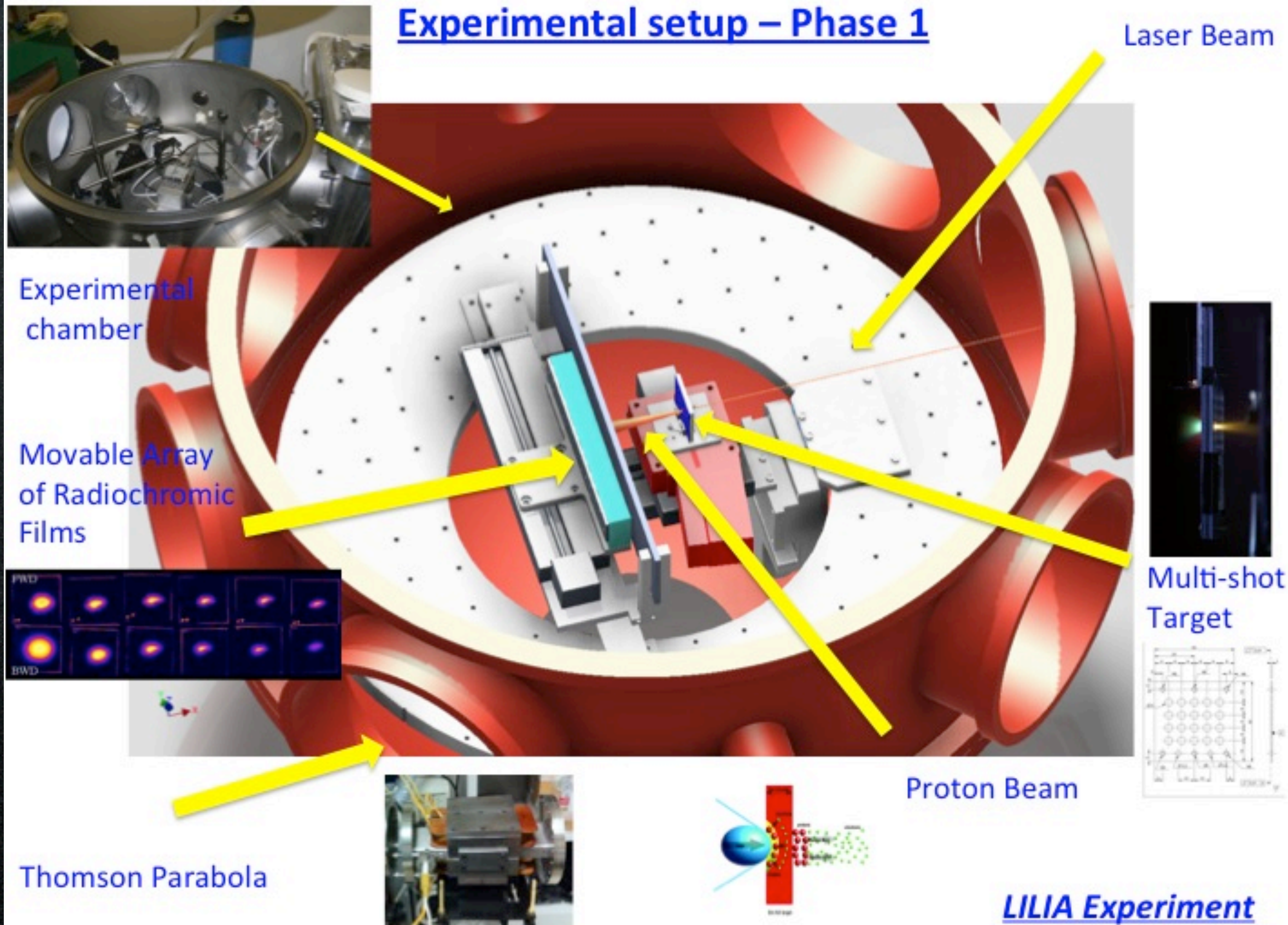
- Energy before compression @ 7.3 J
- Vacuum compressor transmission > 70%
- Pulse duration down to 23 fs
- ASE Contrast ratio: better than 2×10^9
- Pre-Pulse Contrast better than 10^8
- RMS Pulse Stability @ 0.8 %
- Pointing Stability (incl. path) < 2μrad
- Phase front correction needed – adaptive optics;
- Full power vacuum compression to be performed;

LILIA Status
Laser Induced Light Ions Acceleration





Experimental setup – Phase 1



LILIA Experiment

- LILIA is finalized to study, design and verify a scheme which foreseen the production, the characterization and the transport of a proton beam toward a stage of post acceleration (high frequency compact linacs).

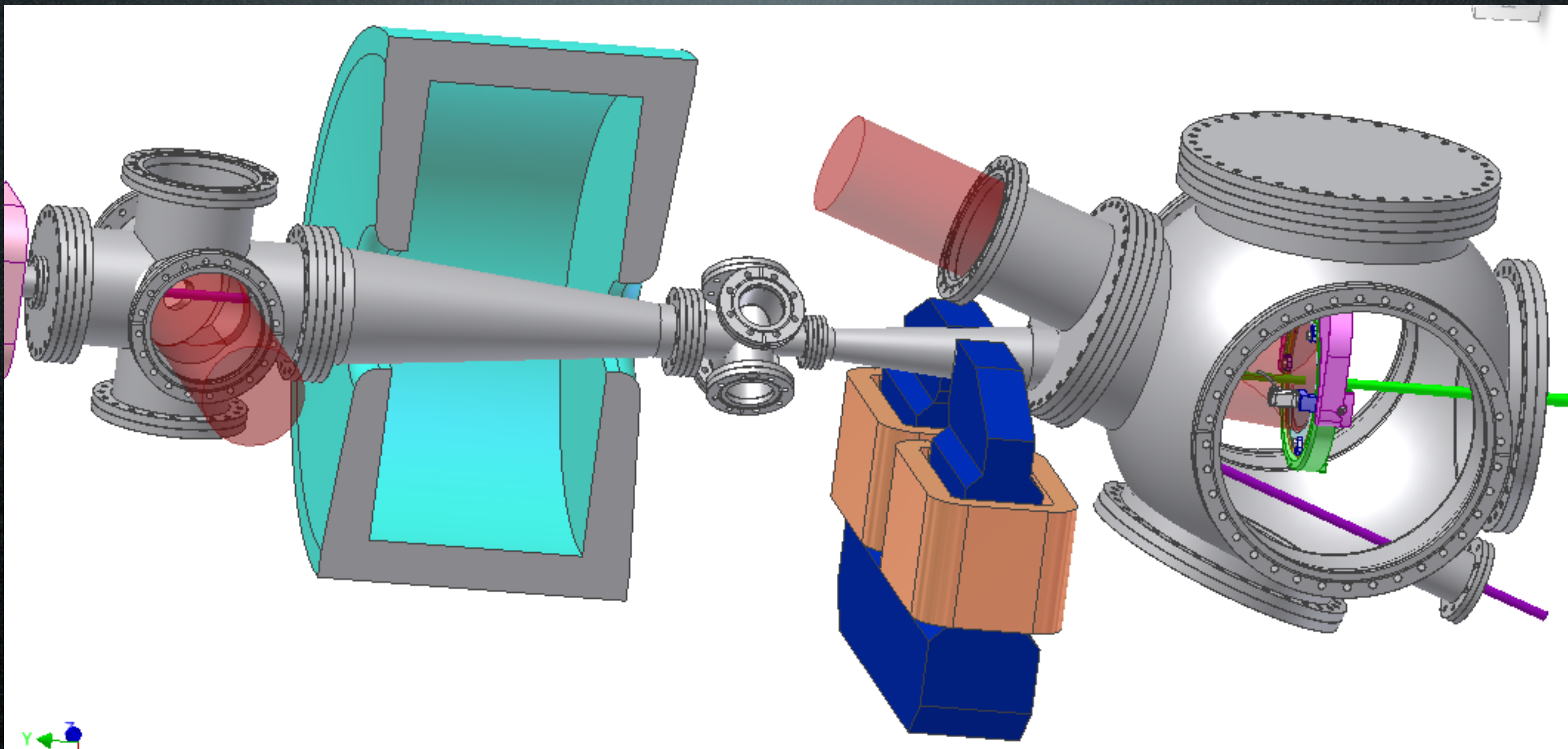
- we expect a proton beam with energy in the range 5-30 MeV and total intensities up to 10^{10}-10^{12} protons/shot.

- Although these values are modest compared to the present state of art, we aim at playing a role as a test facility focused on emission process control and repeatability, and post acceleration tests

- In such a frame we would like to deeply investigate the experimental scale rules within the possibilities offered by the FLAME facility. Moreover, this will provide the opportunity to get experience in the development of diagnostic techniques and in target optimization.

THOMSON Status

Interaction region (20-550 keV)

