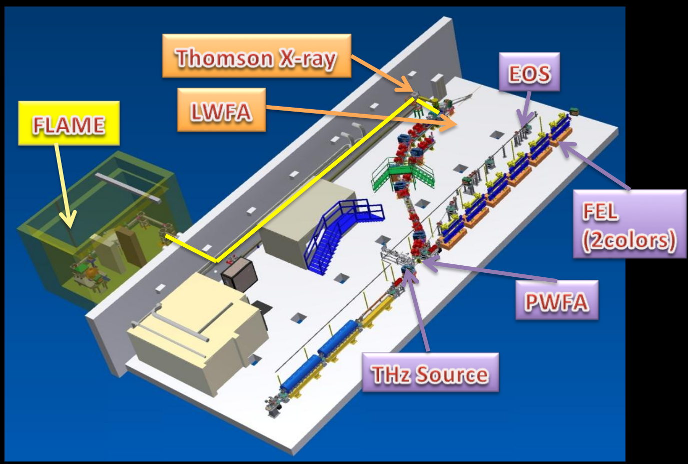
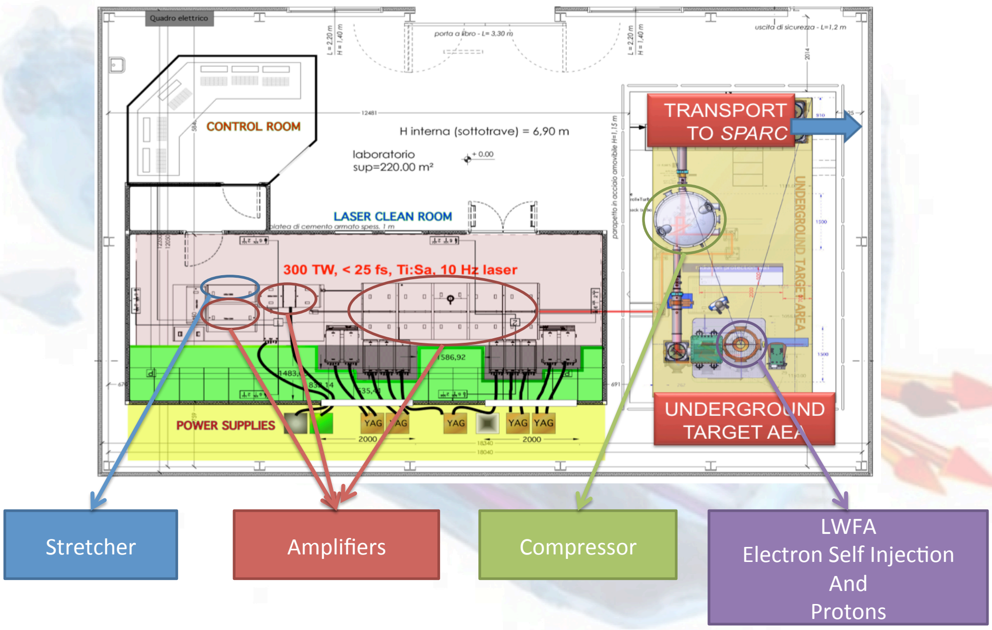
Advanced Accelerator Experiments at SPARC_LAB

