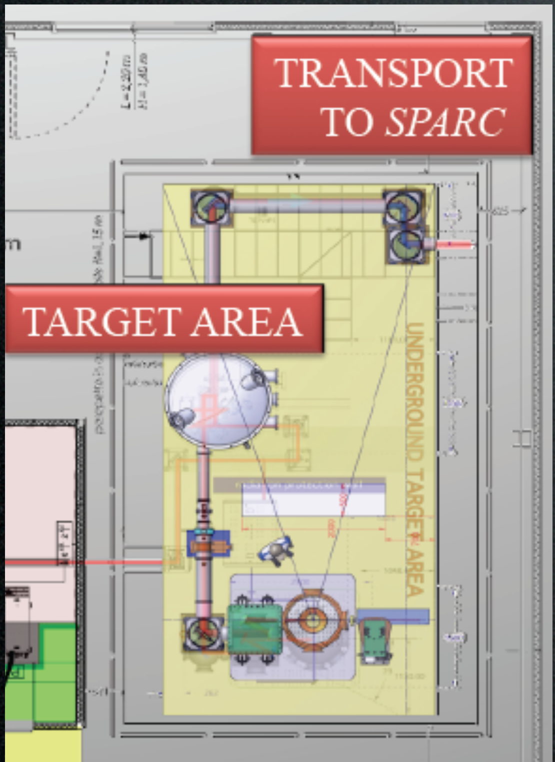
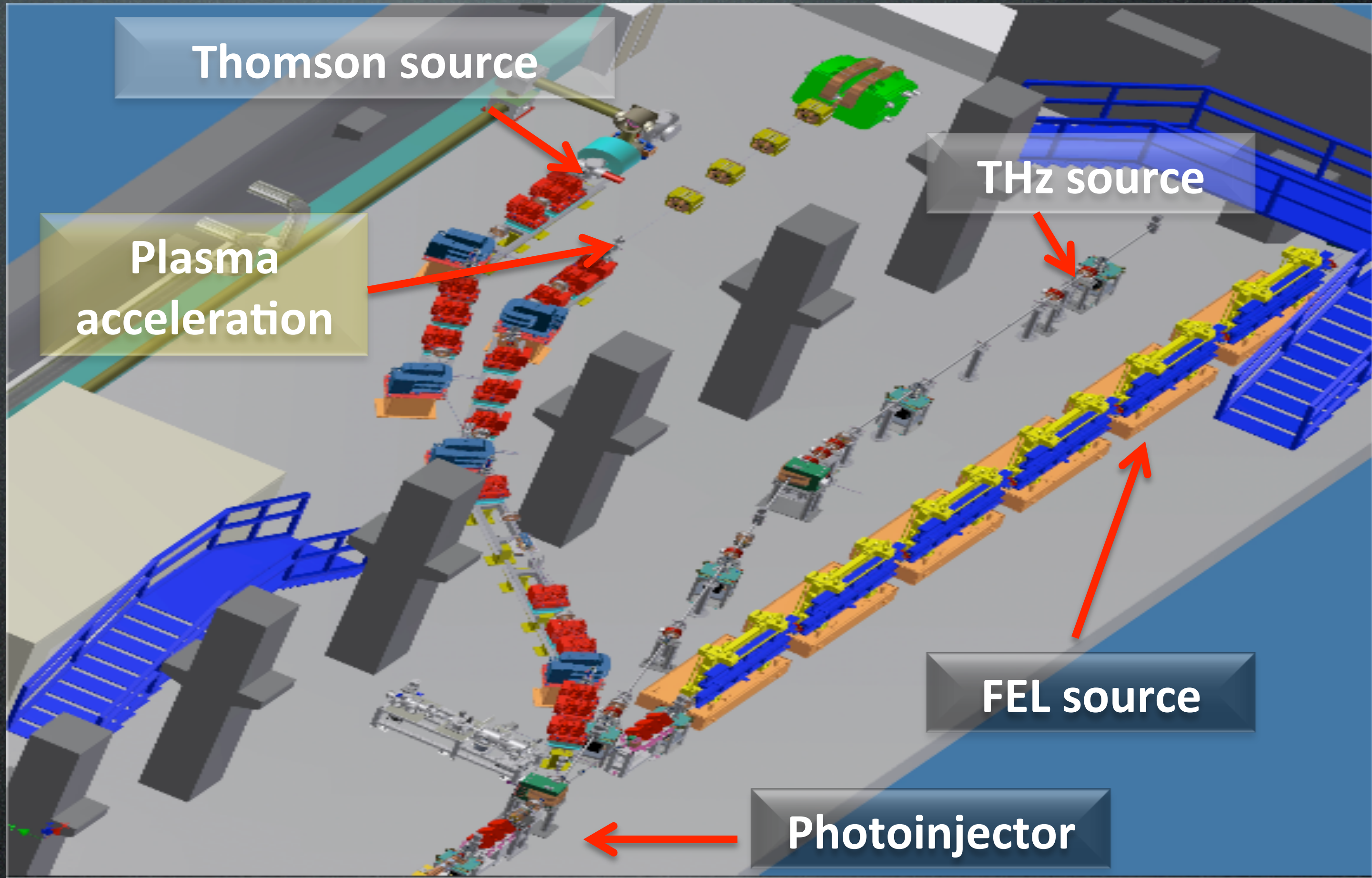
SPARC_LAB

Sources for Plasma Accelerators and Radiation Compton with Lasers And Beams

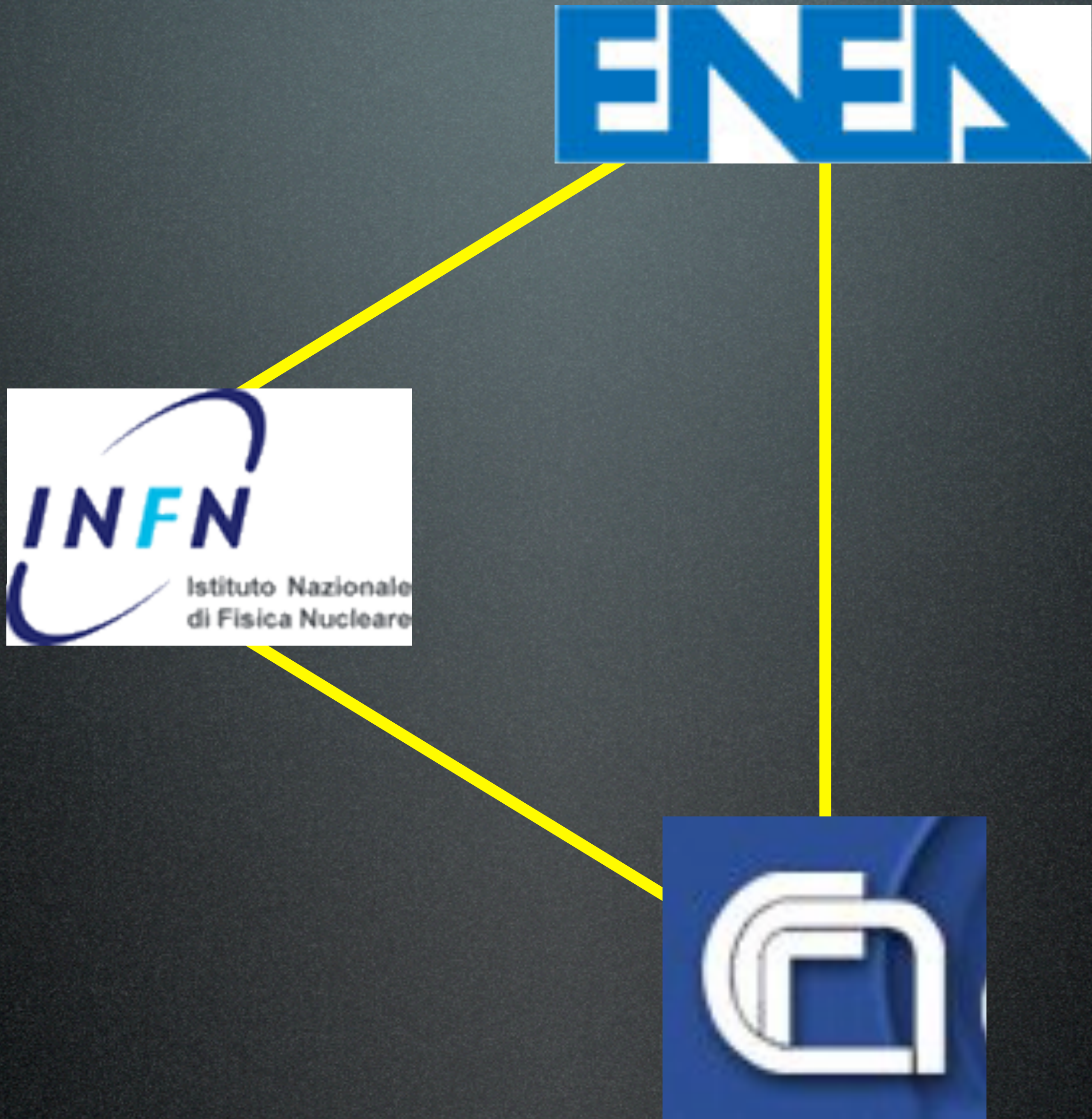
Massimo Ferrario

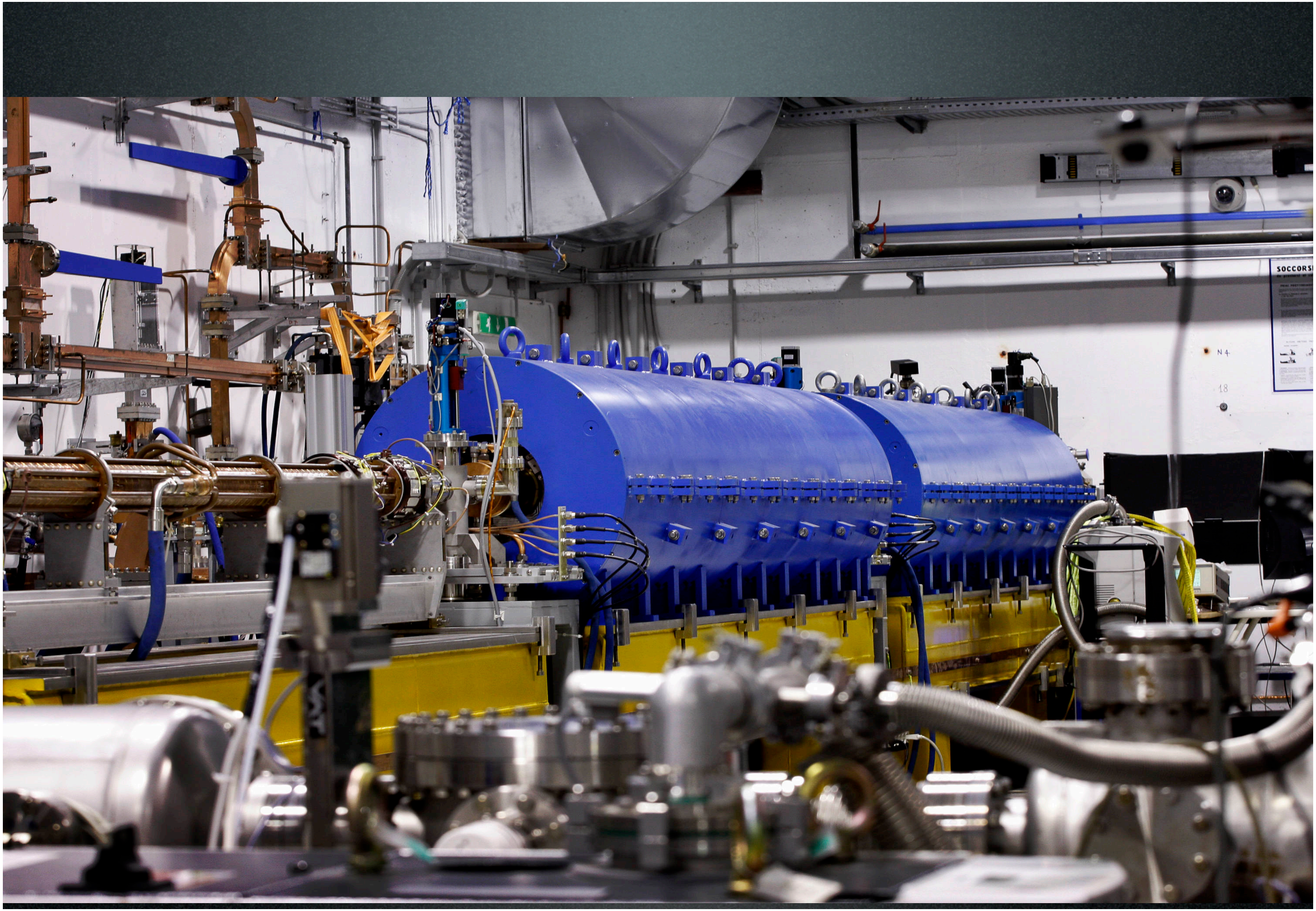
On behalf of the SPARC_LAB collaboration