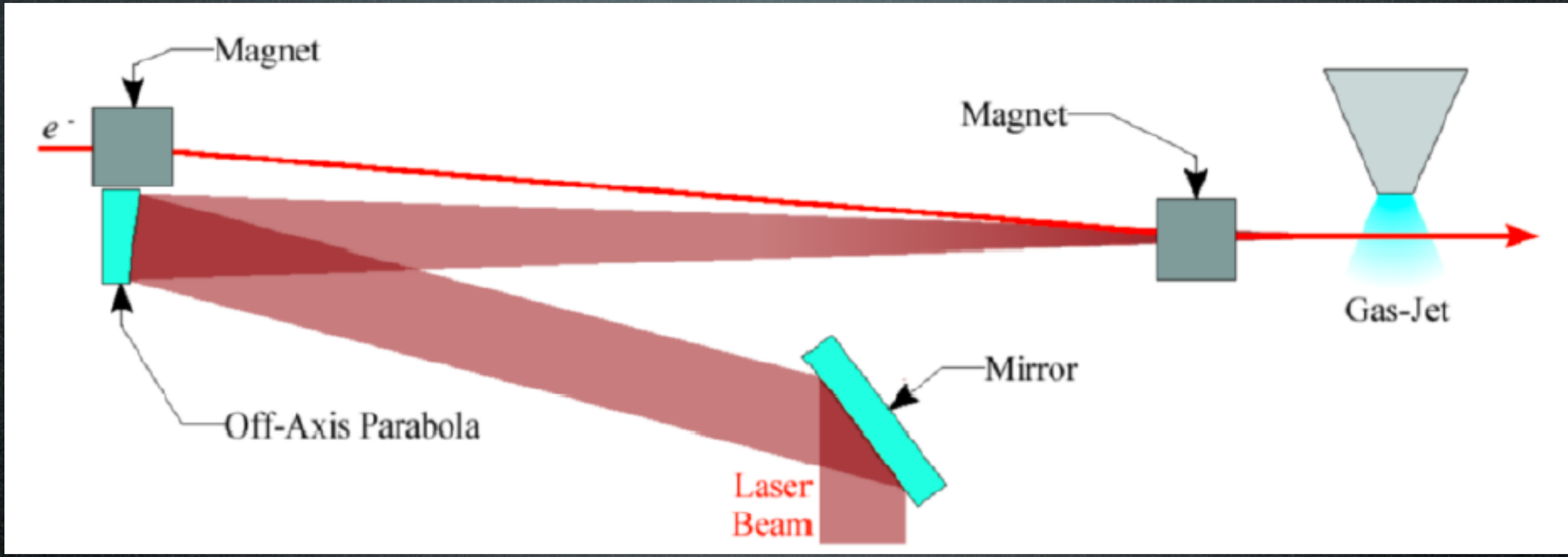


N_{tot}=1.7 10^9

$\Delta\omega/\omega$ rms=5.2 %

div rms= 5.3 mrad

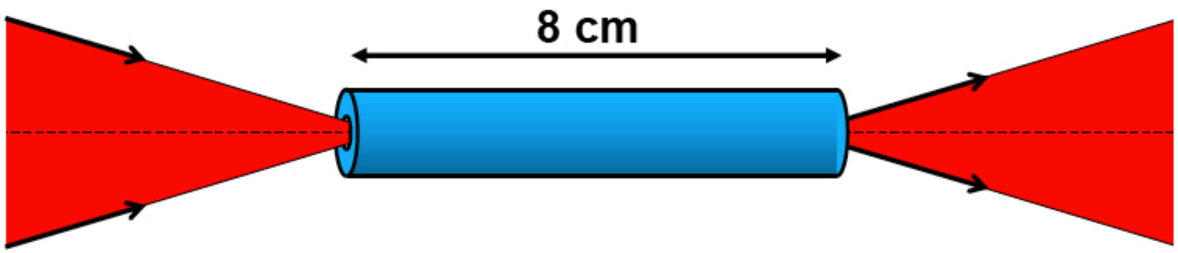
EXIN Status
(External Injection)



n_e [cm^{-3}]	E_{max} [GV/m]	λ_p [μm]	Ldeph [m]	Energy gain over L = 2cm [MeV]	Energy gain over L = 10cm [MeV]
1e16	0.2	330	400	<4	<20
5e16	1	150	5	<20	<100
2.5e17	3.8	66	0.45	<76	<380
7.5e17	7.5	39	0.1	<150	<750
2.5e18	8.5	30	0.04	<190	-

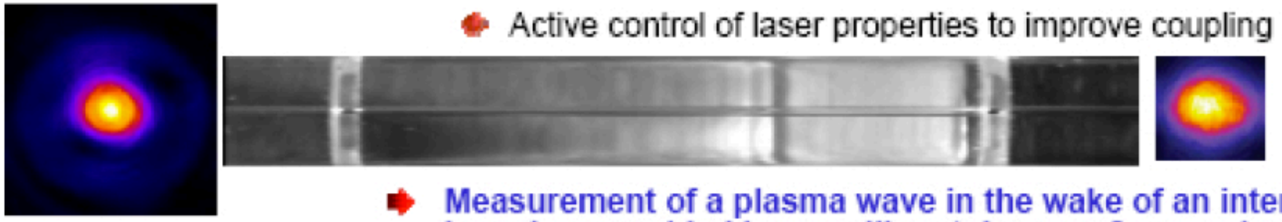
Hollow Dielectric Waveguide Capillaries

With LPGP Orsay, Brigitte Cros *et al.*

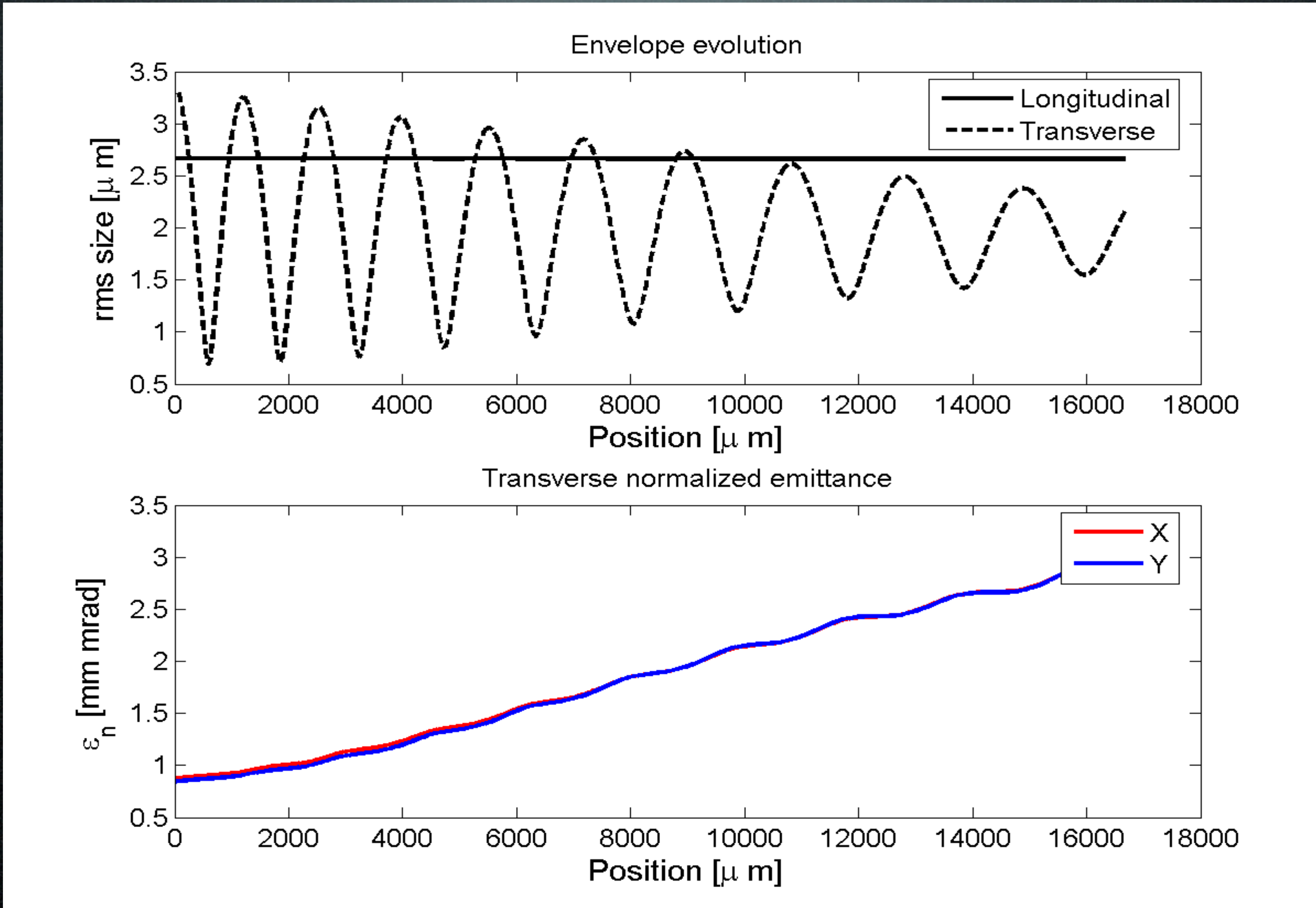


Recent achievements

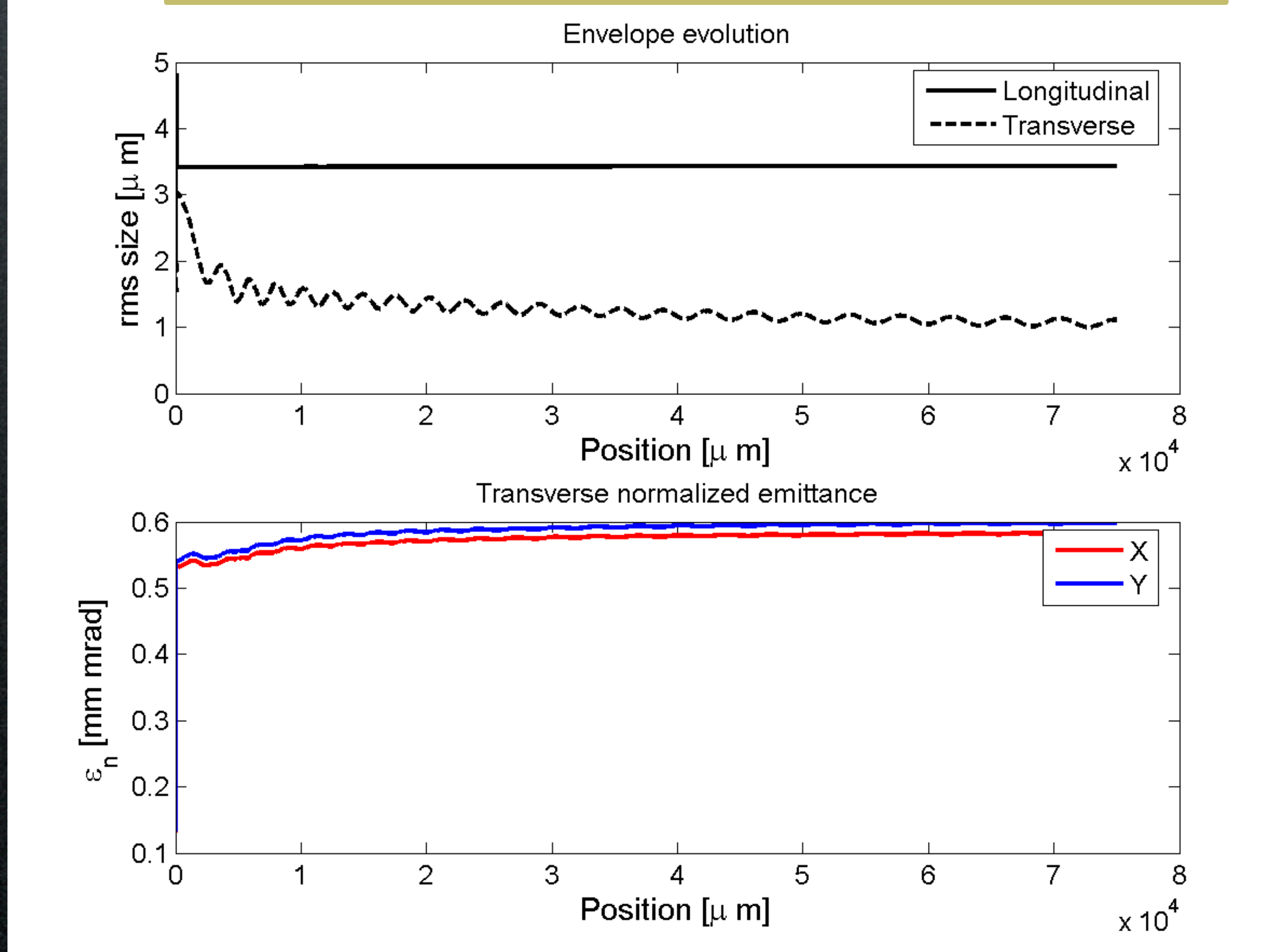
- Optimisation of laser guiding using capillary tubes (10cm):
  - vacuum or under-dense plasmas
  - Relevant for moderate intensities in laser wakefield schemes
  - Active control of laser properties to improve coupling