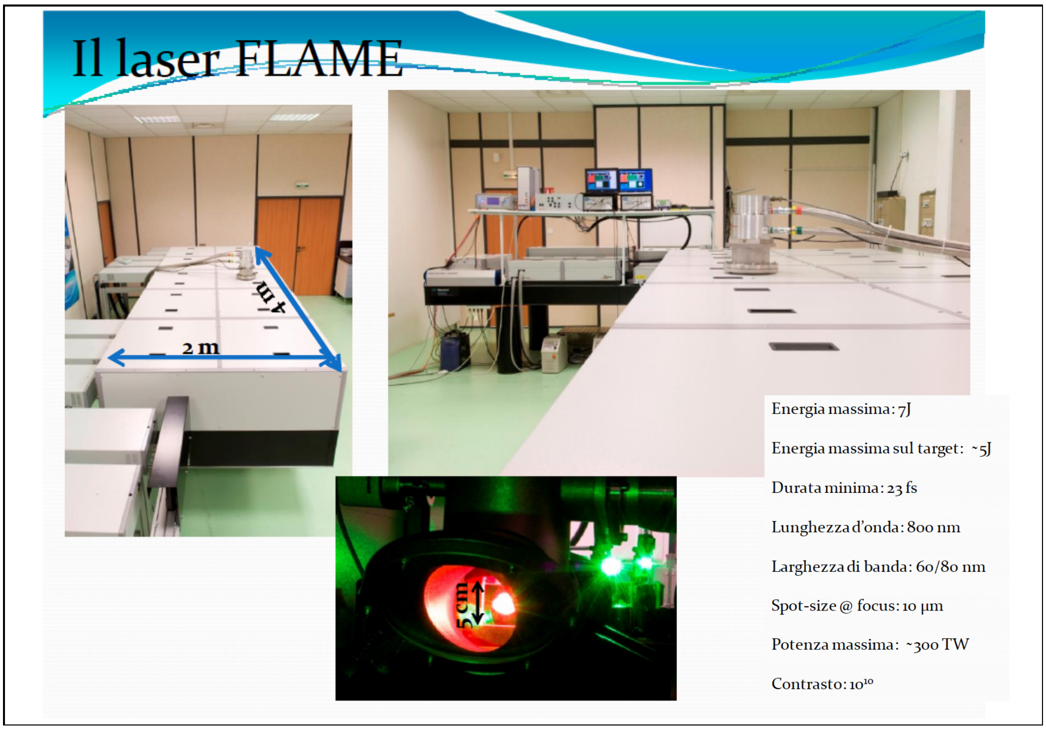
Massimo.Ferrario@LNF.INFN.IT

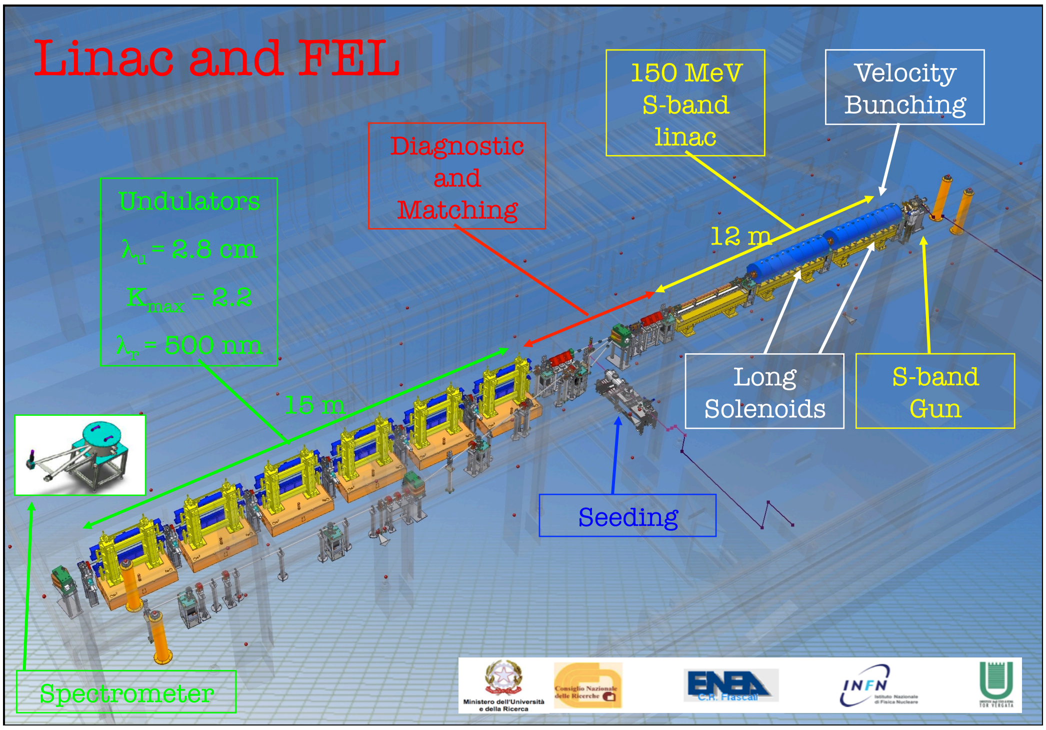


Channeling 2014 – Capri, October 8, 2014

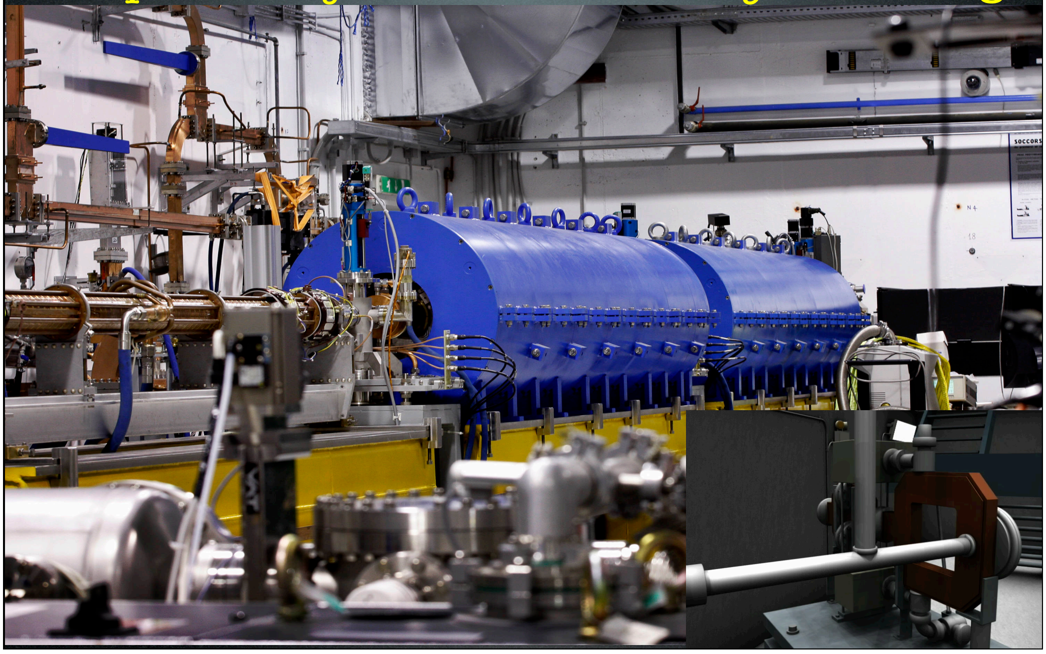
Ti:Sa FLAME laser



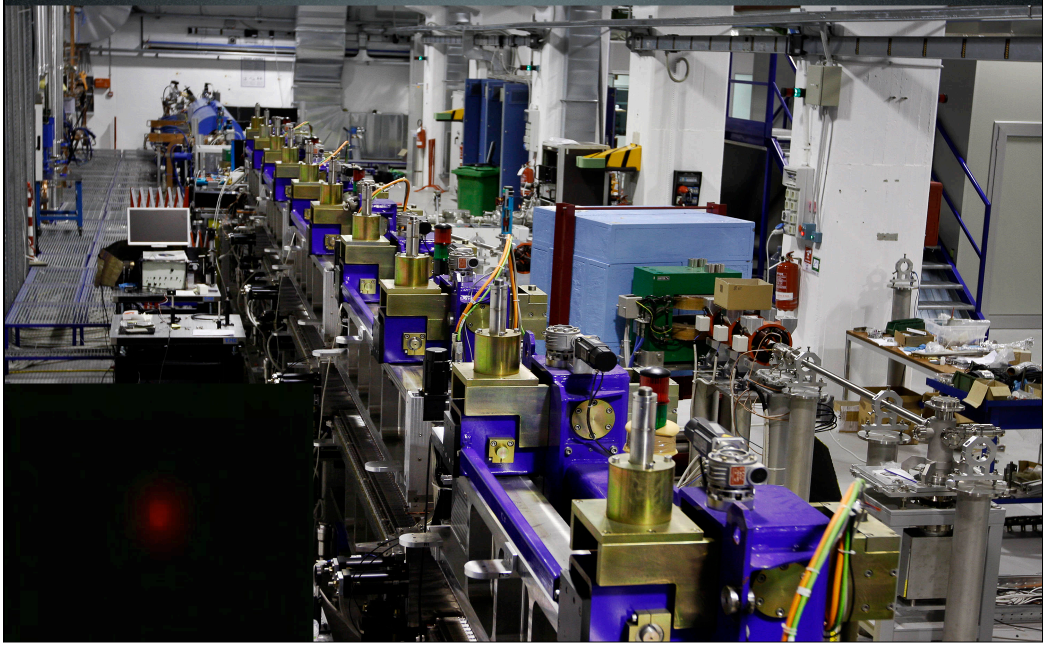

Il laser FLAME
4 m
2 m
5 cm
Energia massima: 7J
Energia massima sul target: ~5J
Durata minima: 23 fs
Lunghezza d'onda: 800 nm
Larghezza di banda: 60/80 nm
Spot-size @ focus: 10 μm
Potenza massima: ~300 TW
Contrasto: 10^{10}