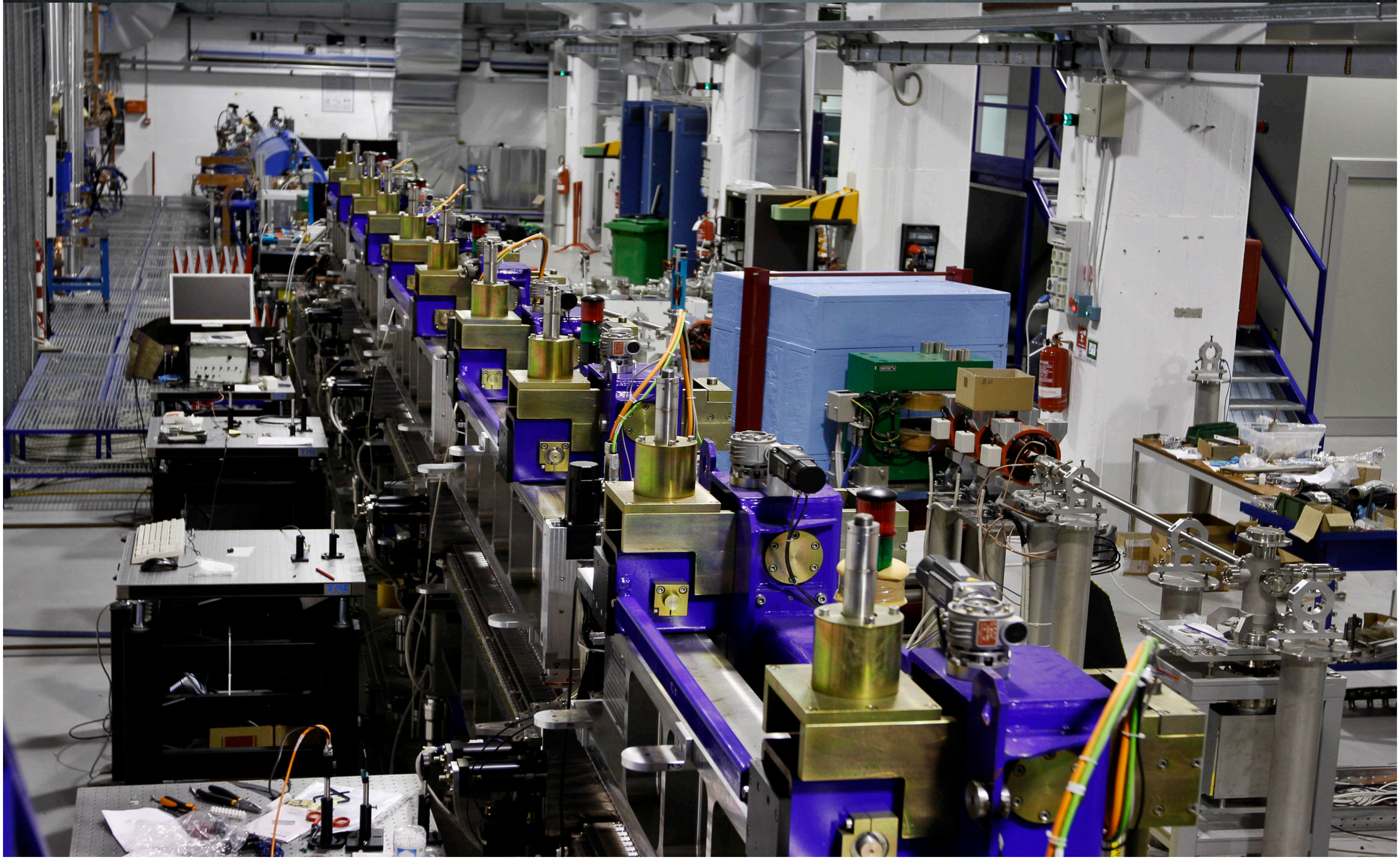


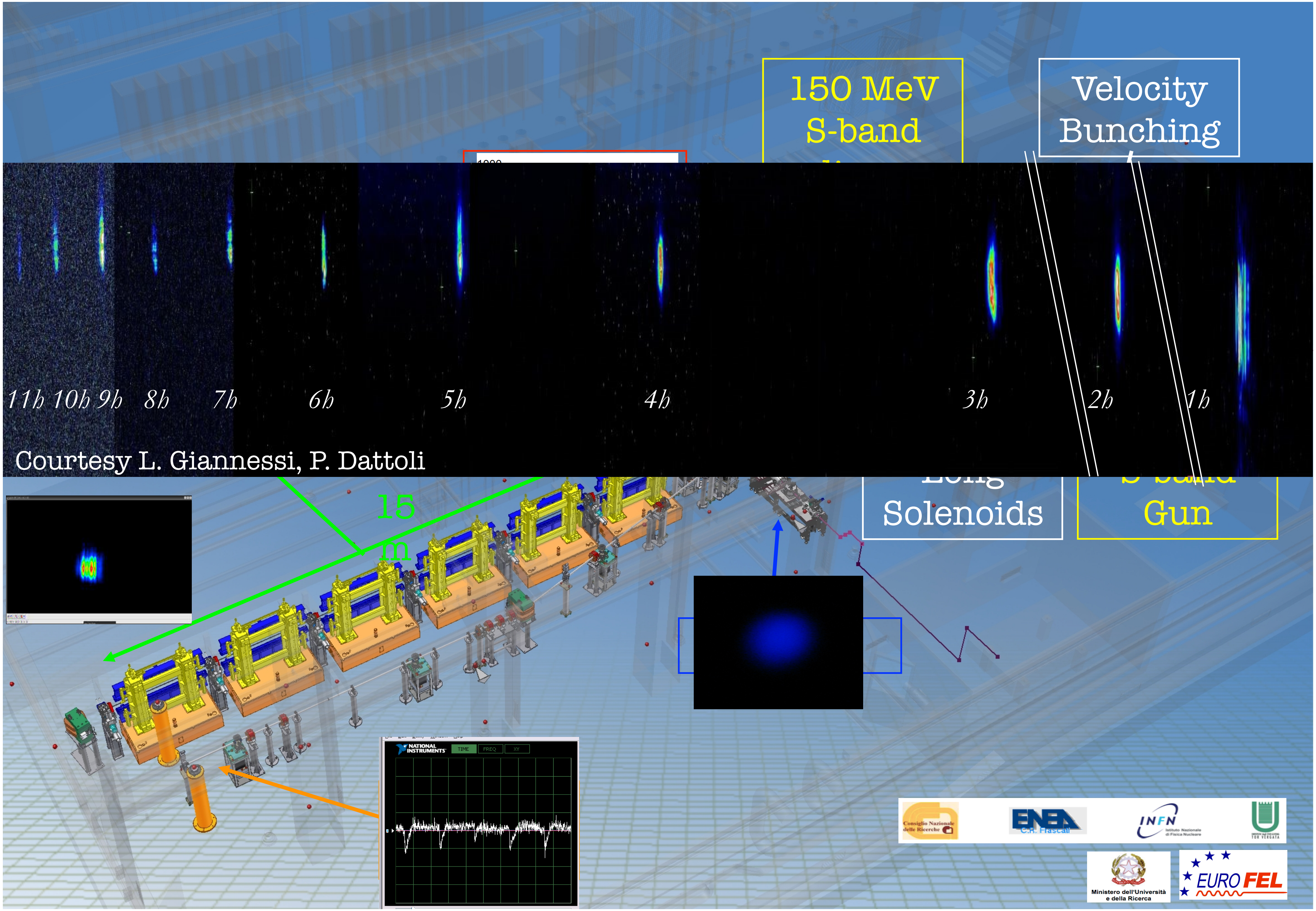


Helmholtz Virtual Institute on Plasma Acceleration @SLAC – October 9, 2012

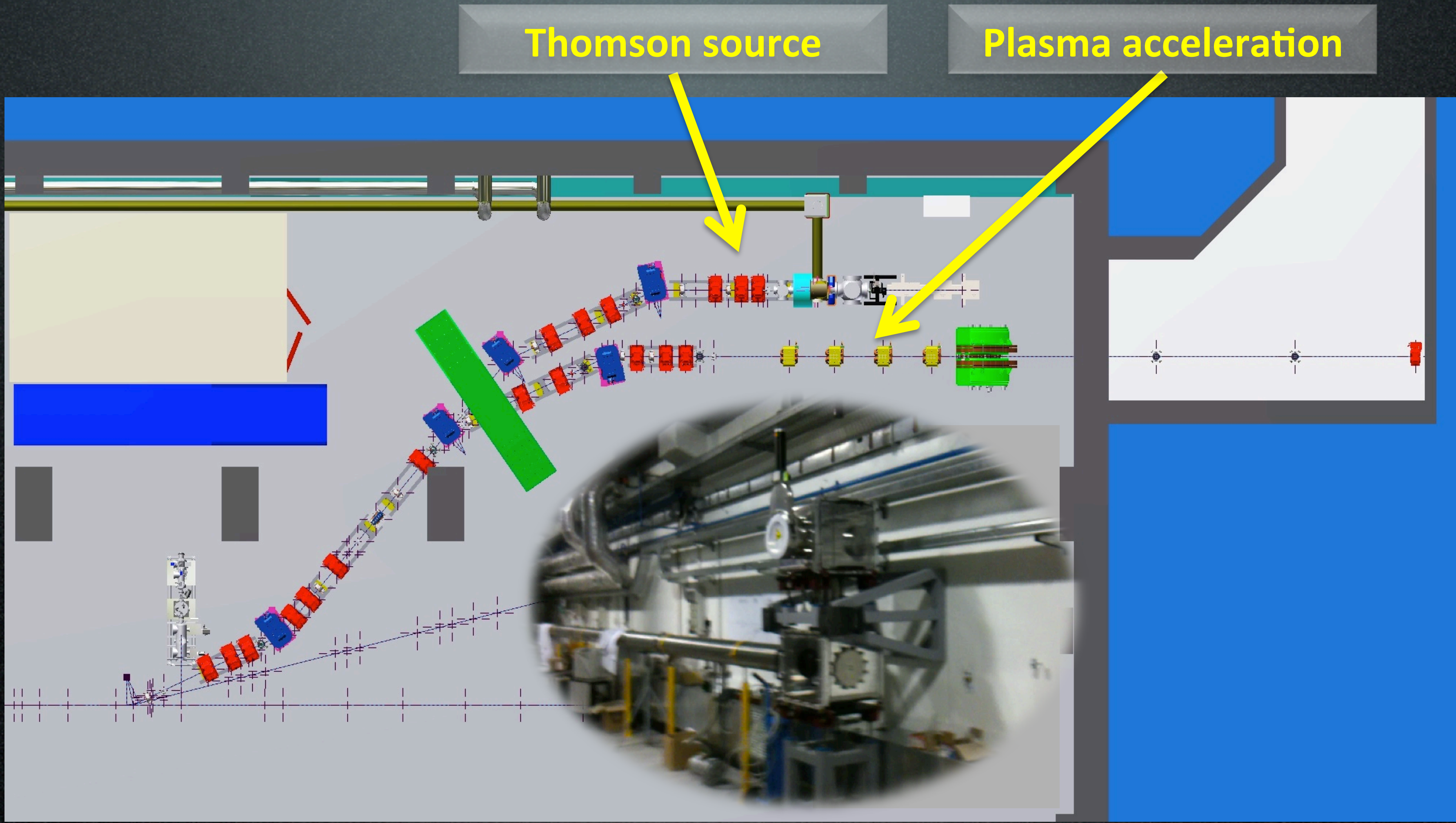

ENEA
INFN
Istituto Nazionale
di Fisica Nucleare






150 MeV
S-band
Velocity
Bunching
11h 10h 9h 8h 7h 6h 5h 4h 3h 2h 1h
Courtesy L. Giannessi, P. Dattoli
Solenoids
Gun
15
m
NATIONAL INSTRUMENTS
TIME
FREQ
XY
Consiglio Nazionale delle Ricerche
ENEA
C.R. Frascati
INFN
Istituto Nazionale di Fisica Nucleare
Ministero dell'Università e della Ricerca
EURO FEL

New installations



SPARC Hall update

Electron beamlines

The SPARC_LAB Activities

- **Laser/Plasma physics (High gradient acceleration)**
  - Particle Beam driven Plasma Acceleration (COMB)
  - Laser Driven with External injection (EXIN)
  - Laser Driven with Self-Injection (SITE => γ-RESIST)

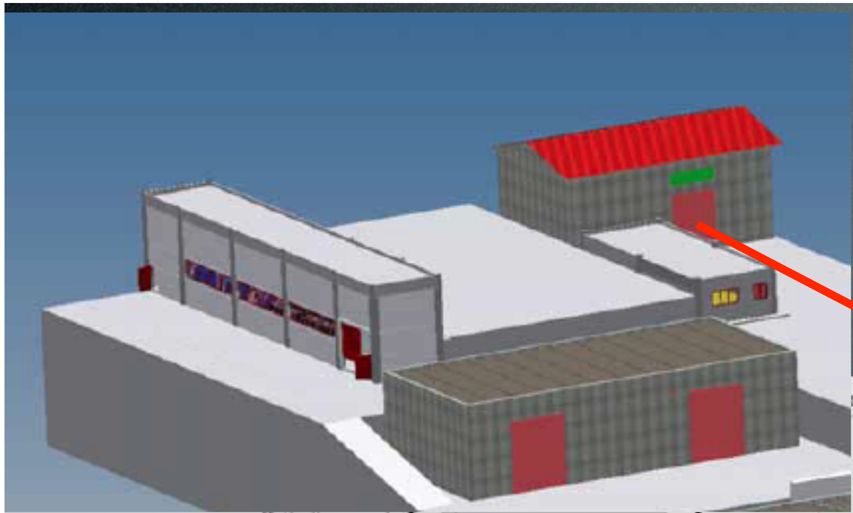
- **FEL physics (EUROFEL)**
  - 4-pulses comb beam
  - Three stages superradiant cascade
  - Seed sources: Kagome' fibers (N. Joly, M. E. Couprie)

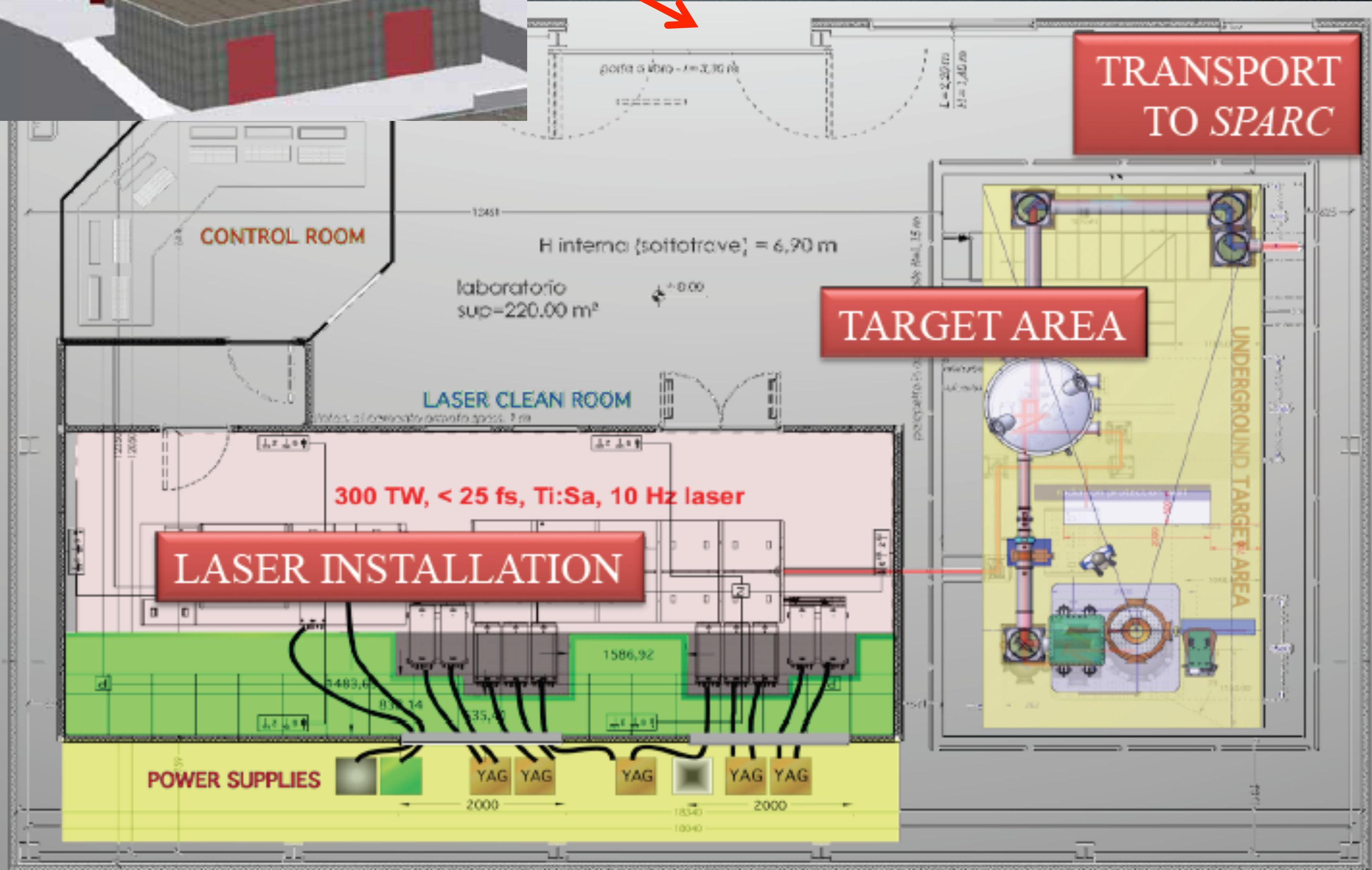
- **Advanced radiation sources and applications**
  - X-ray Thomson (ELI-NP, THOMSON, <= BEATS2, γ-RESIST)
  - THz radiation (TERASPARC => FEMTOTERA)

- **Advanced beam physics and accelerator technology**
  - ELI-NP and XFEL@SuperB
  - COMB