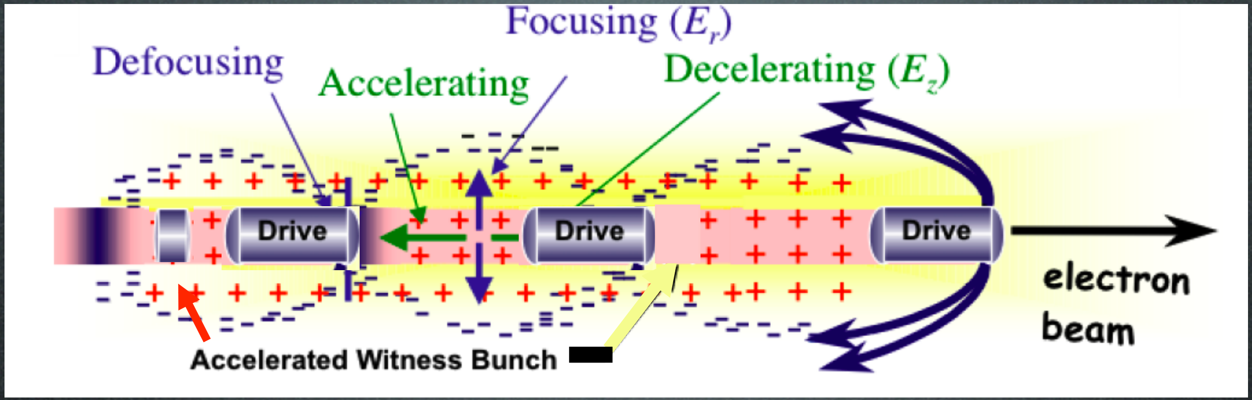
- Measurement of a plasma wave in the wake of an intense laser beam guided in a capillary tube over 8 cm, using optical diagnostics. Measured field up to 7GV/m over 8 cm.


Envelope evolution
Longitudinal
Transverse
rms size [μ m]
Position [μ m]
3.5
3
2.5
2
1.5
1
0.5
0
2000
4000
6000
8000
10000
12000
14000
16000
18000
Transverse normalized emittance
X
Y
ε_n [mm mrad]
Position [μ m]

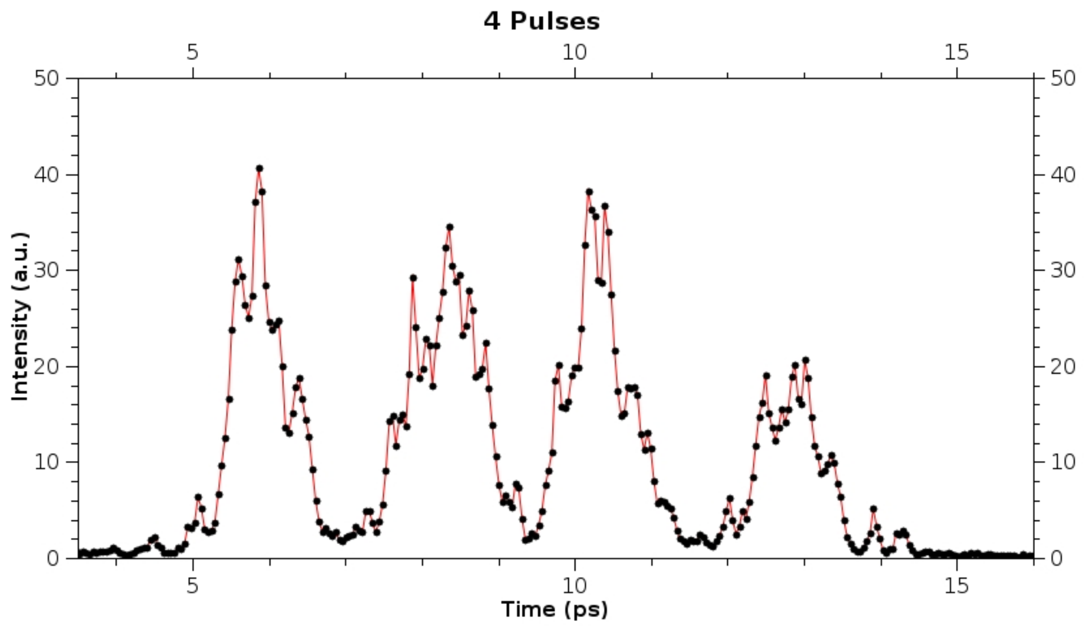
$$\sigma_\varepsilon = \sqrt[4]{\frac{3}{\gamma}}\sqrt{\frac{\varepsilon_n}{k_p}}$$

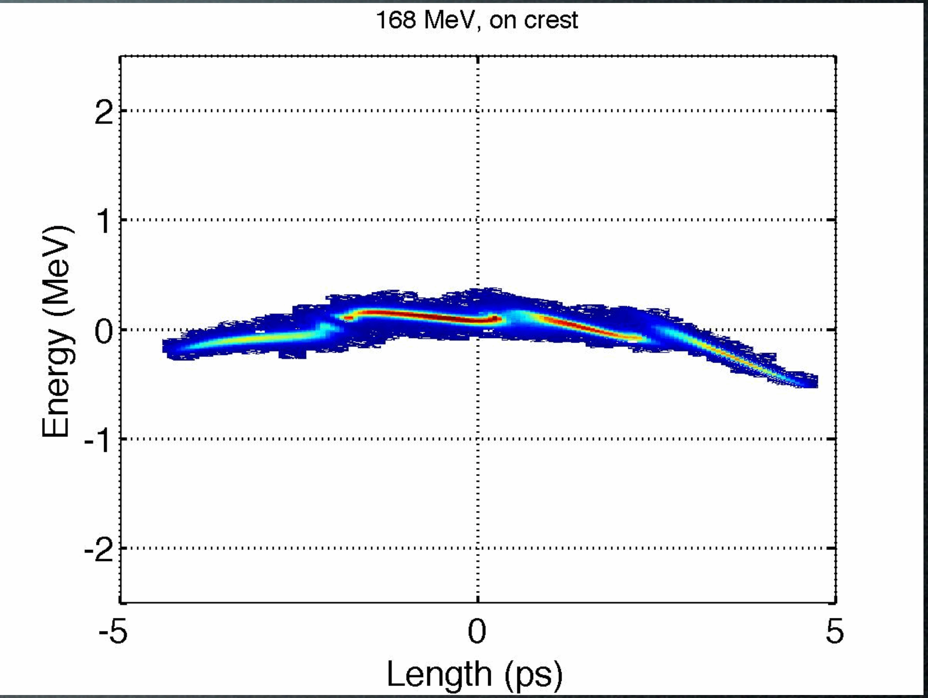


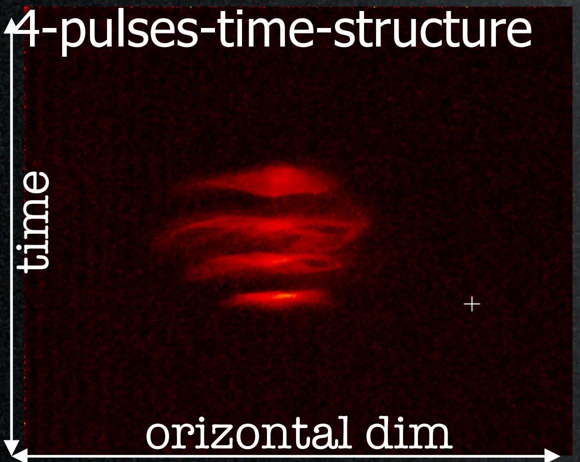
Resonant plasma Oscillations by Multiple electron Bunches

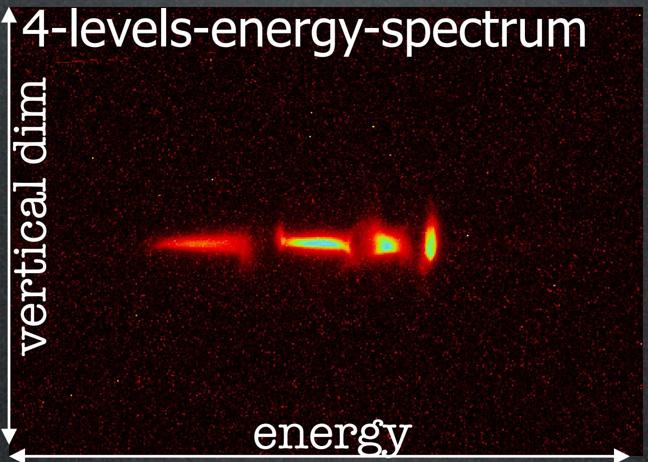


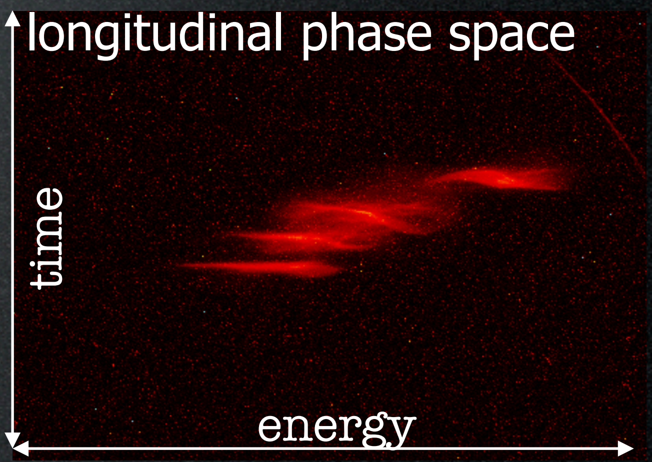
- **Weak blowout regime** with resonant amplification of plasma wave by a train of high Brightness electron bunches produced by **Laser Comb** technique ==> **5 GV/m** with a train of 3 bunches, 100 pC/bunch, 50 μm long, 20 μm spot size, in a plasma of density 10^{22} e^-/m^3 at λ_p=300 μm ?
- **Ramped bunch train configuration** to enhance tranformer ratio?
- **High quality bunch** preservation during acceleration and transport?
- **Strong blowout regime** with pC/fs bunches ==> **TV/m** regime ?