Linac and FEL
150 MeV S-band linac
Velocity Bunching
Diagnostic and Matching
Undulators
λ_u = 2.8 cm
K_{max} = 2.2
λ_r = 500 nm
12 m
15 m
Long Solenoids
S-band Gun
Seeding
Spectrometer

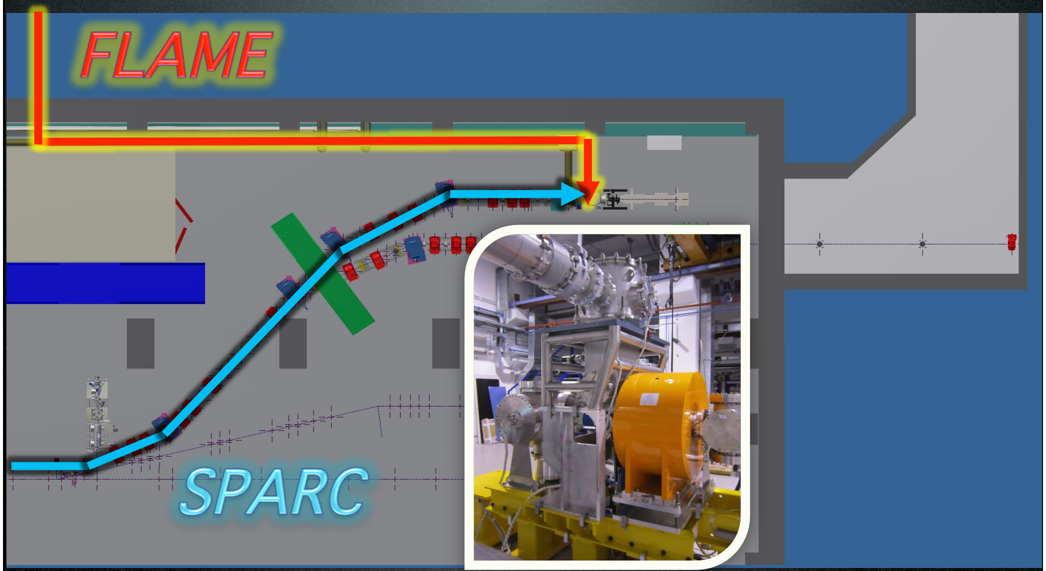
HB photo- injector with Velocity Bunching



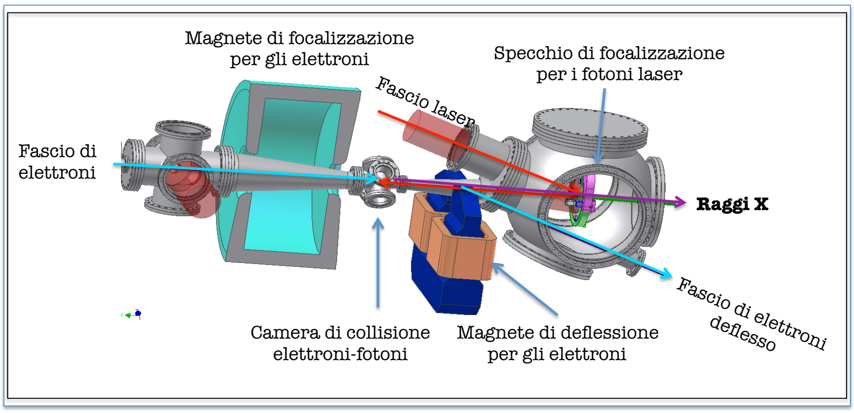
Free Electron Laser



Thomson backscattering

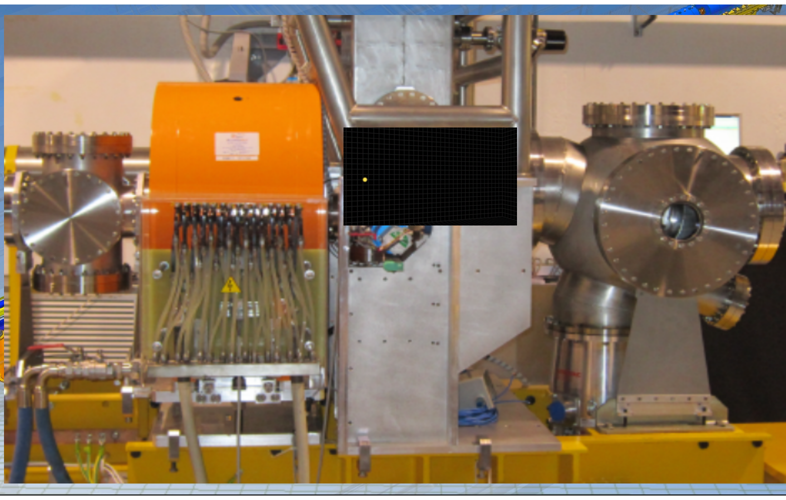


Thomson Interaction region (20-550 keV)