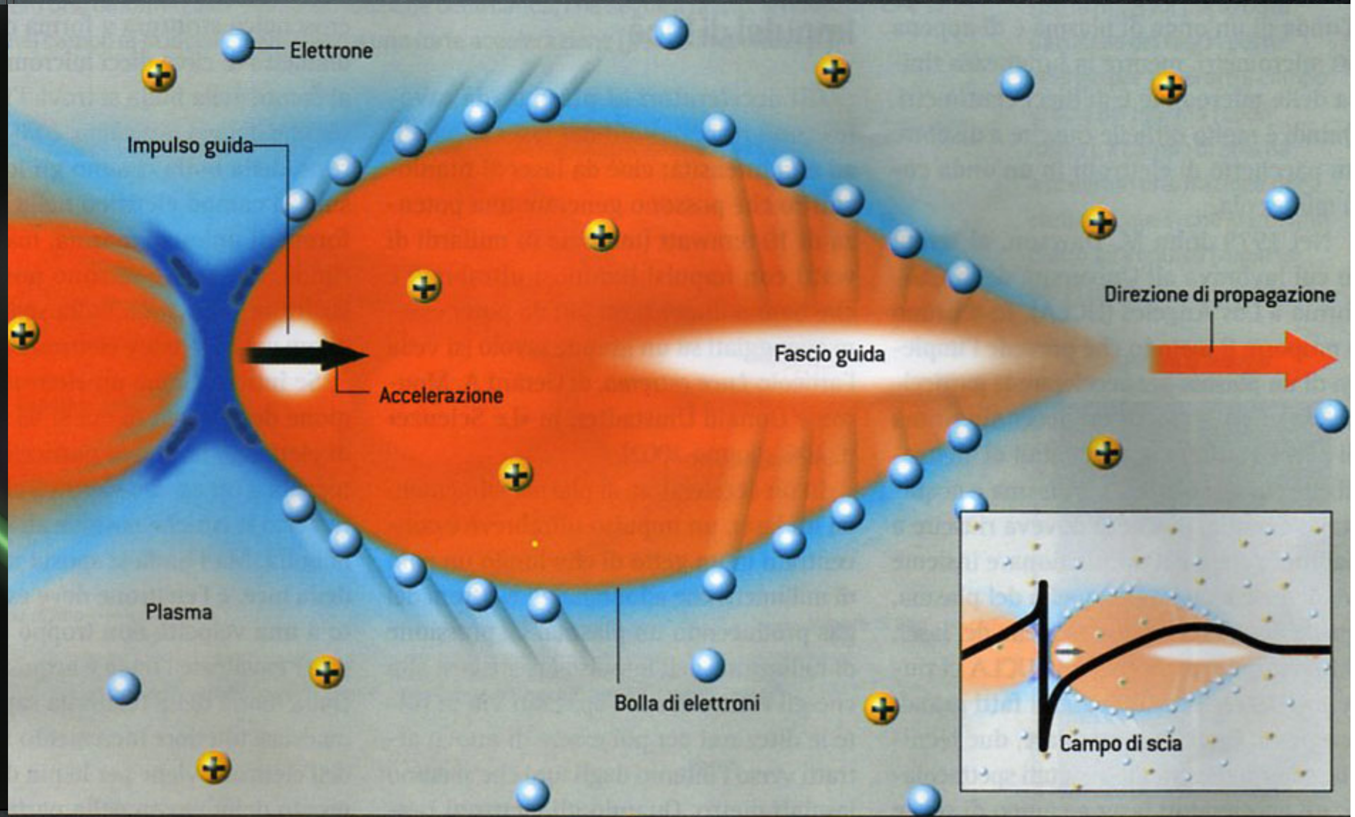
- **Laser/Plasma based ion sources** (LILIA)
- **Positron source** (POSSO)

FLAME Laser



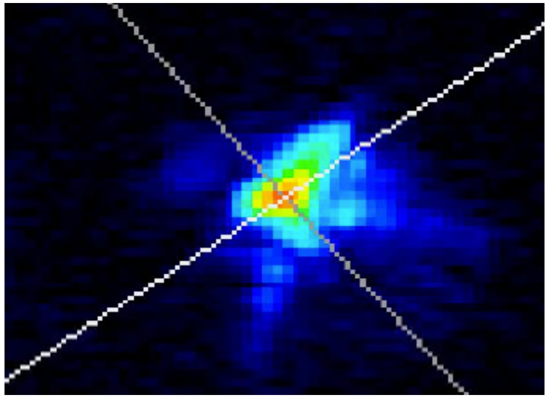

TRANSPORT TO *SPARC*
CONTROL ROOM
H interna (sottotrave) = 6,70 m
laboratorio
sup=220.00 m²
TARGET AREA
LASER CLEAN ROOM
300 TW, < 25 fs, Ti:Sa, 10 Hz laser
LASER INSTALLATION
UNDERGROUND TARGET AREA
POWER SUPPLIES
YAG
YAG
YAG
YAG
YAG
2000
2000

FLAME Target Area

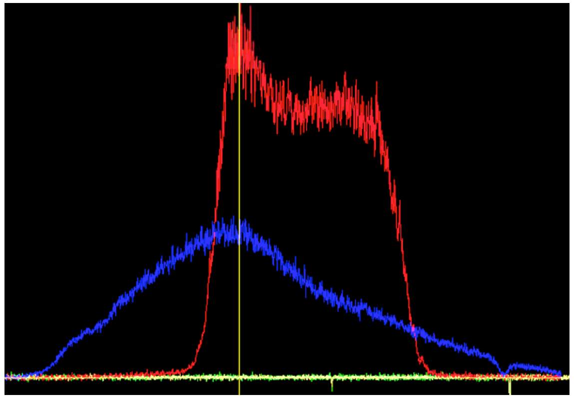


SL-SITE: Status of FLAME

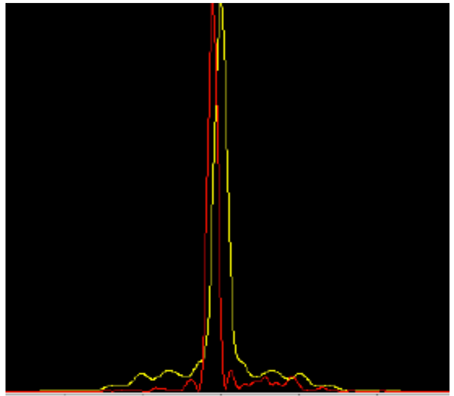
- **FLAME laser now fully operational after major maintenance (April-June 2012);**



Focal spot: 10 μm



Bandwidth: 80 nm



Duration <30 fs

Pulse has been transported on target for the Self-injection operation

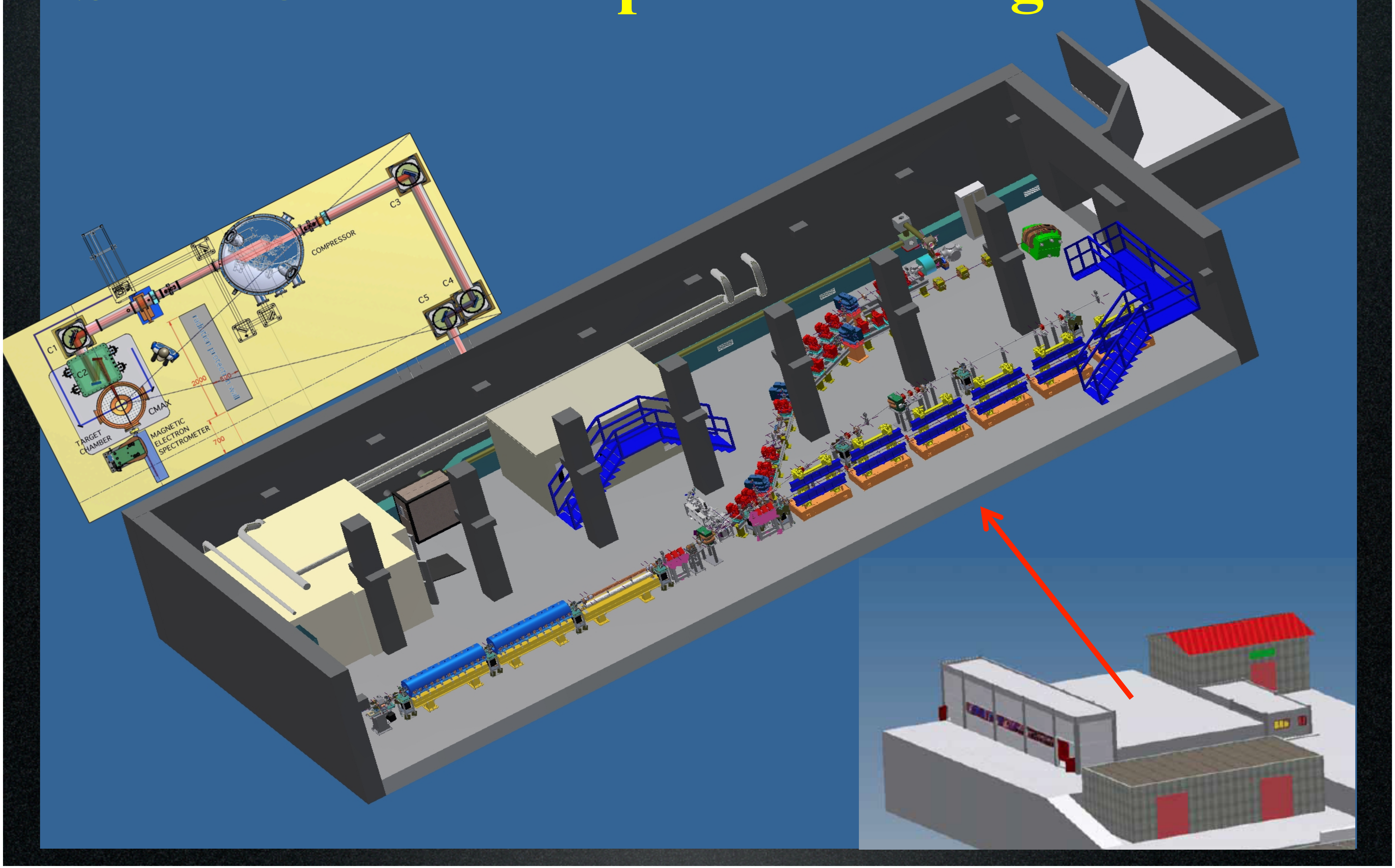
Latest run: LANEX – no magnet

Impact of accelerated bunch on LANEX screen

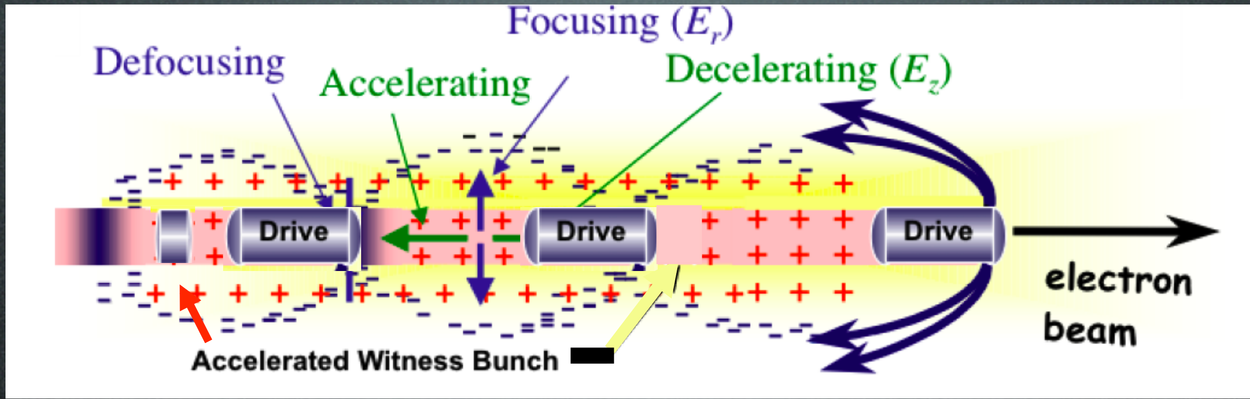
Ultra-collimated bunch <1mrad

After complete re-optimization of FLAME, electron acceleration is now <u>reproducible</u> and <u>reliable</u>, with stable > 100 MeV scale energy

SPARC bunker – present configuration



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 ?

Laser Comb: a train of THz bunches

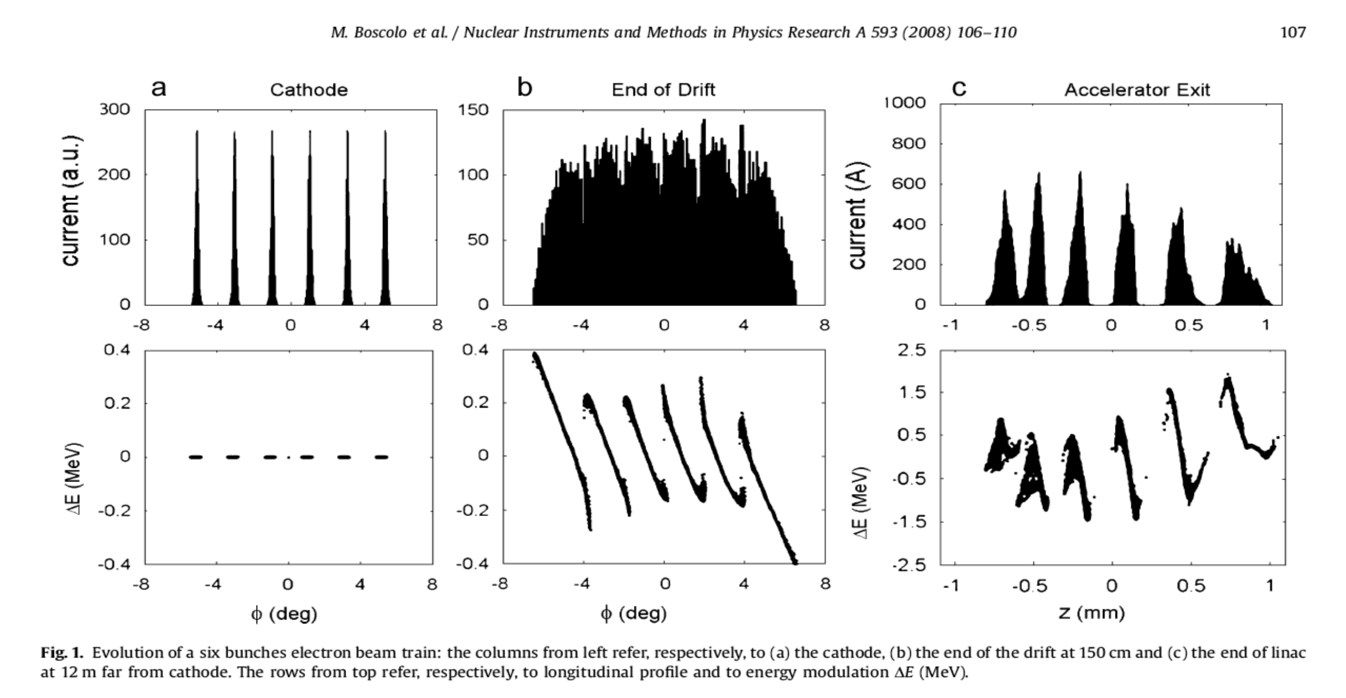
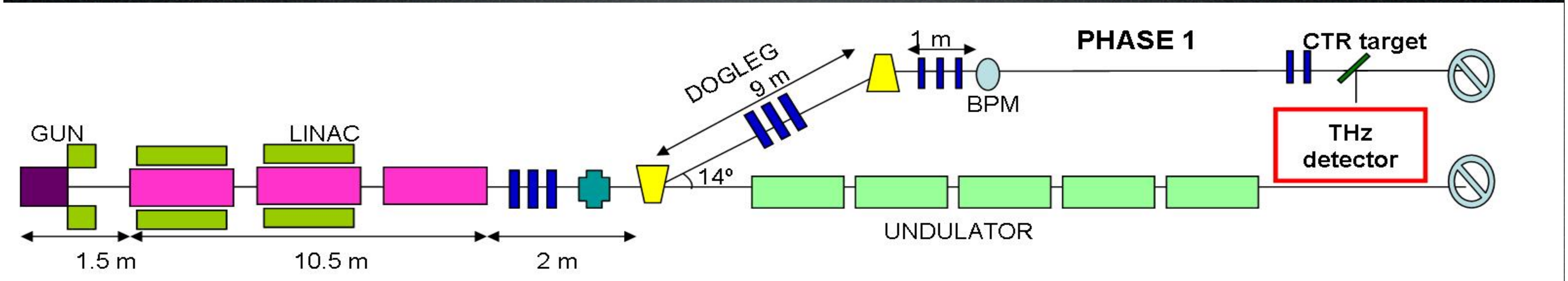