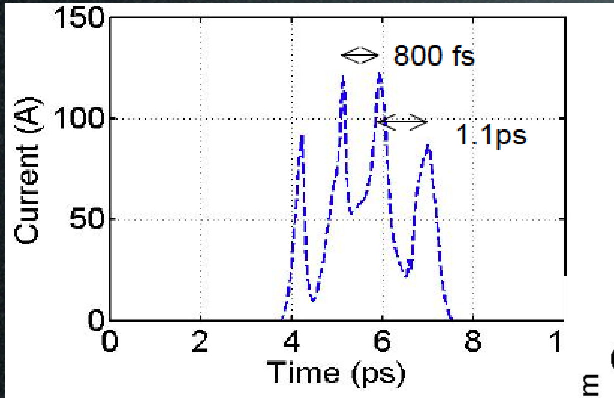

4 Pulses
Intensity (a.u.)
Time (ps)
0
10
20
30
40
50
5
10
15


168 MeV, on crest
Energy (MeV)
Length (ps)
-2
-1
0
1
2
-5
0
5


4-pulses-time-structure
time
orizontal dim


4-levels-energy-spectrum
vertical dim
energy

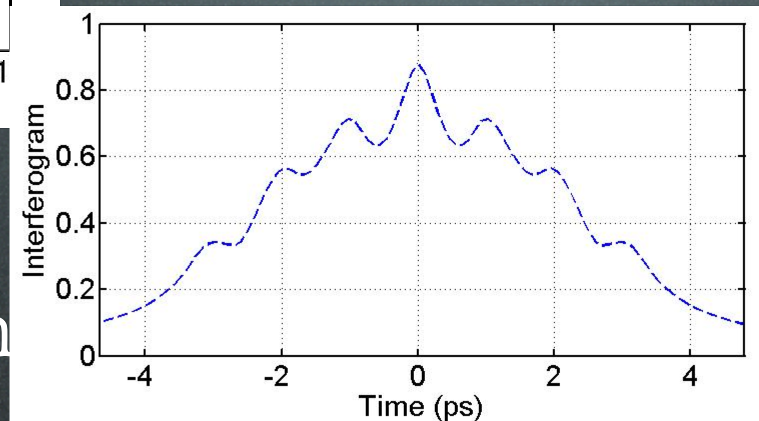

longitudinal phase space
time
energy

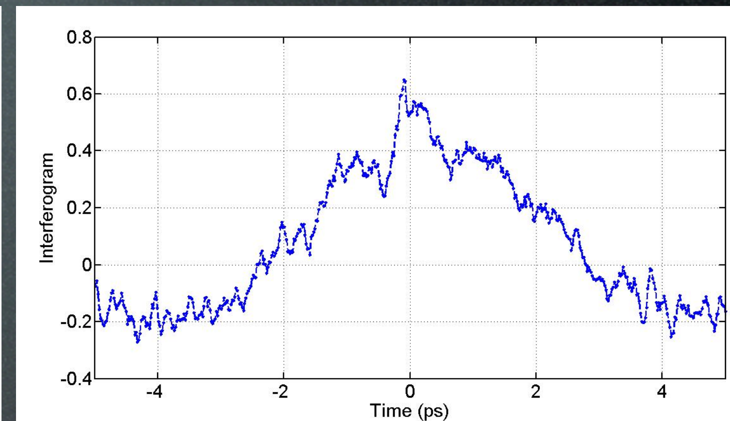


Expected

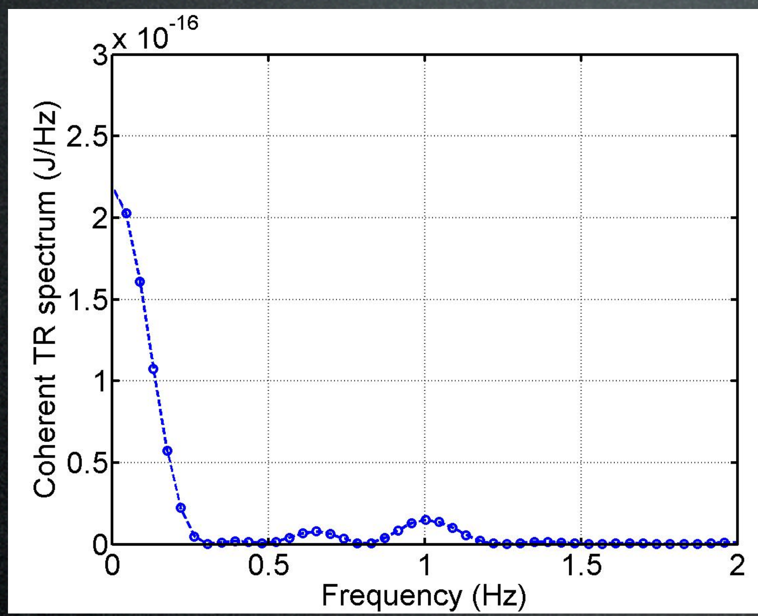
Measured

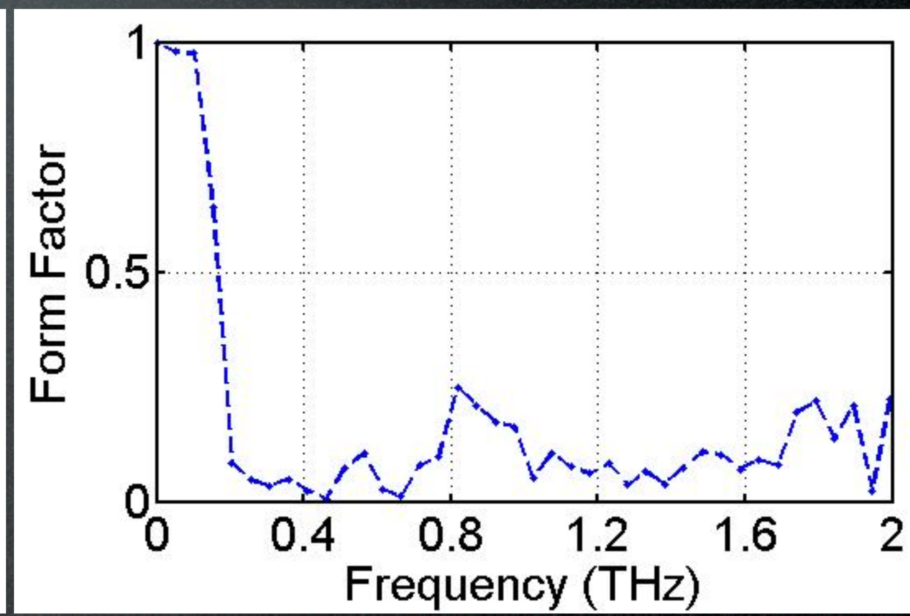
Interferogram



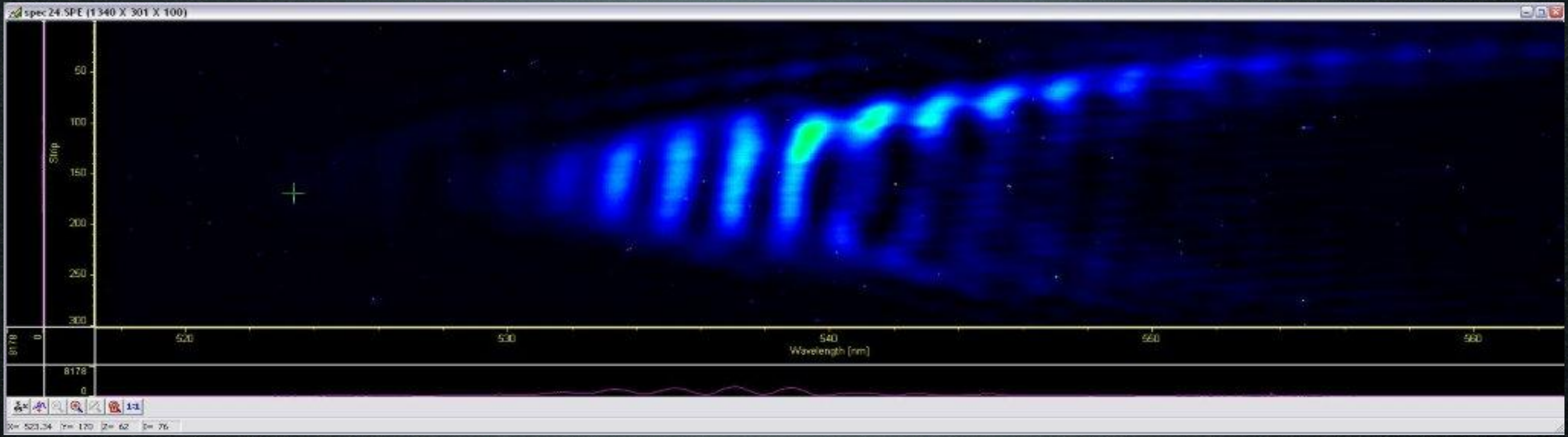


Spectrum

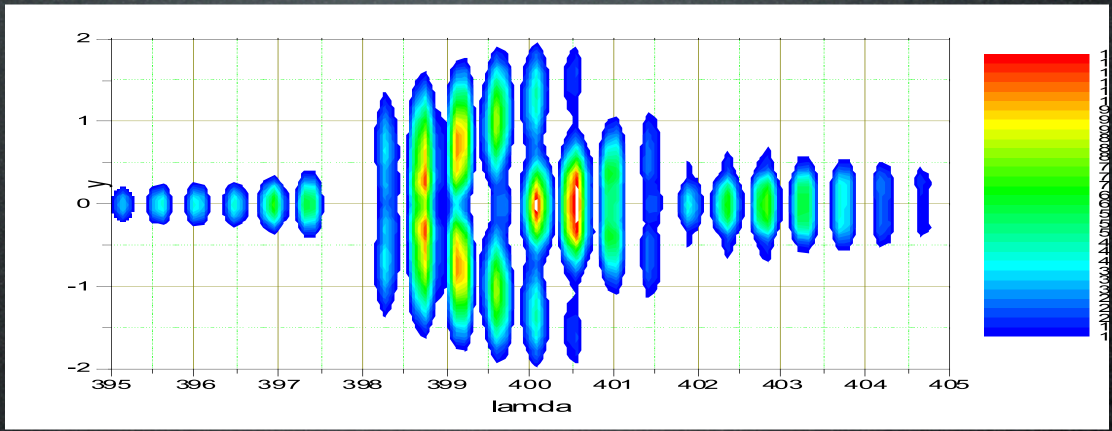




e. chiadroni



$$\Delta x = \frac{\lambda^2}{\Delta\lambda}$$



$$|T|^2 = |T_1|^2 e^{-(k-k_1)^2 \frac{\sigma_1^2}{\sqrt{2}}} + |T_2|^2 e^{-(k-k_2)^2 \frac{\sigma_2^2}{\sqrt{2}}}$$

$$+ 2T_1T_2 e^{-(k-k_1)^2 \frac{(\sigma_1^2+\sigma_2^2)}{2\sqrt{2}}} \cos(k(x_1 - x_2) - k_1x_1 + k_2x_2)$$

PRL **106**, 144801 (2011) PHYSICAL REVIEW LETTERS week ending 8 APRIL 2011

Self-Amplified Spontaneous Emission Free-Electron Laser with an Energy-Chirped Electron Beam and Undulator Tapering

PRL **107**, 224801 (2011) PHYSICAL REVIEW LETTERS week ending 25 NOVEMBER 2011

High-Gain Harmonic-Generation Free-Electron Laser Seeded by Harmonics Generated in Gas

Time-Domain Measurement of a Self-Amplified Spontaneous Emission Free-Electron Laser with an Energy-Chirped Electron Beam and Undulator Tapering

High Order Harmonics and Saturation Effects in a Seeded Free-Electron Laser

Intrinsic normalized emittance growth in laser-driven electron accelerators

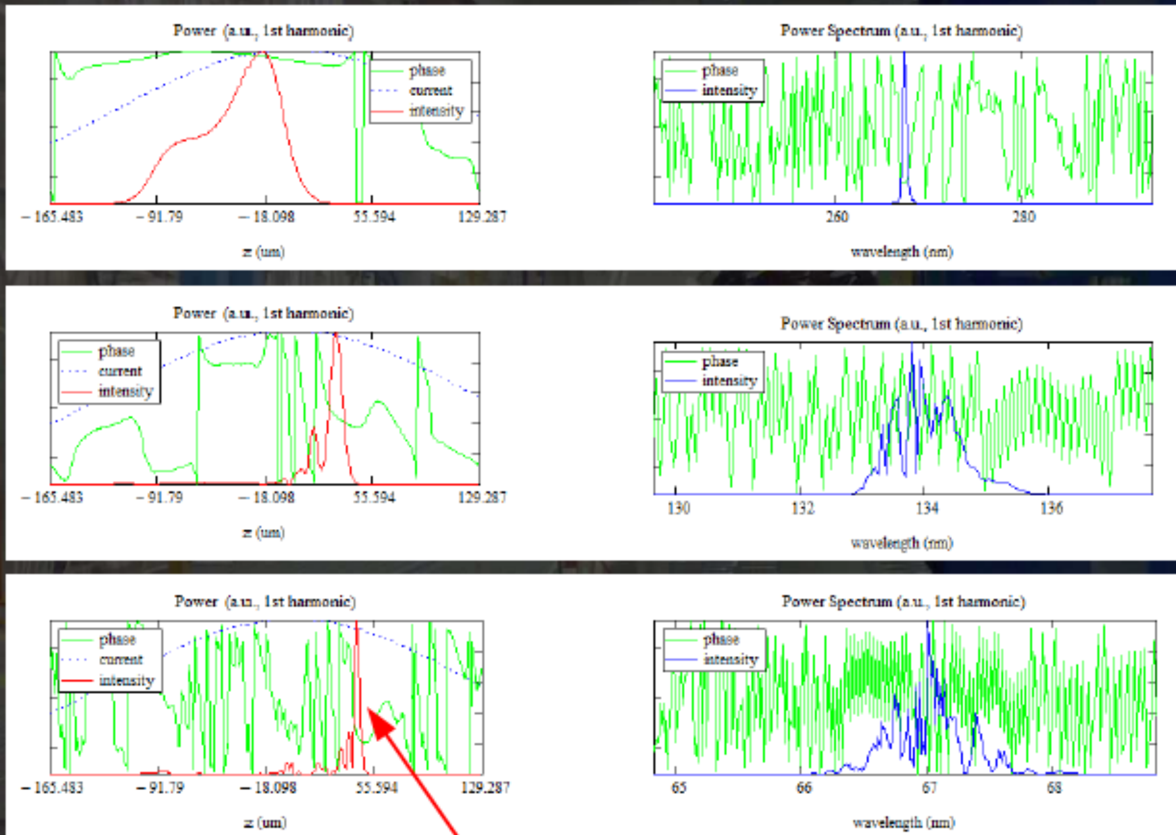
- Harmonic generation in superradiance regime
- Superradiant cascade
- Harmonic cascade
- Chirped beam with tapered undulator and FROG measurements
- COMB beam two pulse generation

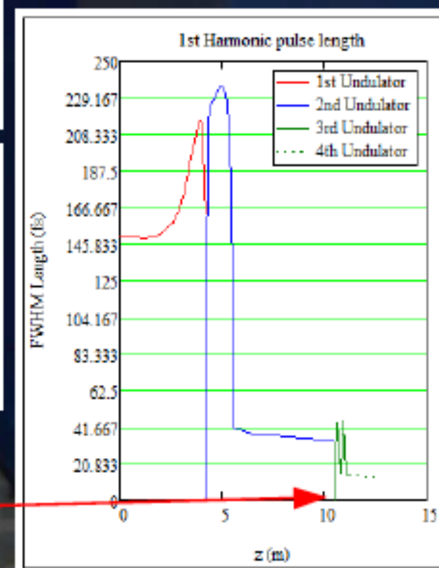
Pulse/spectrum at the end of the three stages

1° stage

2°stage

3° stage

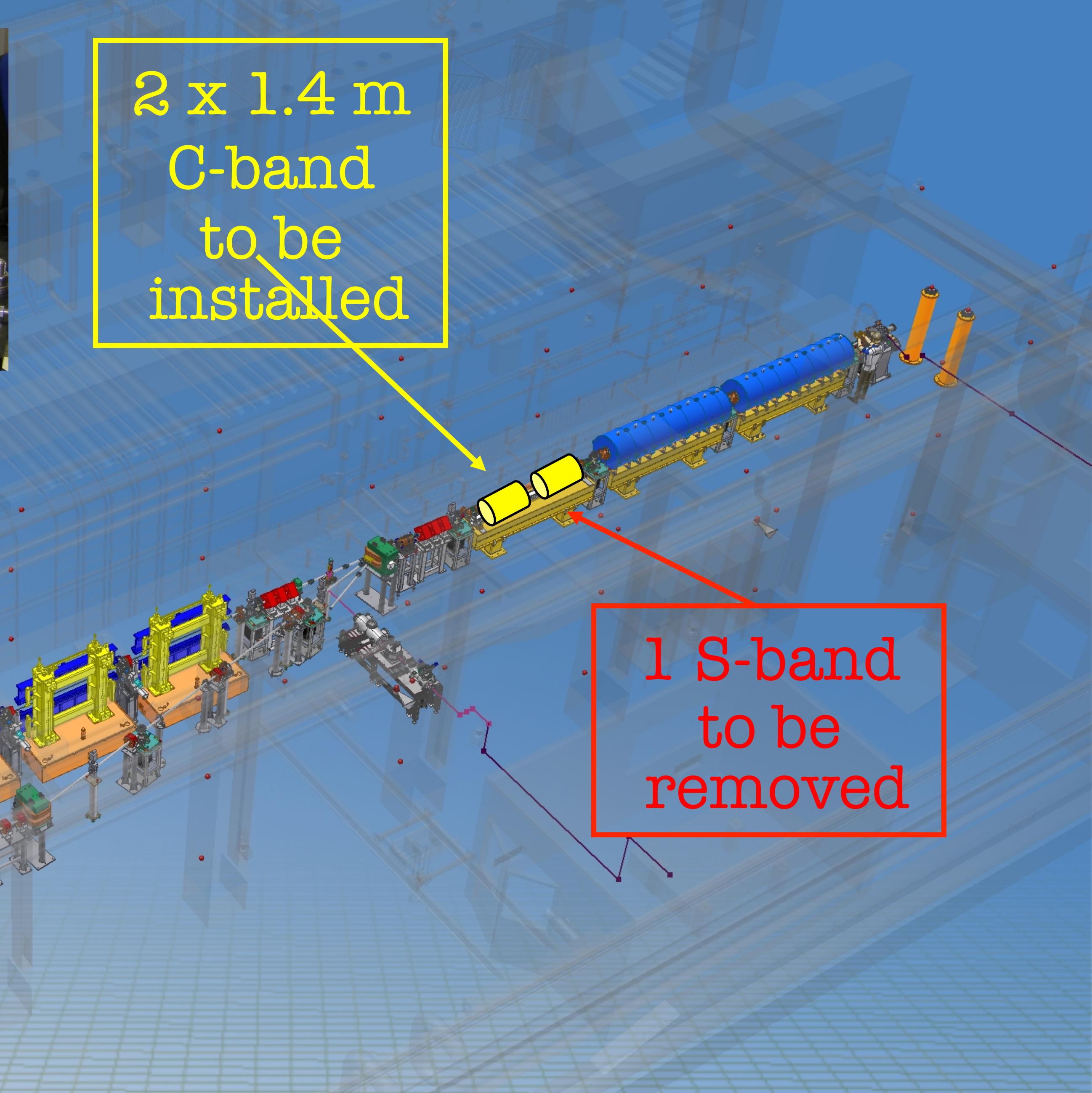


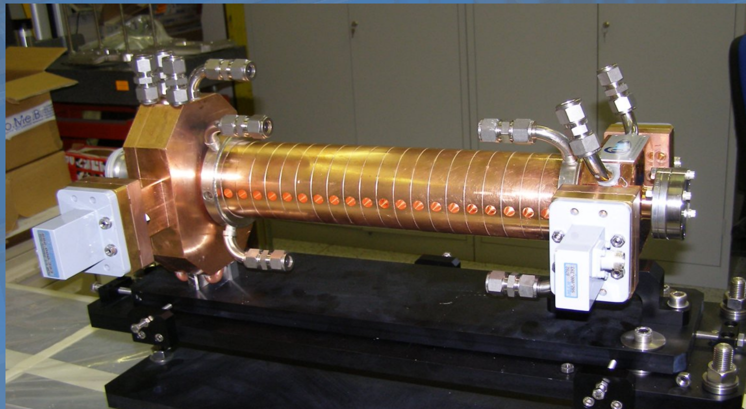


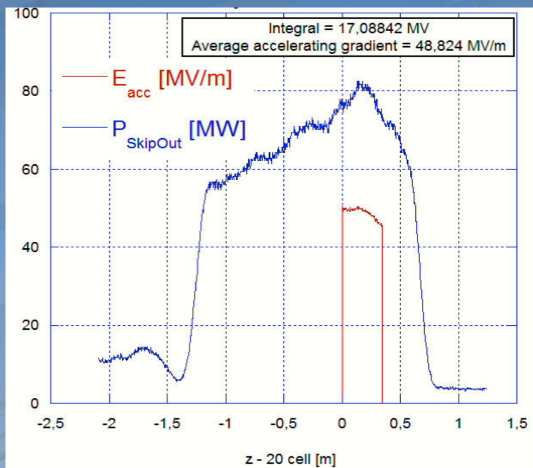
Less than 20 fs pulse length (fwhm)
Up to 1 uJ @ 66nm

2012 schedule

- Injector optimization (January)
- FEL experiments (February)
- End of THOMSON beam line installation (March)
- COMB for THz and FEL experiments (March)
- Commissioning of THOMSON beams (April)
- THz pump-probe experiment (May)
- THOMSON electron-photon collisions (from June)

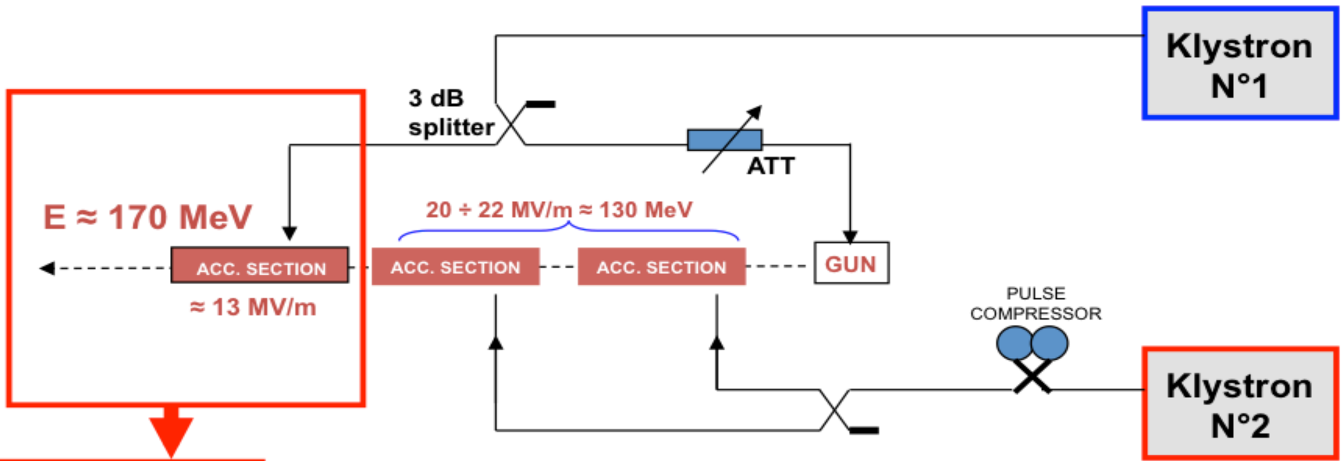


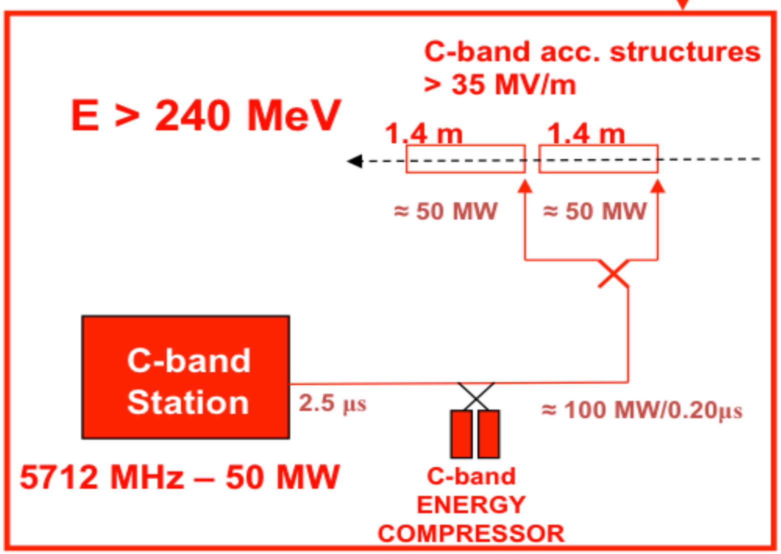




Expected energy upgrade up to 240 MeV

SPARC ENERGY UPGRADE





The new C-band system consists mainly of:

⇒ **2 accelerating sections** (1.4 m long)

⇒ 1 C-band **klystron** (50 MW), by Toshiba Ltd (JP)

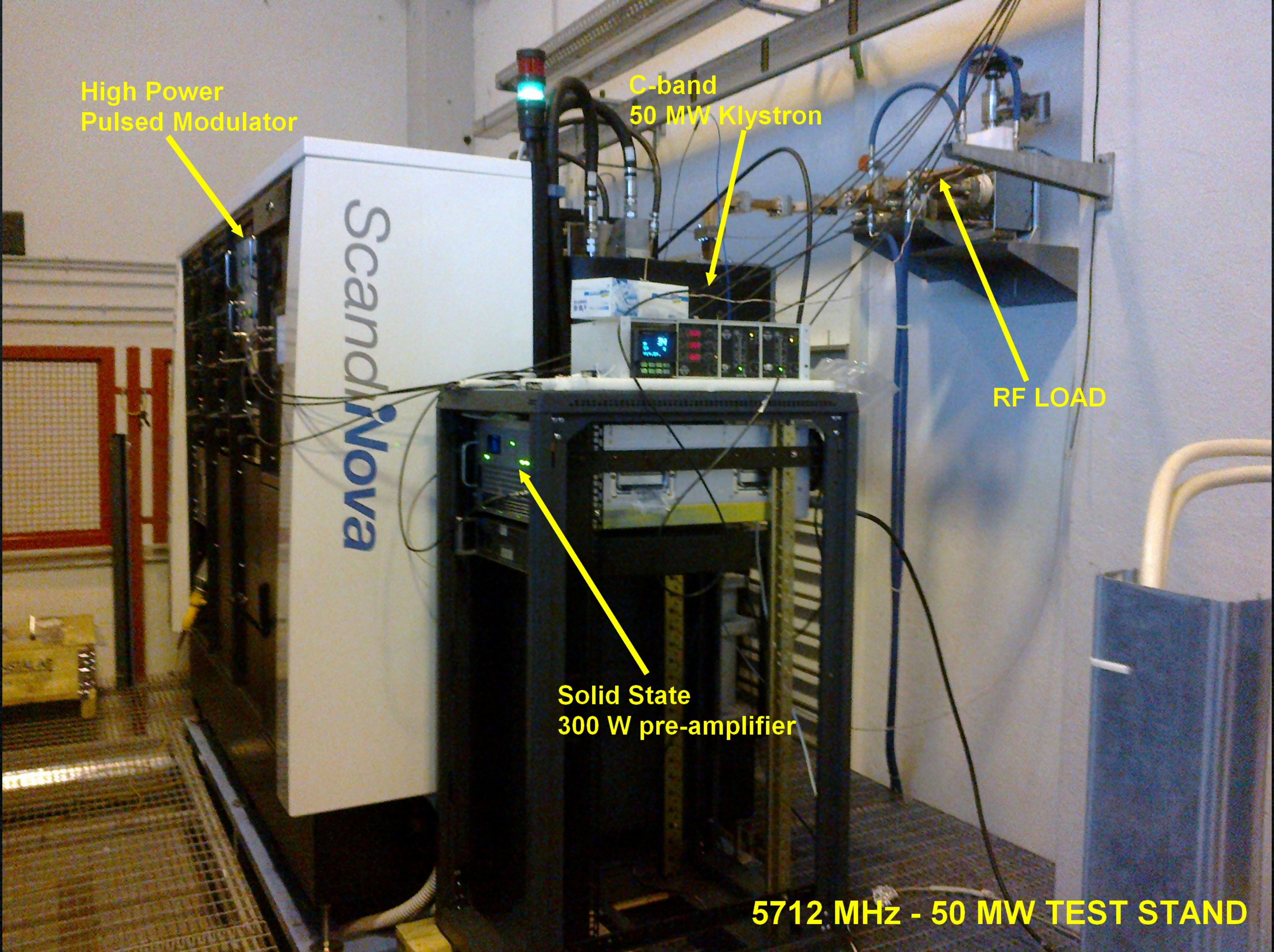
⇒ 1 **Pulsed HV modulator** supplied by ScandiNova (S)