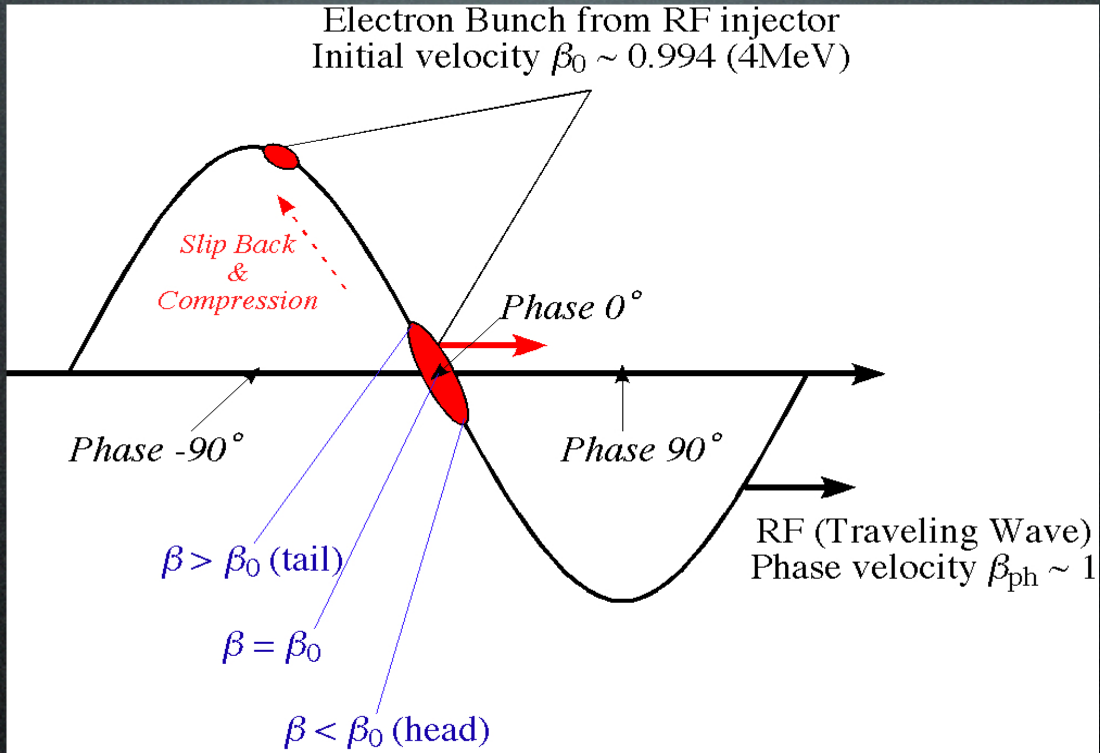
Fig. 1. Evolution of a six bunches electron beam train: the columns from left refer, respectively, to (a) the cathode, (b) the end of the drift at 150 cm and (c) the end of linac at 12 m far from cathode. The rows from top refer, respectively, to longitudinal profile and to energy modulation ΔE (MeV).



- P.O.Shea et al., Proc. of 2001 IEEE PAC, Chicago, USA (2001) p.704.
- M. Ferrario. M. Boscolo et al., Int. J. of Mod. Phys. B, 2006 (Taipei 05 Workshop)

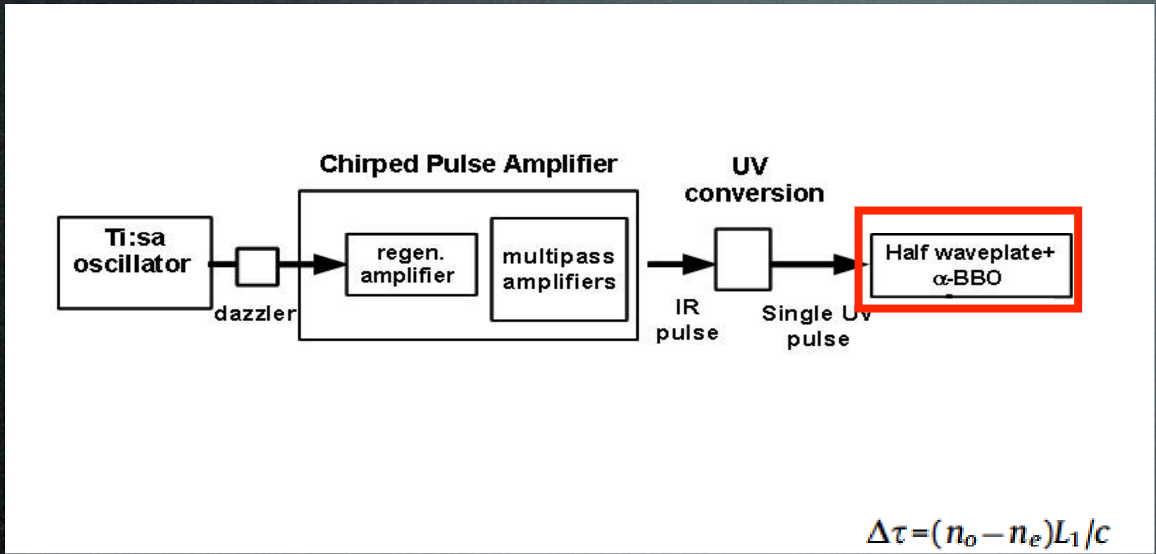
Velocity bunching concept (RF Compressor)

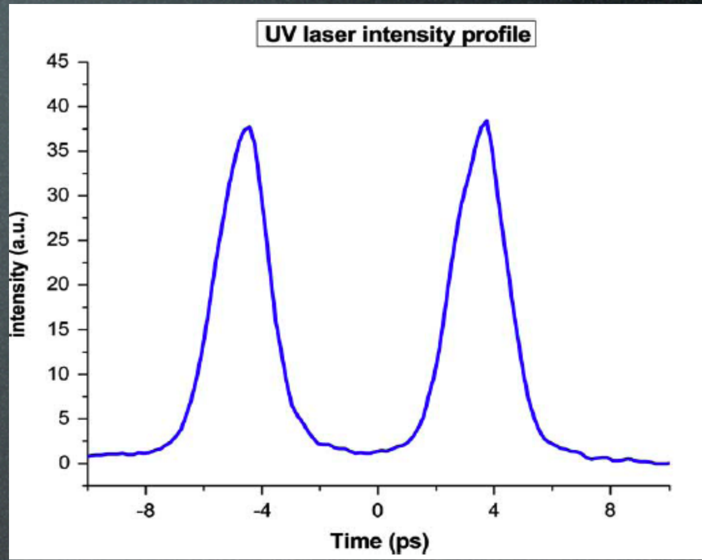
If the beam injected in a long accelerating structure at the crossing field phase and it is slightly slower than the phase velocity of the RF wave , it will slip back to phases where the field is accelerating, but at the same time it will be chirped and compressed.



The key point is that compression and acceleration take place at the same time within the same linac section, actually the first section following the gun, that typically accelerates the beam, under these conditions, from a few MeV (> 4) up to 25-35 MeV.

A train of laser pulses at the cathode

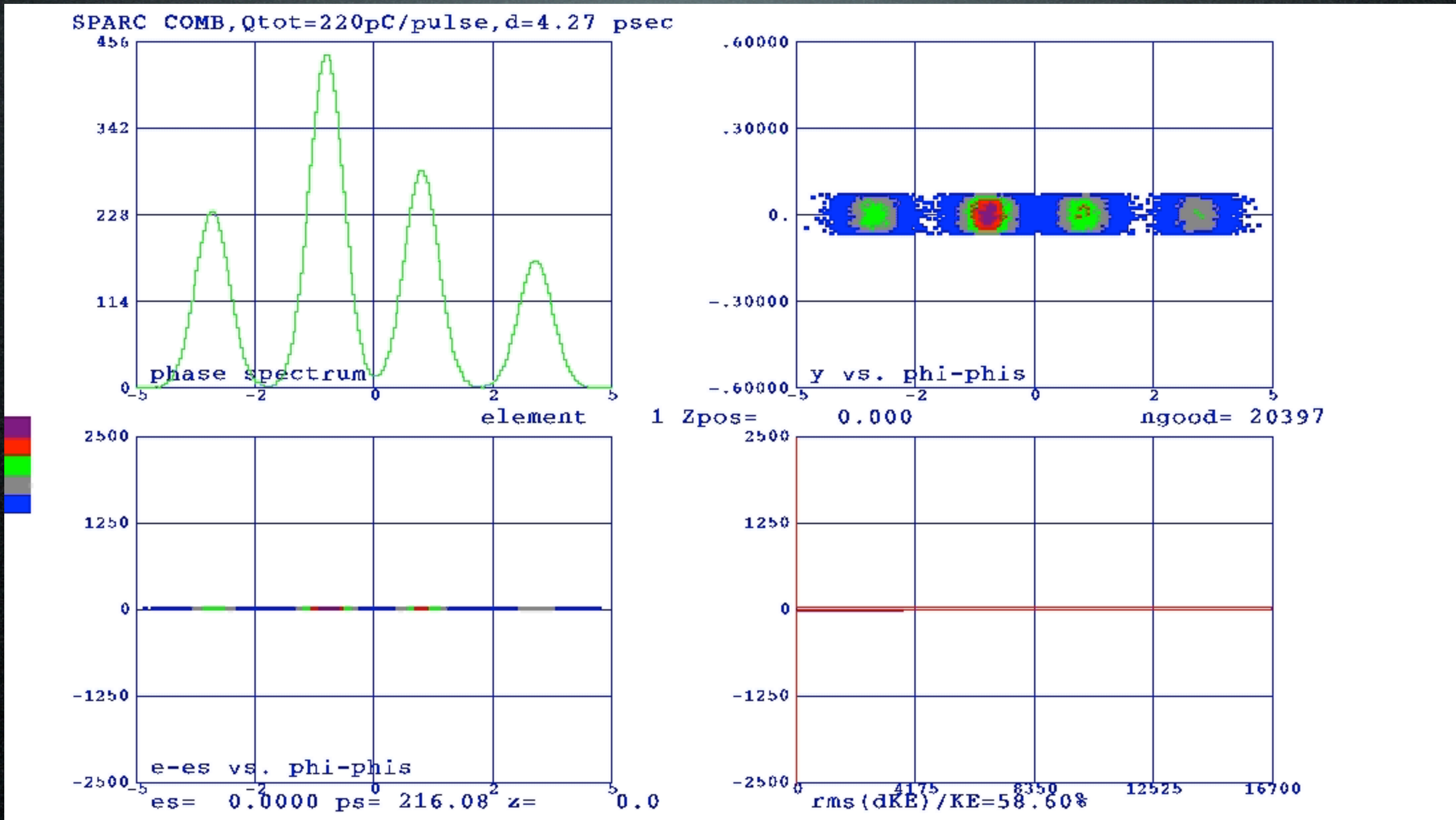




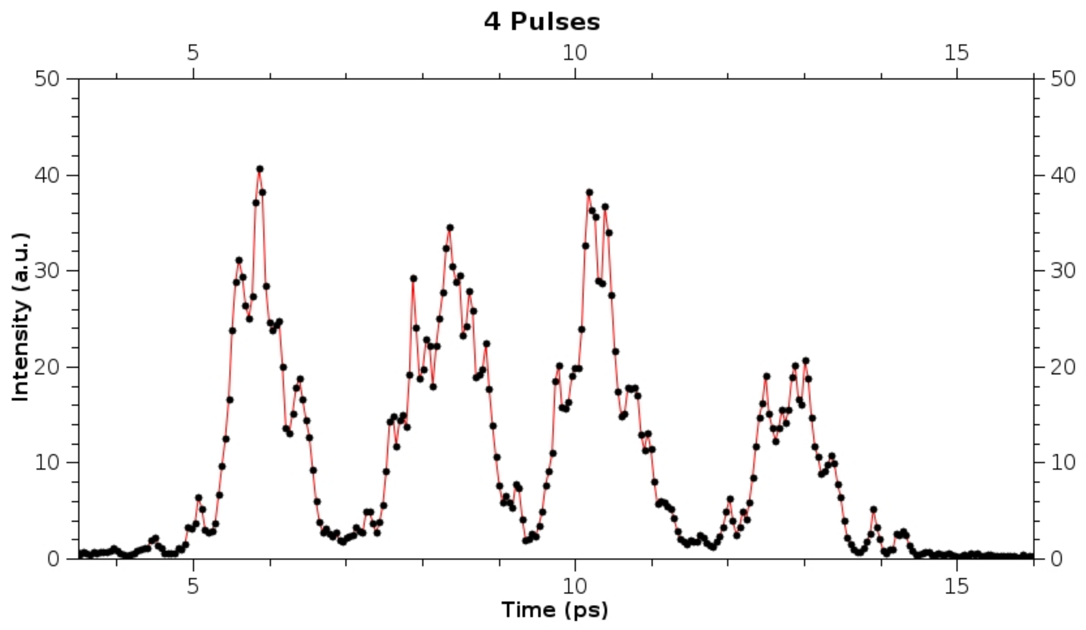
The technique used for this purpose relies on a birefringent crystal, where the input pulse is decomposed in two orthogonally polarized pulses with a time separation proportional to the crystal length.

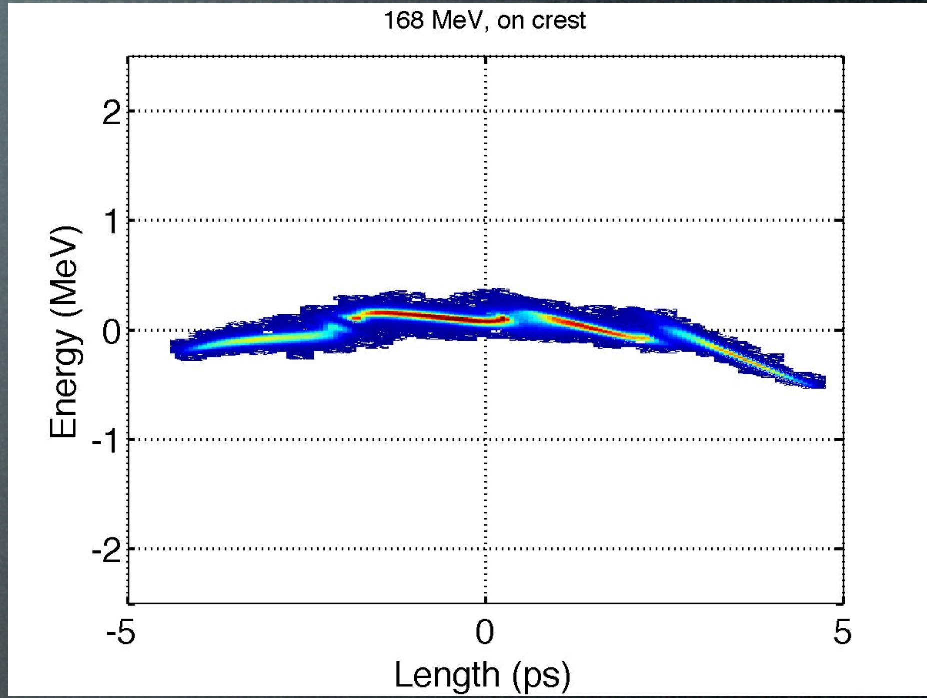
Different crystal thickness are available (10.353 mm in this case).
Using more than one crystals, one can generate bunch trains (e.g. 4 bunches).
The intensity along the pulse train can be modulated

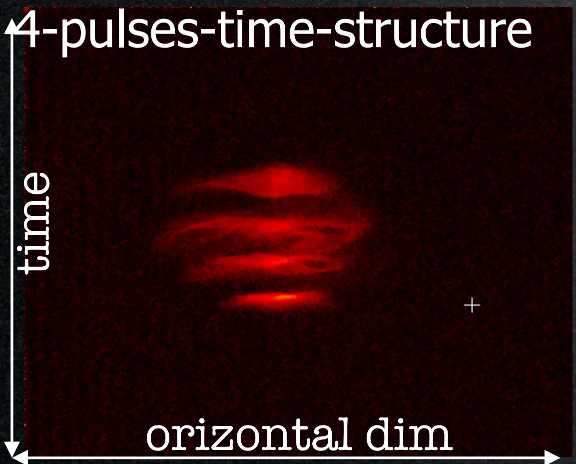
Laser COMB technique

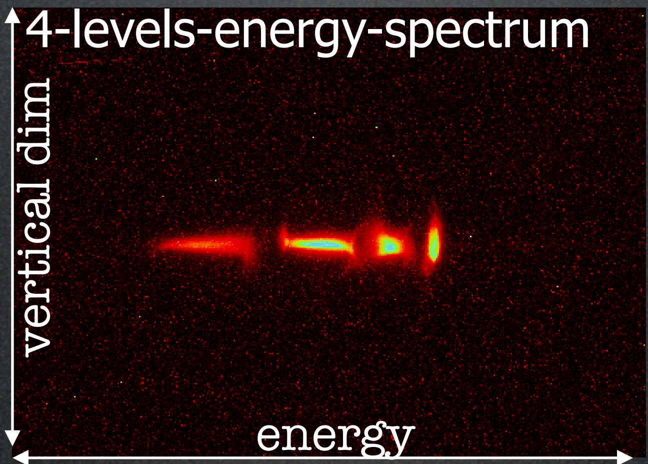


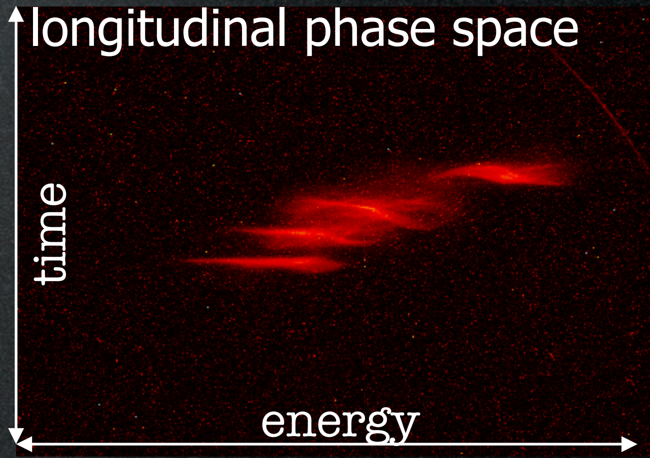
Laser COMB technique





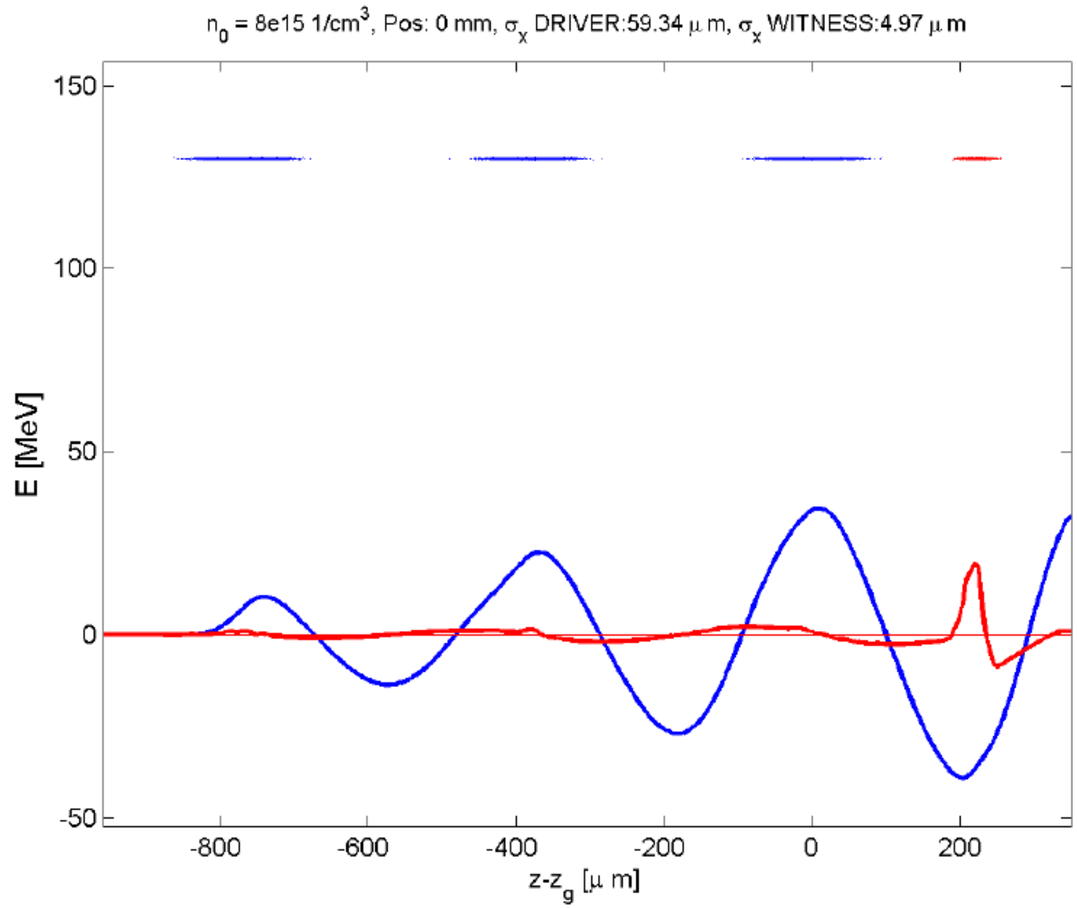


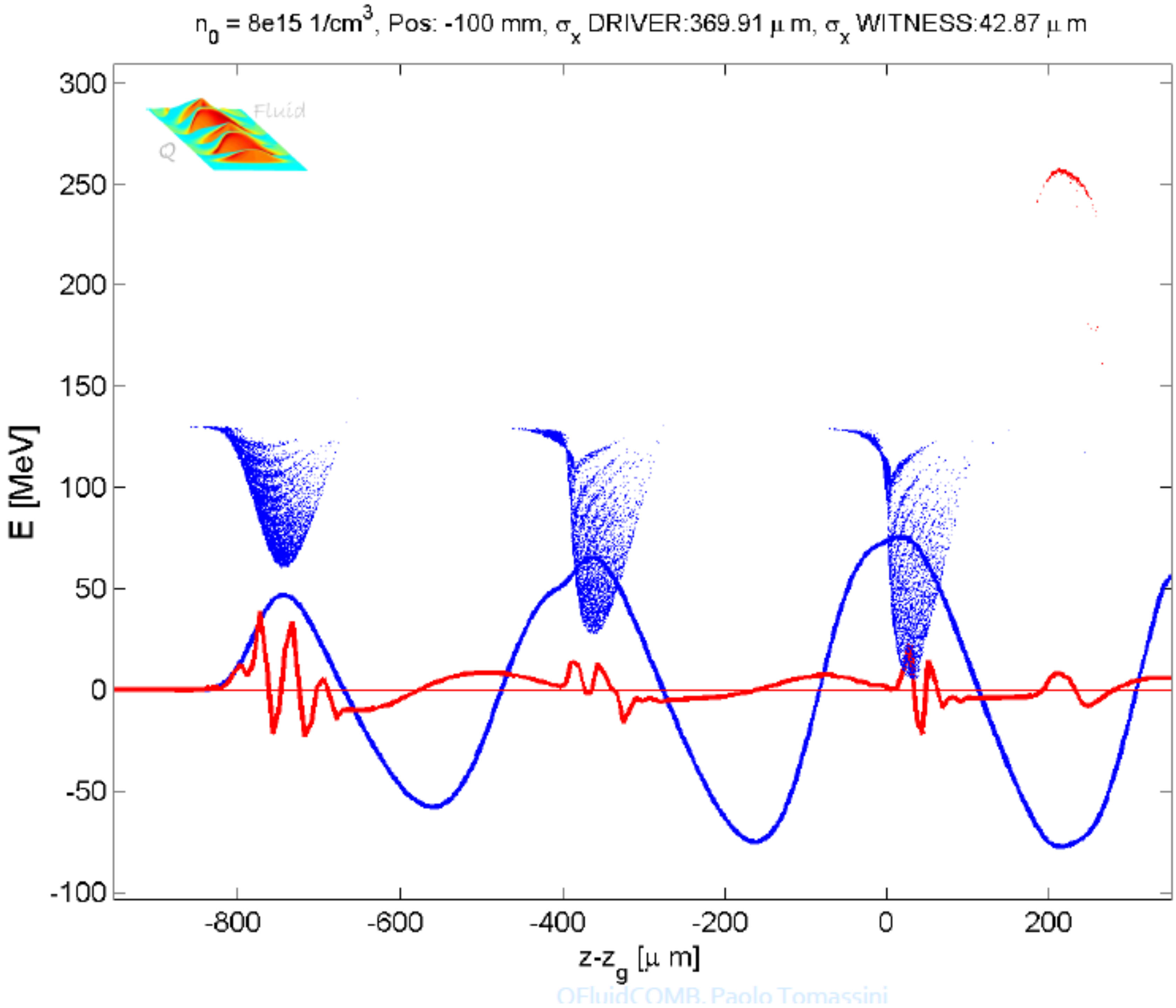




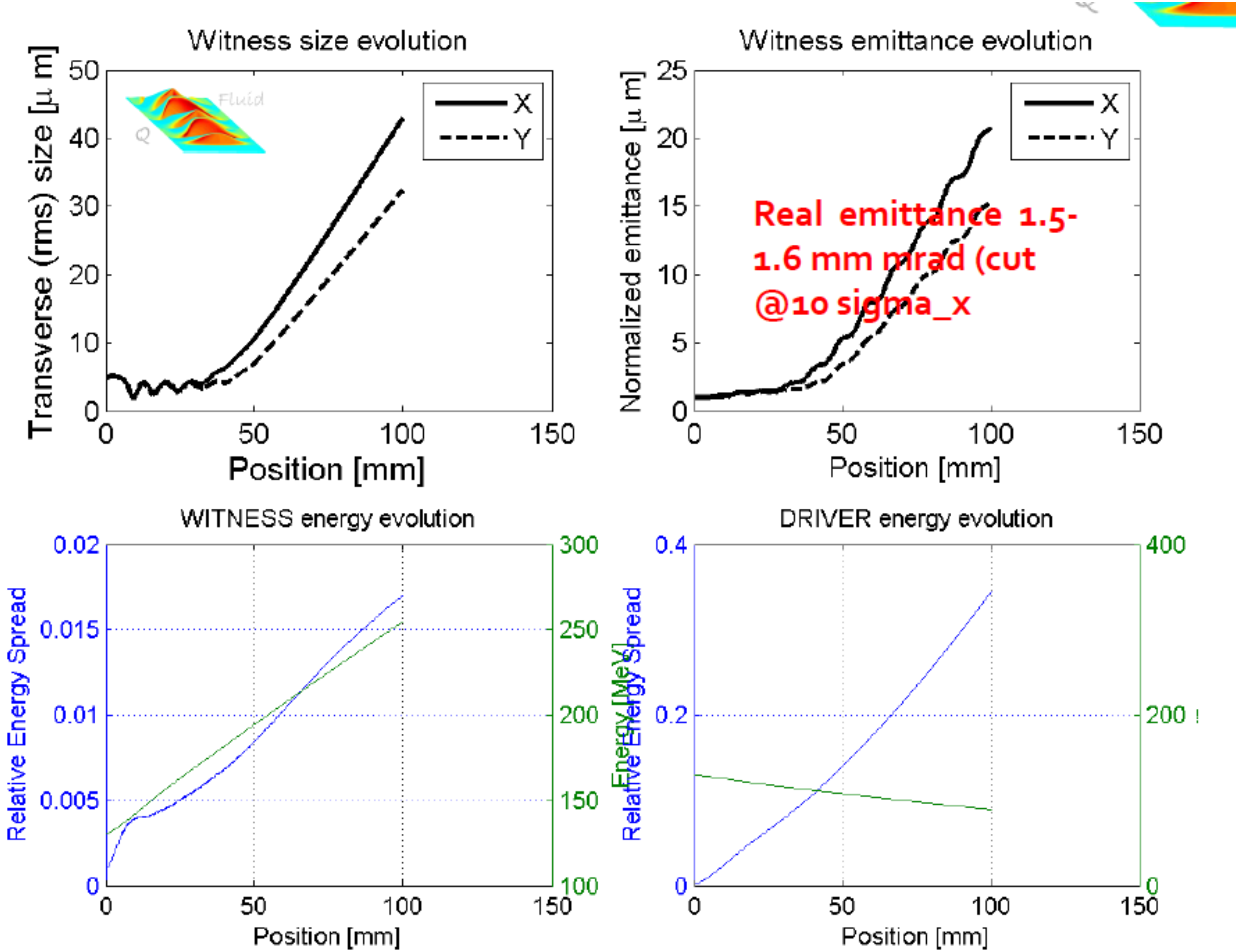
no=0.75e16 1/cm^3 Lambda_p=383 um,
Lacc=10cm Ez=1.2GV/m

	DRIVER (each, pC)	WITNESS
Charge (pC, each)	200	20
sigma_x (um)	**60**	**5**
Sigma_z (um)	25	10



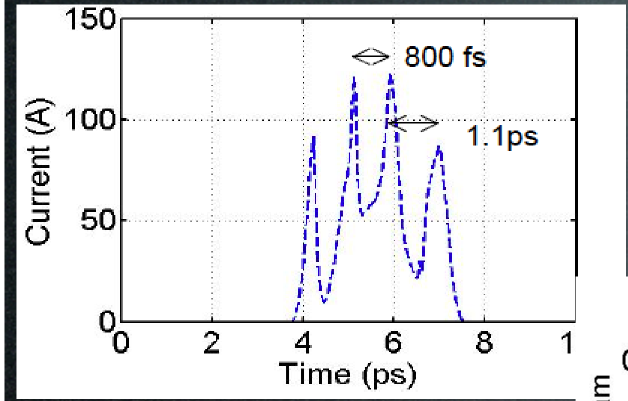


n_0 = 8e15 1/cm^3, Pos: -100 mm, σ_x DRIVER:369.91 μ m, σ_x WITNESS:42.87 μ m
Fluid
Q
E [MeV]
300
250
200
150
100
50
0
-50
-100
-800
-600
-400
-200
0
200
z-z$_g$ [μ m]
QFluidCOMB, Paolo Tomassini



Witness size evolution
Transverse (rms) size [μ m]
Position [mm]
X
Y
Fluid
Q
Witness emittance evolution
Normalized emittance [μ m]
Position [mm]
X
Y
Real emittance 1.5-1.6 mm mrad (cut @10 sigma_x
WITNESS energy evolution
Relative Energy Spread
Position [mm]
DRIVER energy evolution
Relative Energy Spread
Energy [MeV]
Position [mm]

	DRIVER (each, pC)	WITNESS
energy (mean, MeV)	90	255
energy spread	35	0.9%
norm. emittance (um)	303	1.6
sigma_x (um)	370	3.5