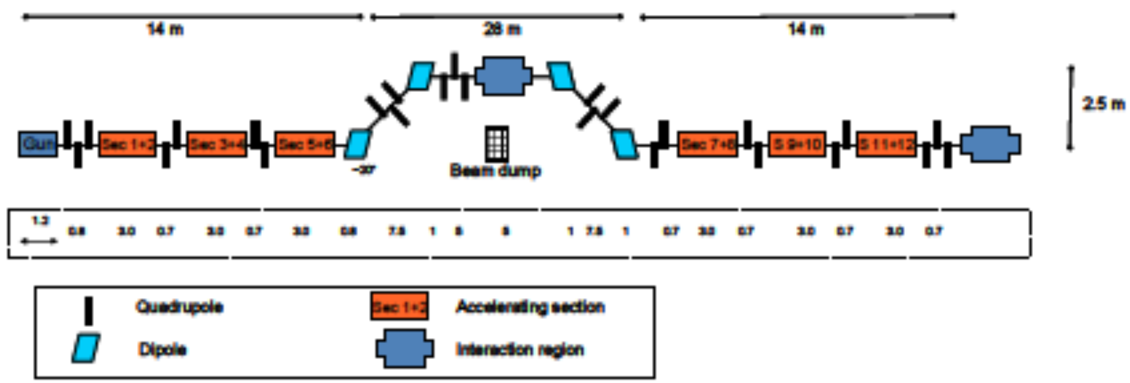
⇒ WR187 waveguide system

⇒ **400 W solid state driver** supplied by MitecTelecom (CDN)

⇒ **SLED**

D. Alesini et al. SPARC-RF-11/002 (2011)


High Power
Pulsed Modulator
C-band
50 MW Klystron
RF LOAD
ScandiNova
Solid State
300 W pre-amplifier
5712 MHz - 50 MW TEST STAND



Proposal for a high-brightness γ source for the ELI-NP facility

Version 1.02

The Romanian pillar, devoted to nuclear physics applications (ELI-NP) and aiming at producing high intensity γ ray sources, has gathered since then a broad community of scientists that have identified the technical needs of the machine in order to let it elevate to the world leading facility for this scientific activity. In particular, the γ source shall produce very intense and brilliant γ beam in the Energy range from 1-20 MeV with a bandwidth equal or lower than 10^{-3} and total photon flux higher than 10^{13} photons/sec at 100 %BW (equivalent to a peak brilliance higher than 10^{21} photons/mm²/mrad²/s/(0.1% BW)). This γ source can be obtained by incoherent Compton back scattering of direct laser light with a high-brightness (normalized emittance better than 0.5 mm.mrad), high energy (energy ~720 MeV) electron beam. It is envisioned that the γ source will be used in conjunction with the low repetition rate ELI-NP 10 PW laser beams for synergetic experiments.

Proposal for a high-brightness γ source for the ELI-NP facility

Version 1.02

JRA-ANAC2 Assessment of Novel Accelerator Concepts

Task 1. ANAC Coordination and Communication.

Coordination and scheduling of the WP tasks

Monitoring the work, informing the project management and participants within the JRA

WP budget follow-up

Task 2. Achievement of high brightness electron beam with laser plasma accelerators

Feasibility study of external injection done at INFN and HZDR

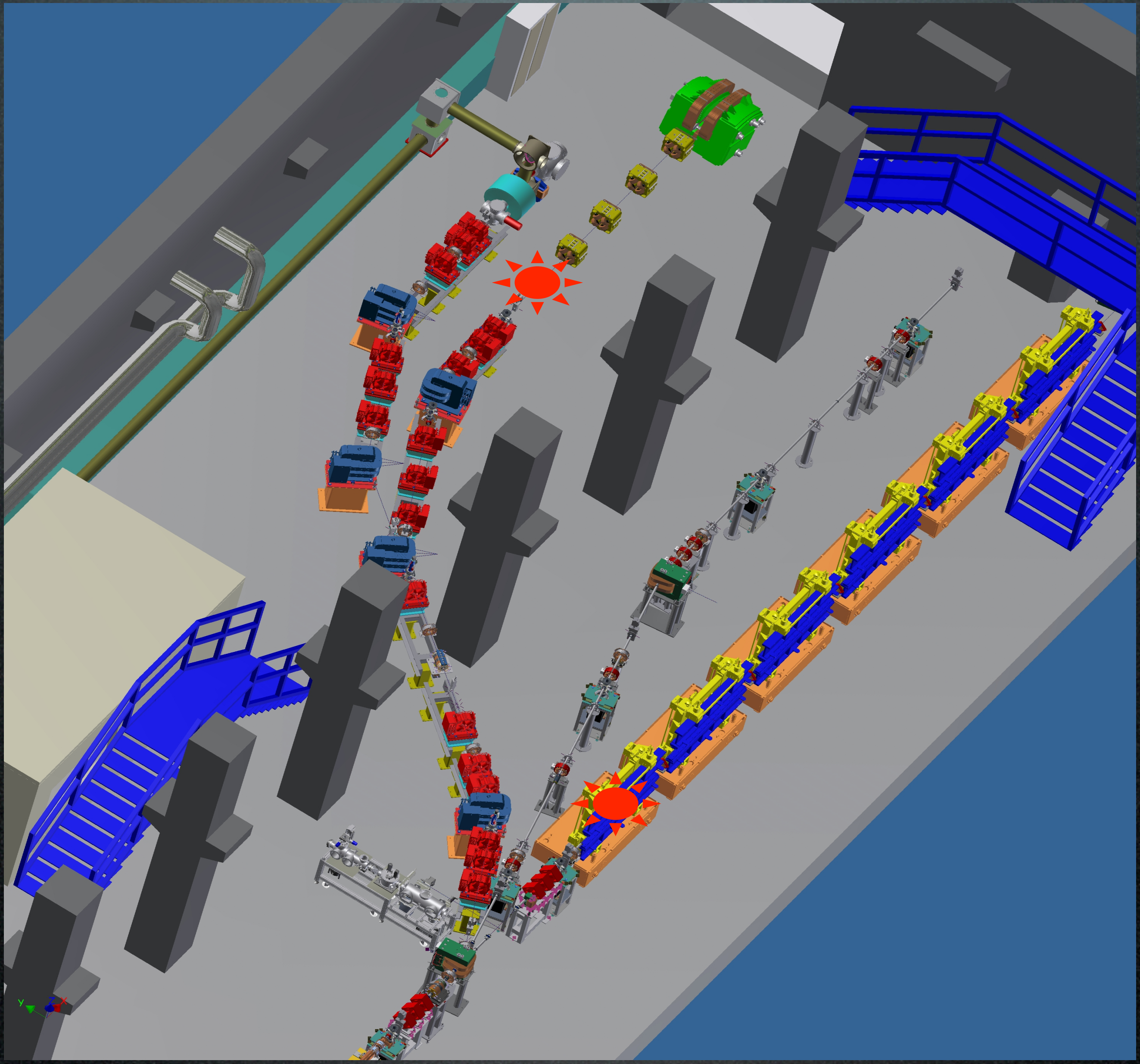
Optical injection done at LOA and LLC

Two stage laser plasma accelerator done at STRATH

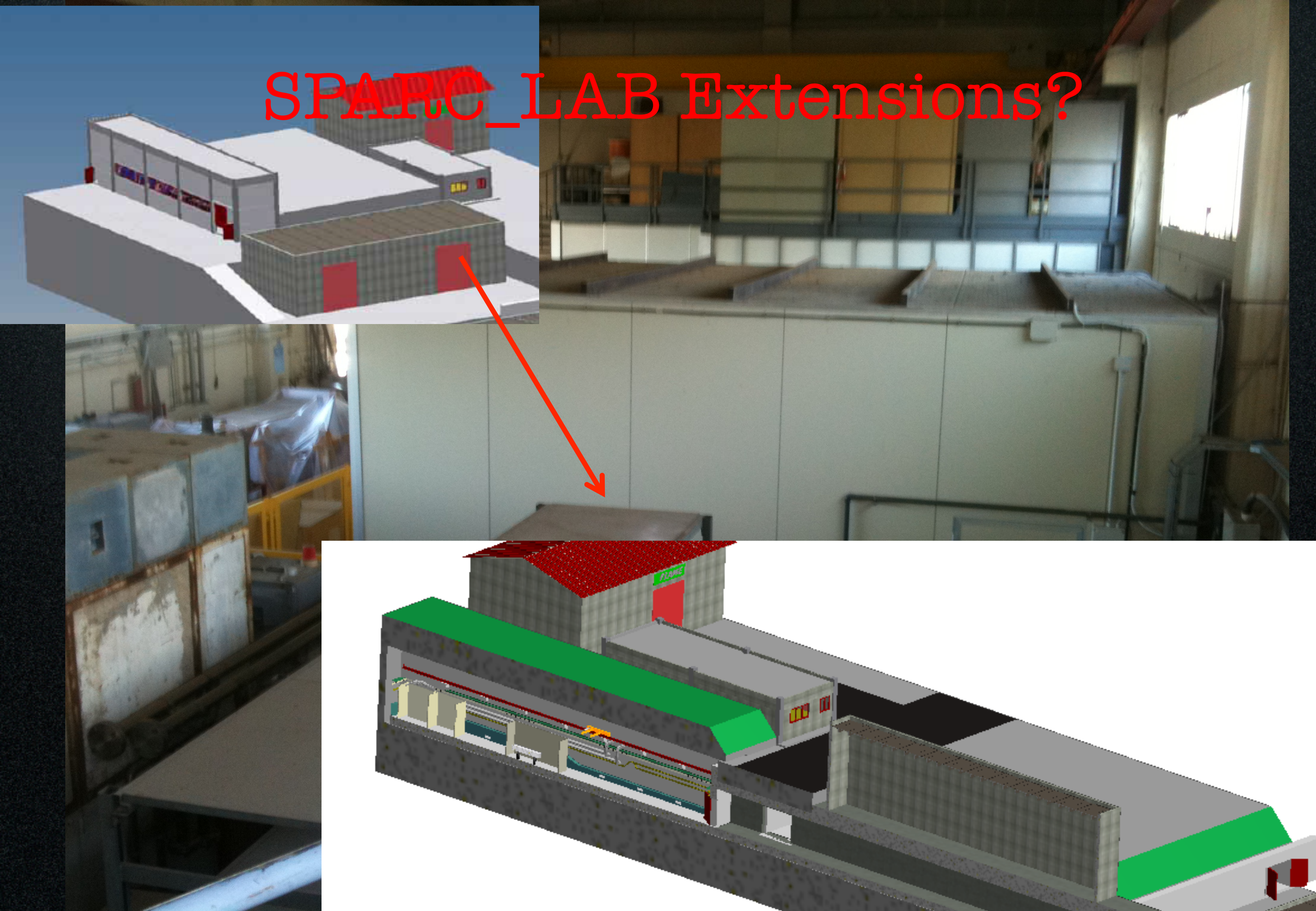
EuroNNAc

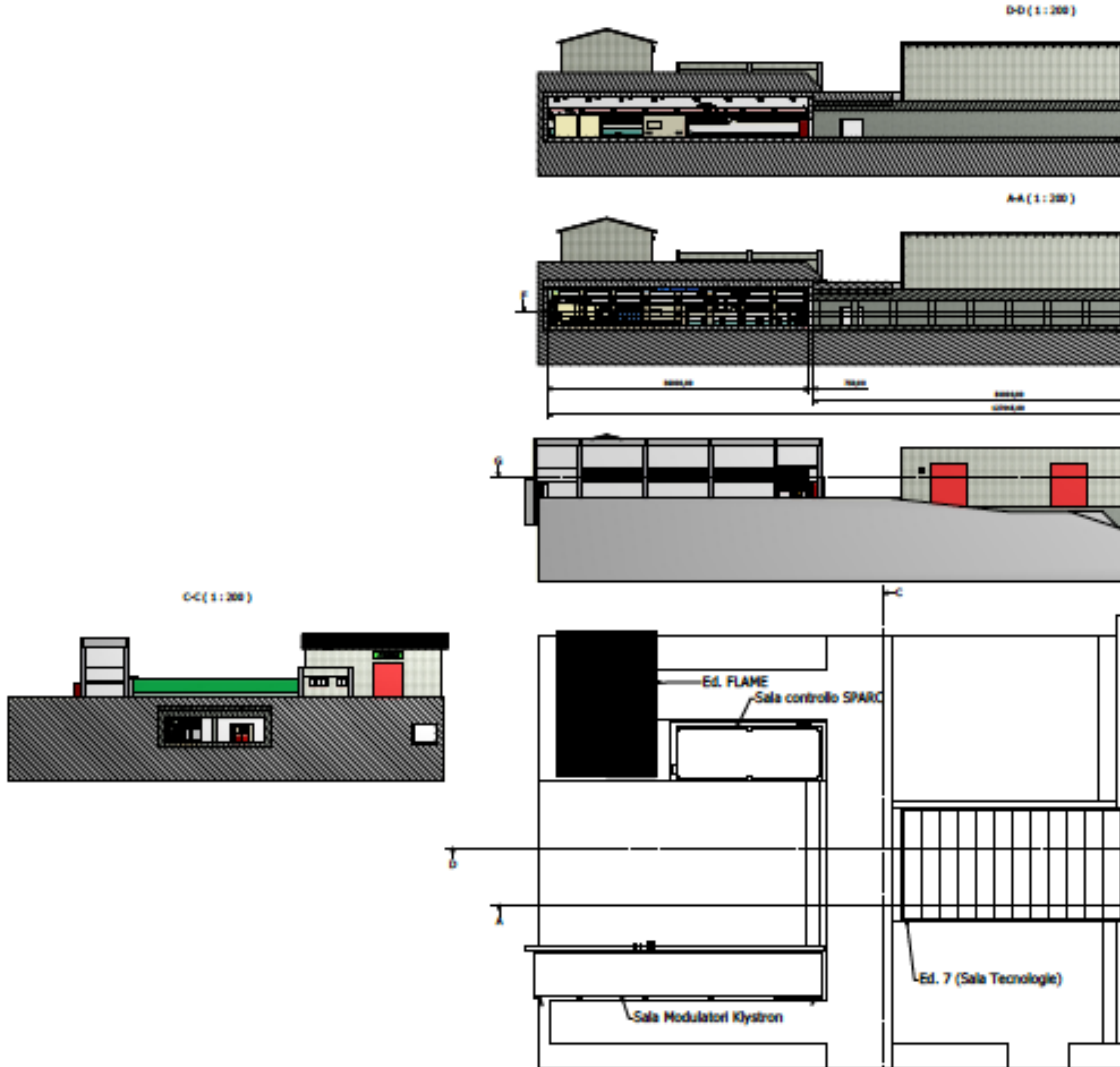
- What are the top x goals of the field (10y ahead)?
  - Demonstrate working plasma-based FEL at realistic frequencies
  - Reliable 24/7 operation of plasma-based accelerators @ 1 GeV
  - Staging
  - High plasma-based beam quality at 10 GeV
  - > GV/m positron acceleration with plasma devices and preserve emittance
  - Demonstrate proton drivers for wake acceleration

A FEL driven by Plasma Accelerator at LNF?



SPARC_LAB Extensions?

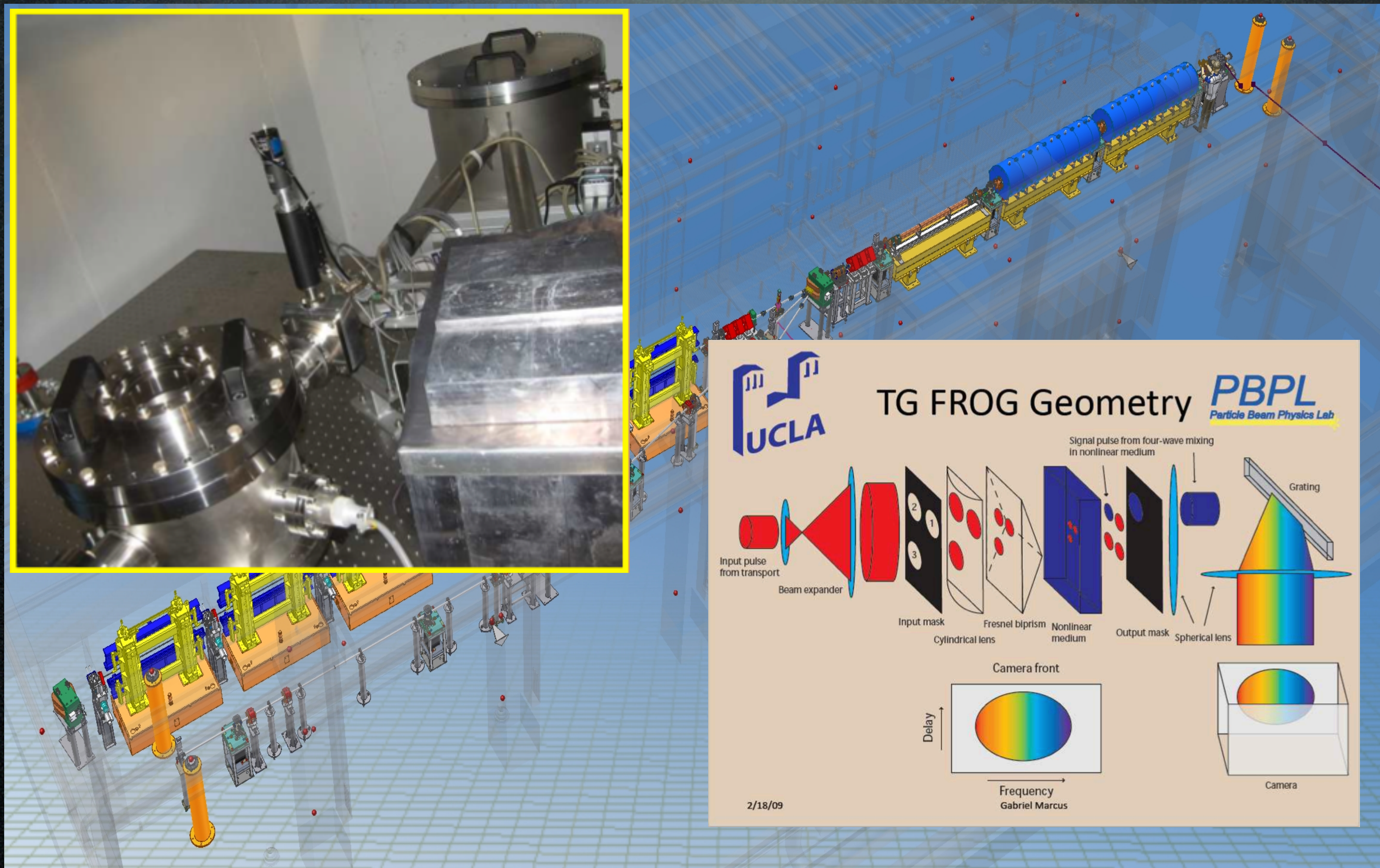



D-D (1 : 200)
A-A (1 : 200)
C-C (1 : 200)
Ed. FLAME
Sala controllo SPARC
Sala Modulatori Klystron
Ed. 7 (Sala Tecnologie)

SPARC_LAB Wishes

A facility based on the unique combination of high brightness electron beams with high intensity ultra-short laser pulses will be soon available for the entire accelerator community, such to allow the investigation of all the different configurations of plasma accelerator and the development of a wide spectrum inter-disciplinary leading-edge research activity


Thank you


UCLA
TG FROG Geometry
PBPL
Particle Beam Physics Lab
Signal pulse from four-wave mixing in nonlinear medium
Grating
Input pulse from transport
Beam expander
Input mask
Cylindrical lens
Fresnel biprism
Nonlinear medium
Output mask
Spherical lens
Camera front
Delay
Frequency
Camera
2/18/09
Gabriel Marcus