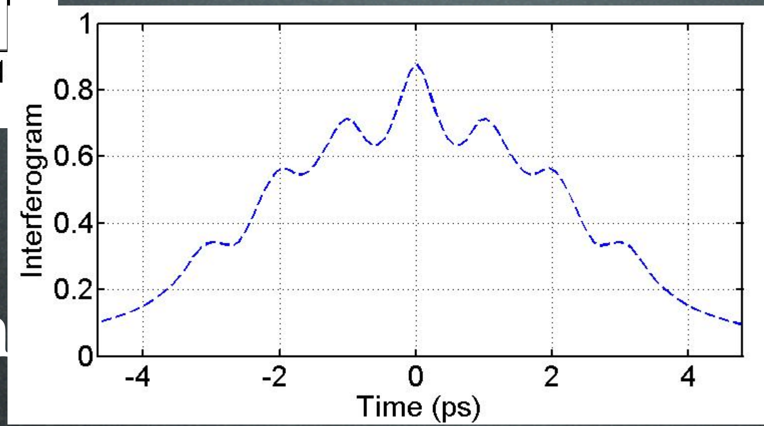


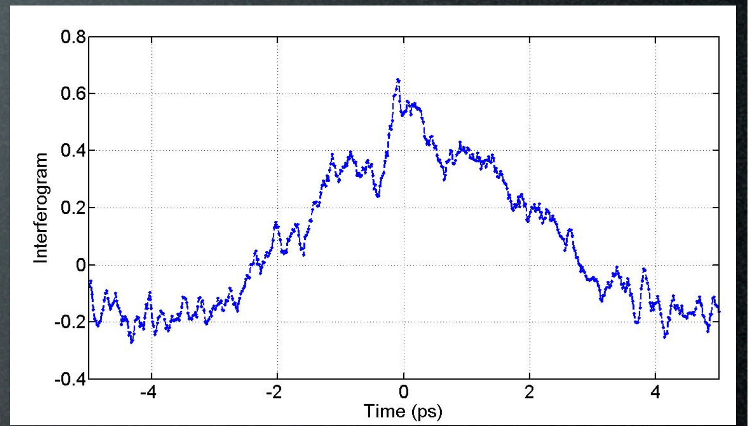
THz source

Expected

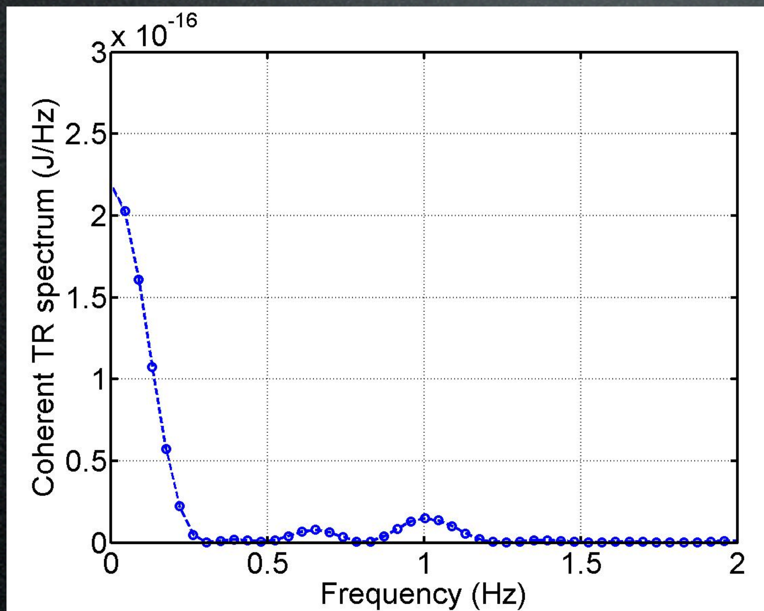
Measured

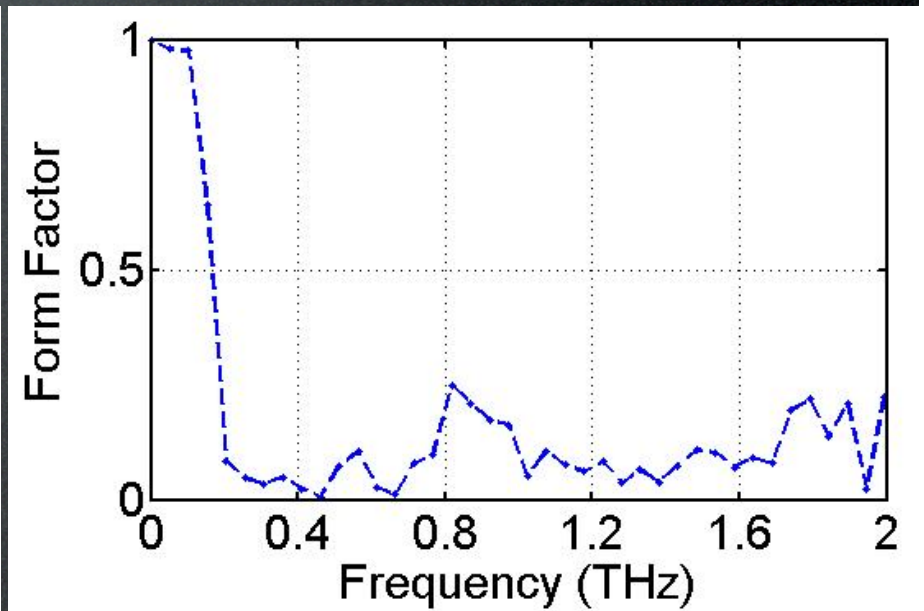
Interferogram





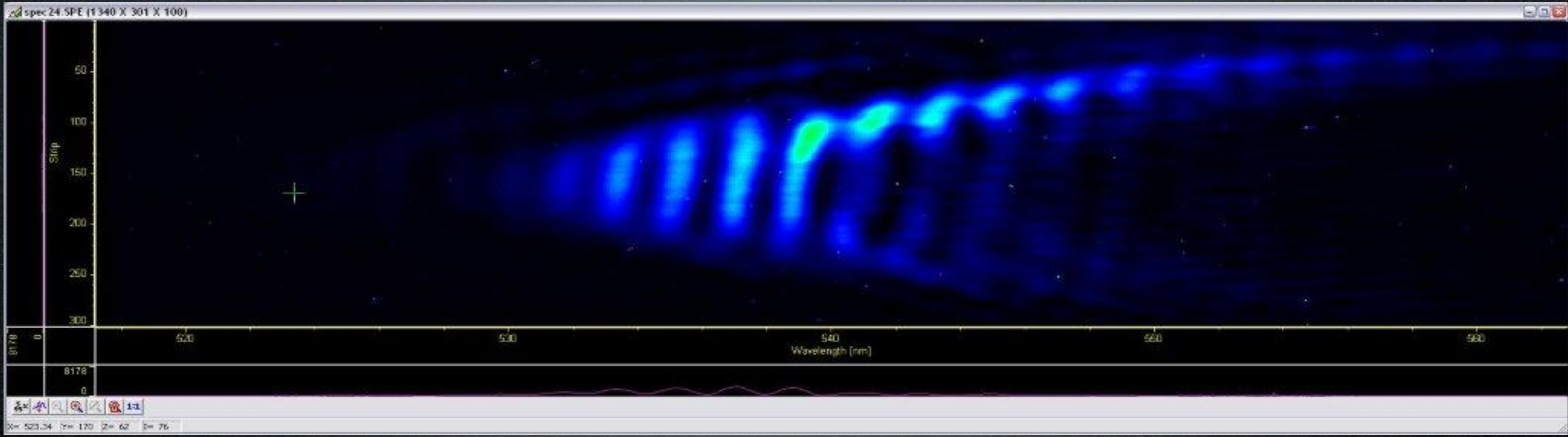
Spectrum



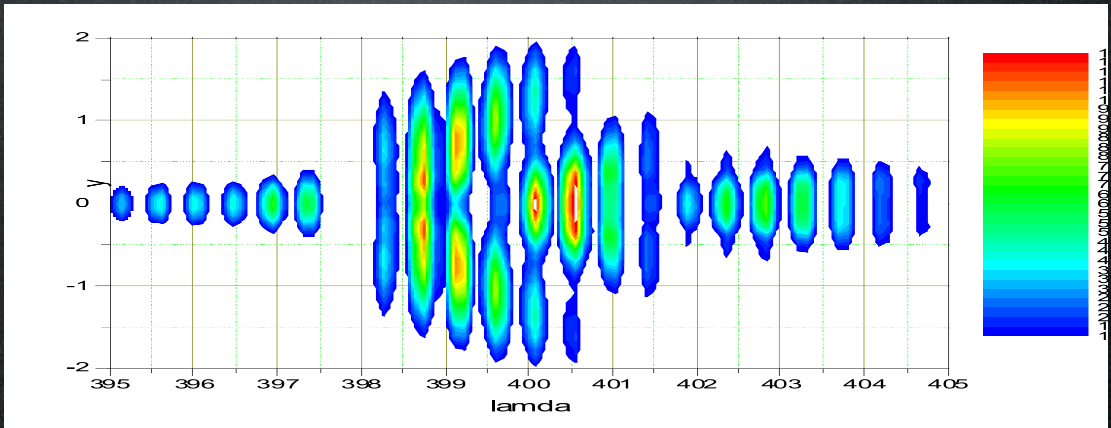


Courtesy E. Chiadroni

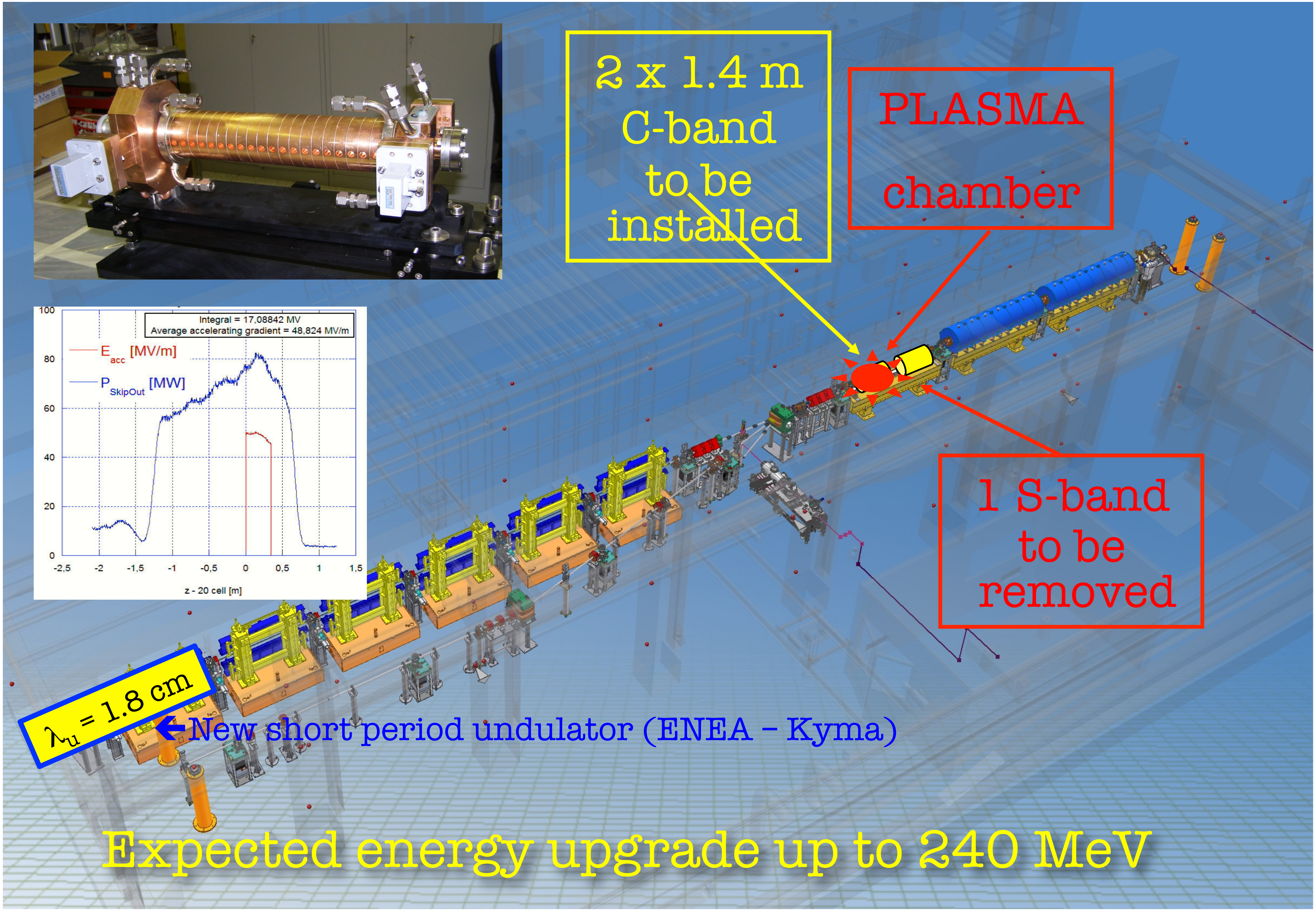
Double FEL pulse



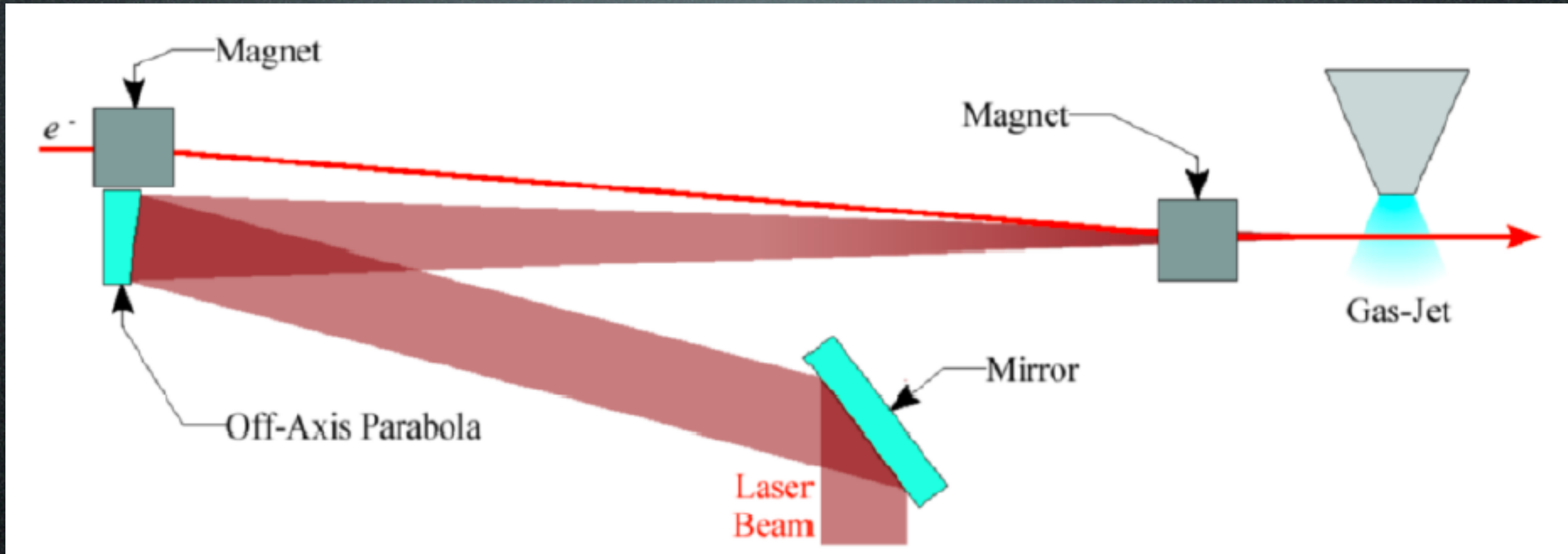
$$\Delta x = \frac{\lambda^2}{\Delta \lambda}$$



Courtesy L. Giannessi, V. Petrillo


2 x 1.4 m
C-band
to be
installed
PLASMA
chamber
1 S-band
to be
removed
Integral = 17,08842 MV
Average accelerating gradient = 48,824 MV/m
E acc [MV/m]
P SkipOut [MW]
100
80
60
40
20
0
-2,5
-2
-1,5
-1
-0,5
0
0,5
1
1,5
z - 20 cell [m]
λ_u = 1.8 cm
New short period undulator (ENEA – Kyma)
Expected energy upgrade up to 240 MeV

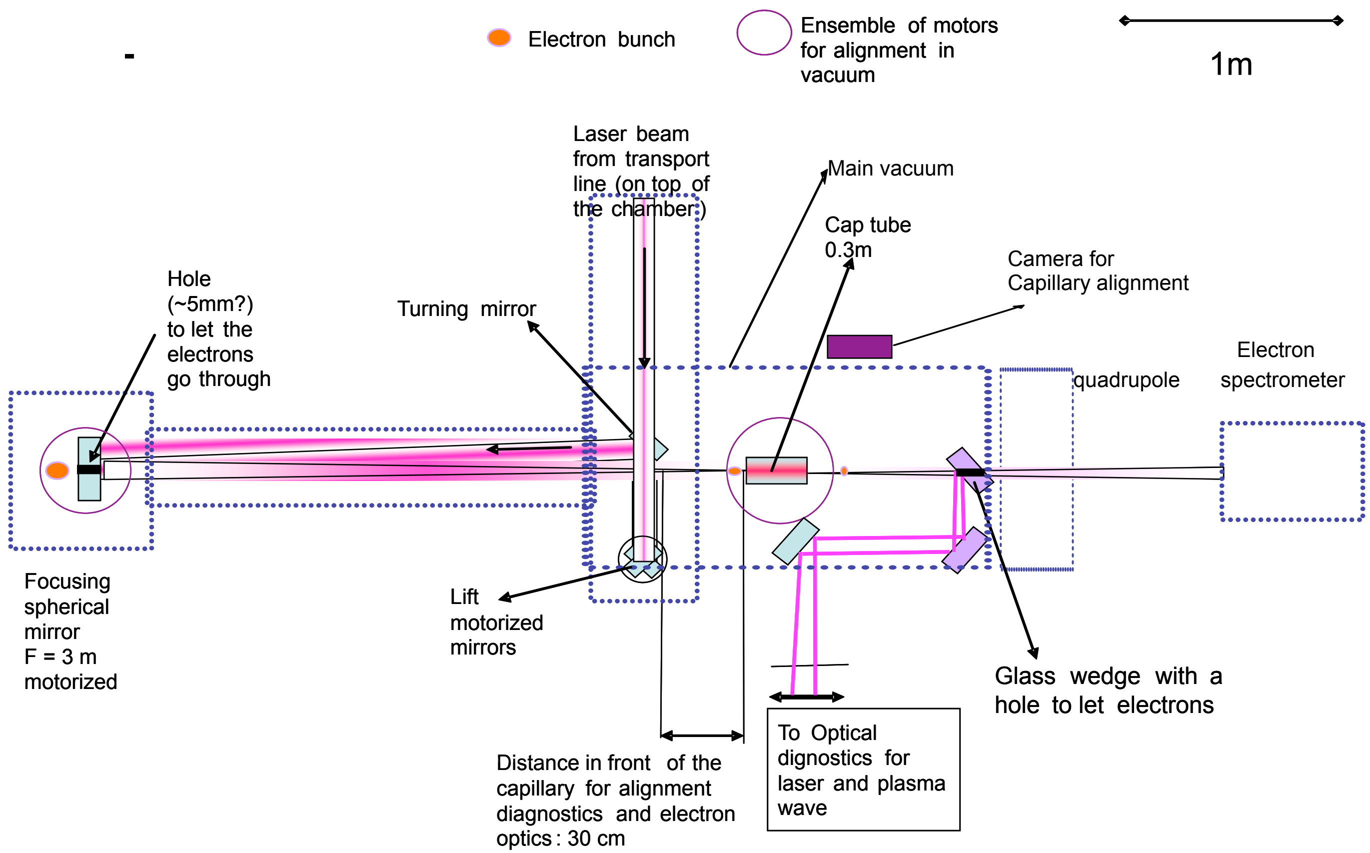
EXIN (EXternal INjection)

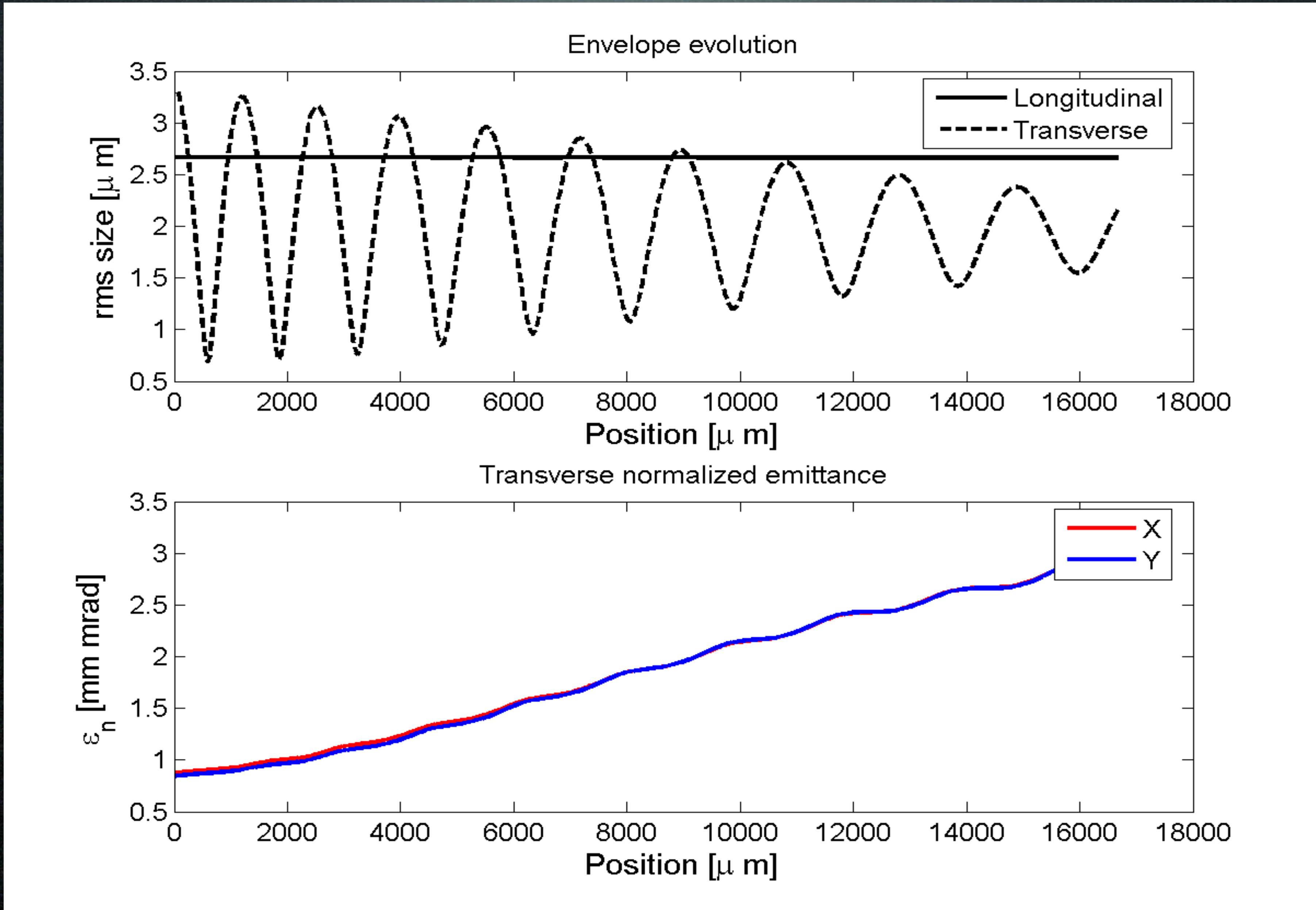


n_e [cm^{-3}]	E_{max} [GV/m]	λ_p [μm]	Ldeph [m]	Energy gain over L = 2cm [MeV]	Energy gain over L = 10cm [MeV]
1e16	0.2	330	400	<4	<20
5e16	1	150	5	<20	<100
2.5e17	3.8	66	0.45	<76	<380
7.5e17	7.5	39	0.1	<150	<750
2.5e18	8.5	30	0.04	<190	-

Courtesy L. Serafini

Interaction chamber





Courtesy P. Tomassini

When $\eta = \frac{4\gamma k_p^2}{3\gamma'^2} >> 1$ $\rho = \frac{k_{sc}^0 \sigma_x^2}{\gamma_o \varepsilon_n^2} << 1$

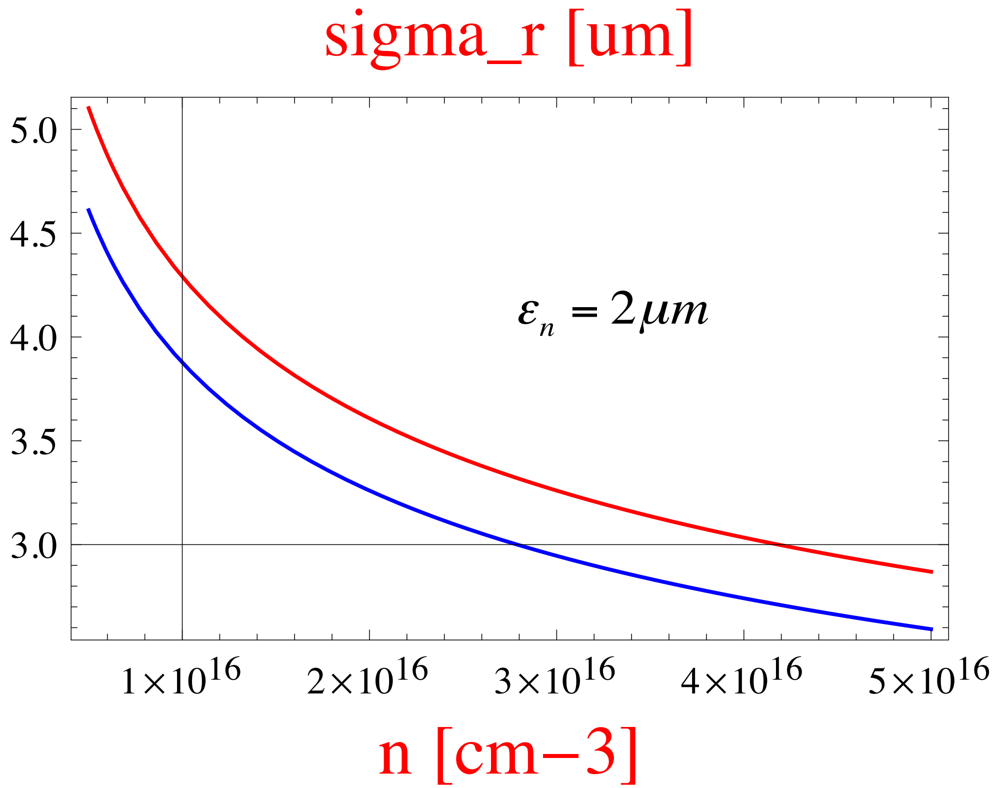
$$\gamma'' = 0$$
$$\gamma' \neq 0$$

$$\boxed{\sigma_x'' + \frac{k_p^2}{3\gamma}\sigma_x = \frac{\varepsilon_n^2}{\gamma^2 \sigma_x^3}}$$

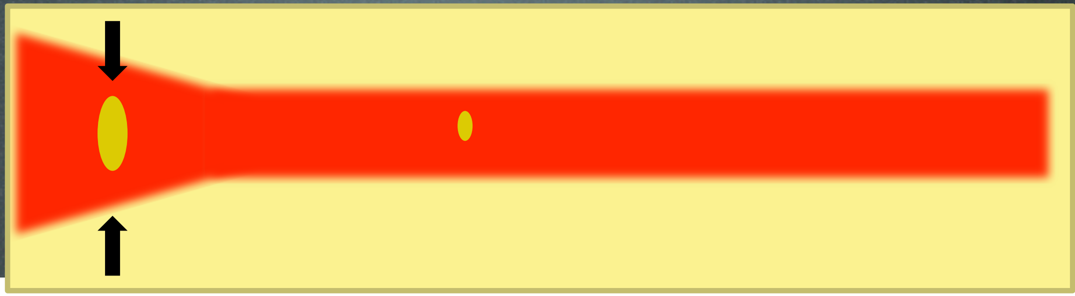
Looking for an equilibrium solution of the form: $\sigma_\varepsilon = \gamma^n \sigma_o$

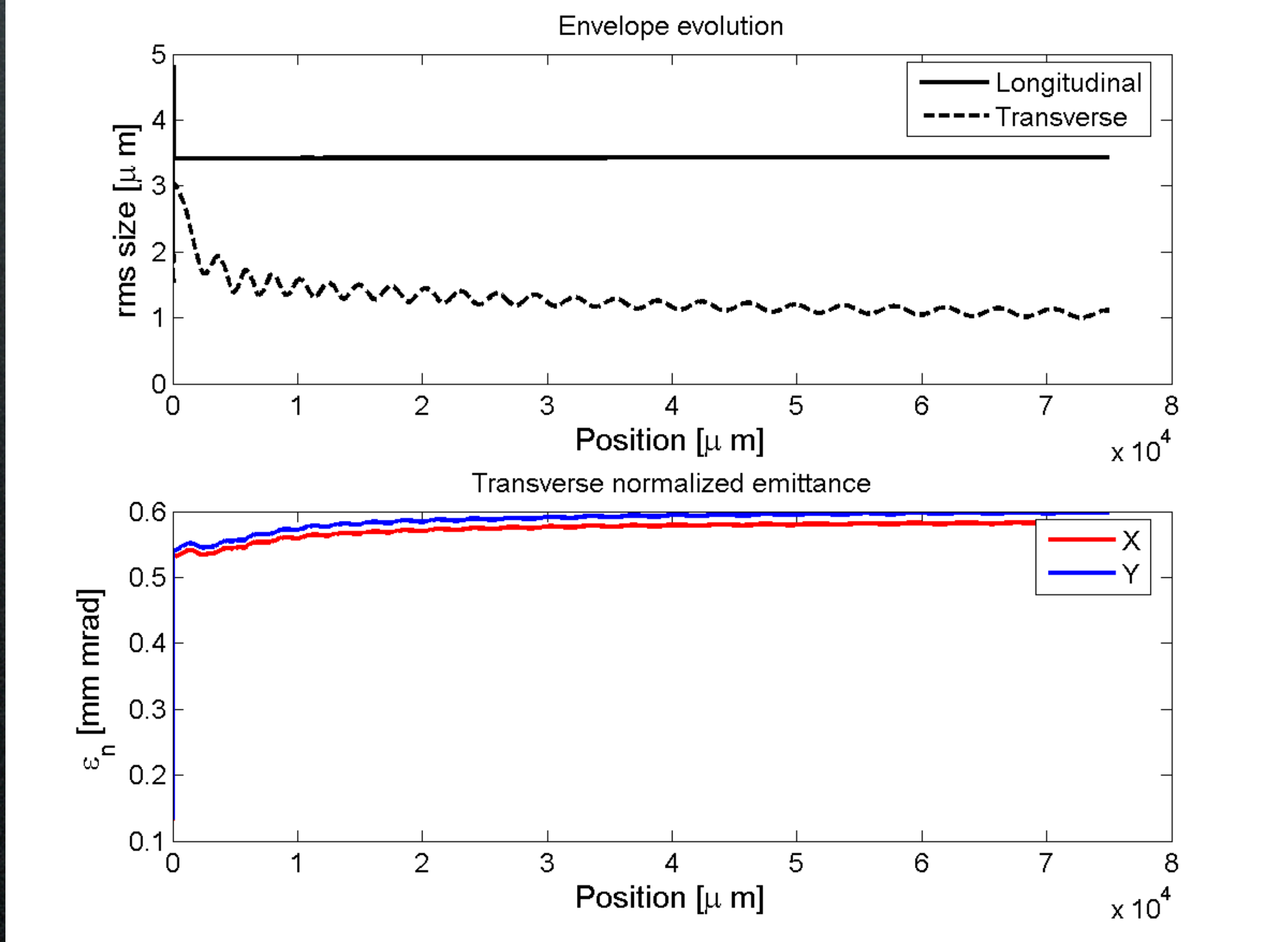
We get the matching condition with acceleration:

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



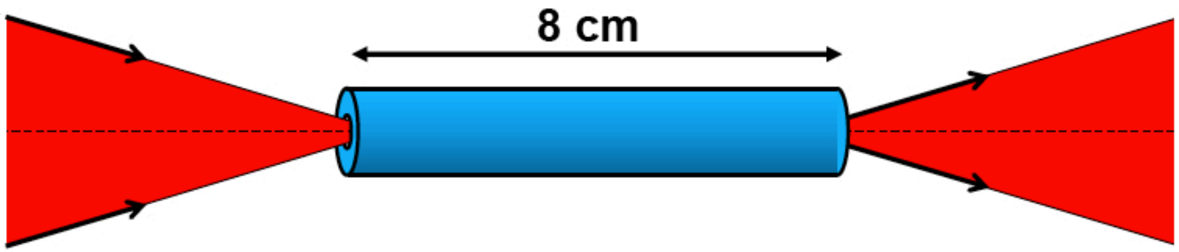
$$\sigma_\varepsilon = \sqrt[4]{\frac{3}{\gamma}}\sqrt{\frac{\varepsilon_n}{k_p}}$$





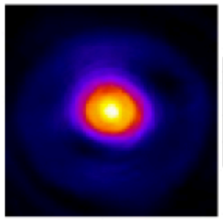
Hollow Dielectric Waveguide Capillaries

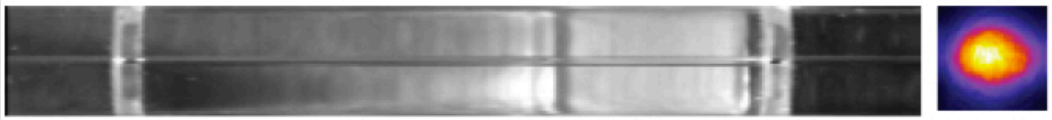
With LPGP Orsay, Brigitte Cros *et al.*



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

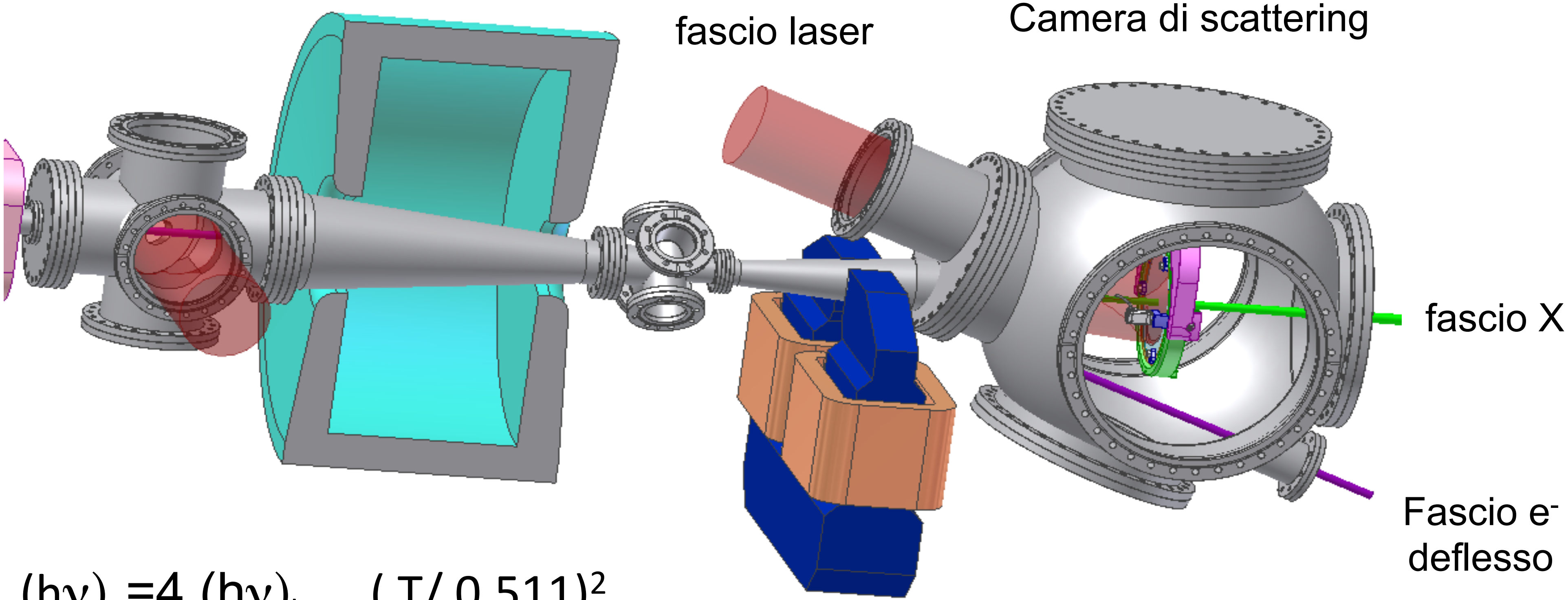




- Measurement of a plasma wave in the wake of an intense laser beam guided in a capillary tube over 8 cm, using optical diagnostics. Measured field up to 7GV/m over 8 cm.

Courtesy B. Cros, C.G. Wahlstrom

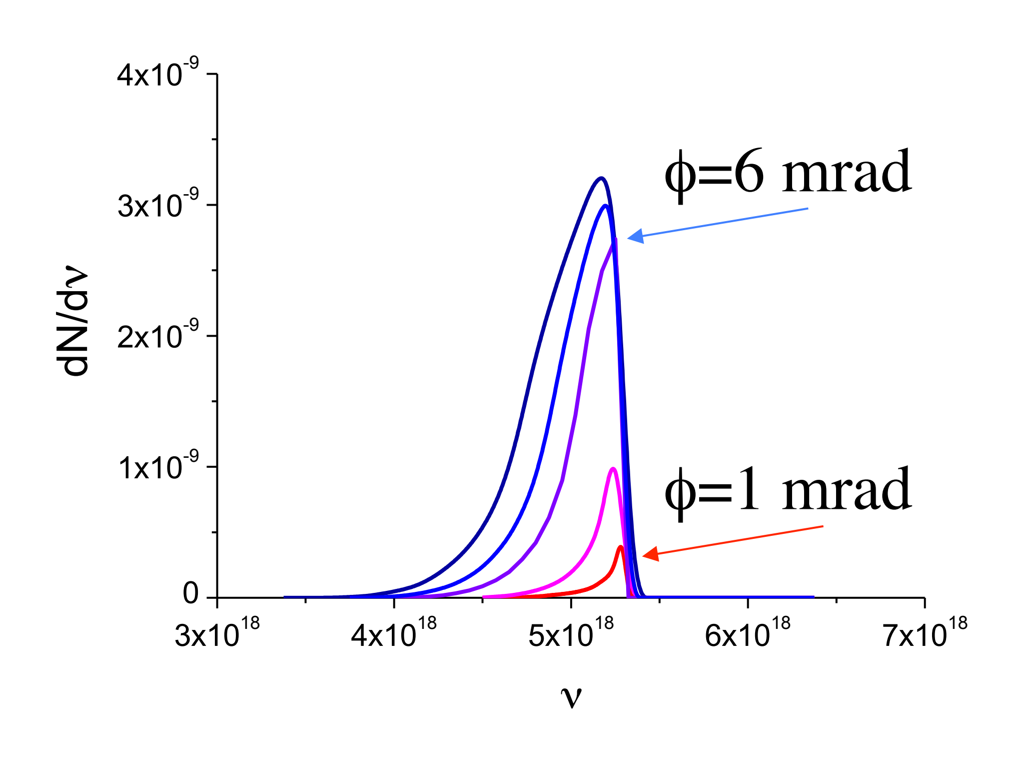
Thomson Interaction region (20-550 keV)

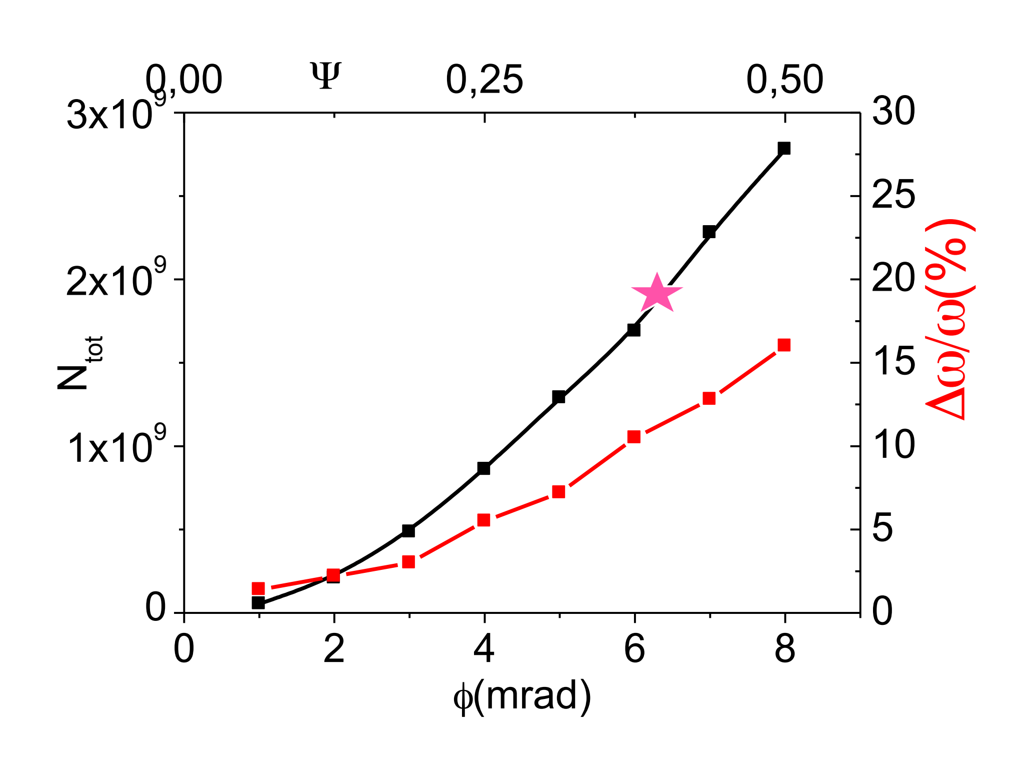


$$(h\nu)_X = 4\ (h\nu)_{laser}\ (T/0.511)^2$$

$(h\nu)_{laser}$ = 1.2 eV
T = 30.28 MeV
$(h\nu)_X$ = 20 keV mammografia

Impulso laser: 6 ps, 5 J
pacchetto e^- : 1 nC , l: 2 mm (rms)
Impulso X: 10 ps, 10^9 fotoni per interazione
α emissione: 12 mrad





N_{tot}=1,69 10^9

Δω/ω (FWHM)=10.5 %

div (FWHM)= 22 mrad

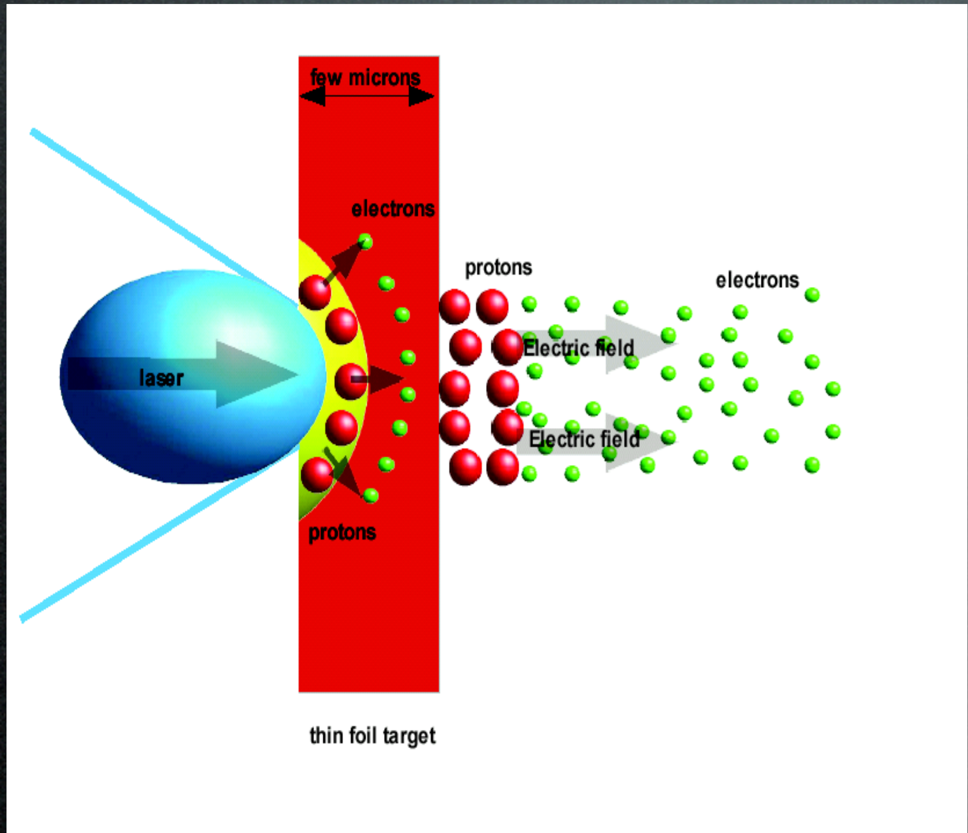
Δω/ω rms=5.2 %

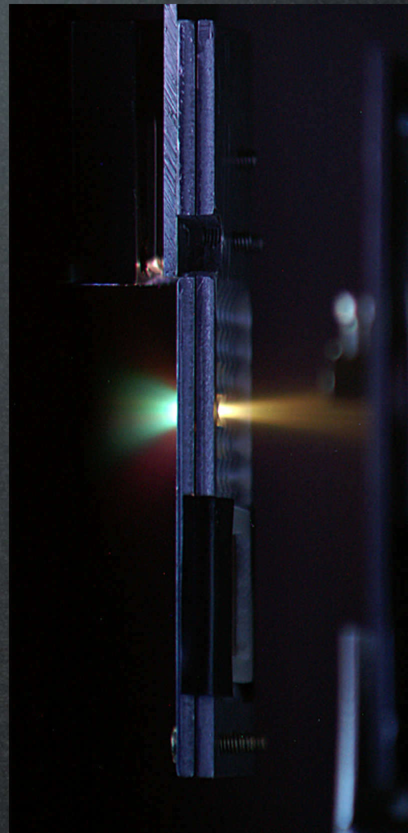
div rms= 5.3 mrad

Courtesy V. Petrillo

LILIA

Laser Induced Light Ions Acceleration





Courtesy C. De Martinis

- 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.

CONCLUSIONS

SPARC_LAB, 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 scientific 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 with advanced radiation sources