Thomson back-scattering source

carica (pC)	energia (MeV)	enx (mm mrad)	eny (mm mrad)	IP sigmax mm	IP sigmay (mm)
230	157	2.7	4.5	.50	.55
220	75	2.9	5	.28	.36
230	50	1.2	2.3	.17	.18

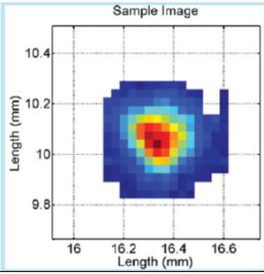


Working Point: electron beam and FLAME pulse

Electron Beam	Units	WP Parameters
Energy	MeV	50
Energy Spread	%	0.1 ± 0.03
Pulse Length	ps	3.1 ± 0.2
Spot Size	μm	90 ± 3
Charge	pC	200
Emittance	mm mrad	1.5 : 2.2 ± 0.2

FLAME laser pulse	Units	WP Parameters
Pulse Energy	J	0.5
Wavelength	nm	800
Pulse Length	ps	6
Spot Size	μm	10
Repetition Rate	Hz	10

- Electron beam spot size had to be of 50μm. Because of a limit in the magnet cooling system, the solenoid upstream the IP could be used at 70% of its nominal value.
  In this condition the minimum rms spot size was of about 90 μm.
- Best results obtained with σ_{x-y} = 240 : 160 ± 10 μm.

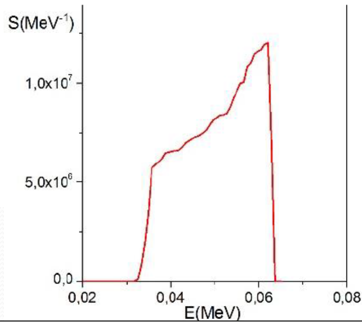


Emitted X-Rays: From Simulations…

- Simulation results with electron beam spot size of 150 μm and FLAME pulse waist of 30 μm.

X-Rays	Units	From Simulations…
Energy Edge	keV	63
BW	%	19
Photons	Number per shot	≈ 2 × 10^5

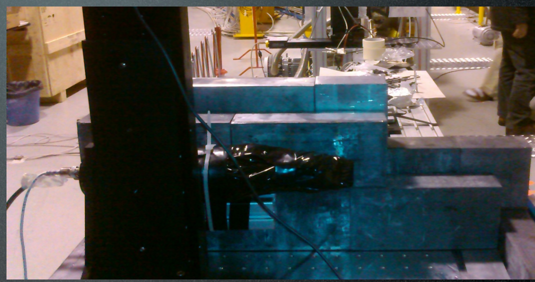
- Spectral density S (MeV^{-1}) versus photon energy



Courtesy of
P. Cardarelli, P. Oliva,
G. Di Domenico INFN-FE
P. Delogu INFN-Pisa

Detector: CsI scintillator (20x20x2 mm) + Photo Multiplier Tube

Front view (shielding)



Rear view (PMT)

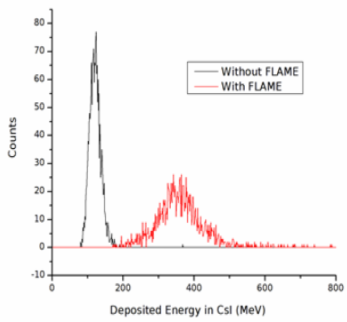
Emitted X-Rays: First Commissioning Results

Courtesy of
P. Cardarelli, P. Oliva,
G. Di Domenico INFN-FE
P. Delogu INFN-Pisa

- Two type of measurements of the X-Rays:
  1. 20 GHz BW oscilloscope for a fast response.
  2. Multichannel analyser to acquire an integral measurement over various interactions.

- Best results obtained with σ_{x-y} = 240 : 160 ± 10 μm
  1. Average Energy: 60 keV
  2. Number of photons for each pulse 6.7×10^3

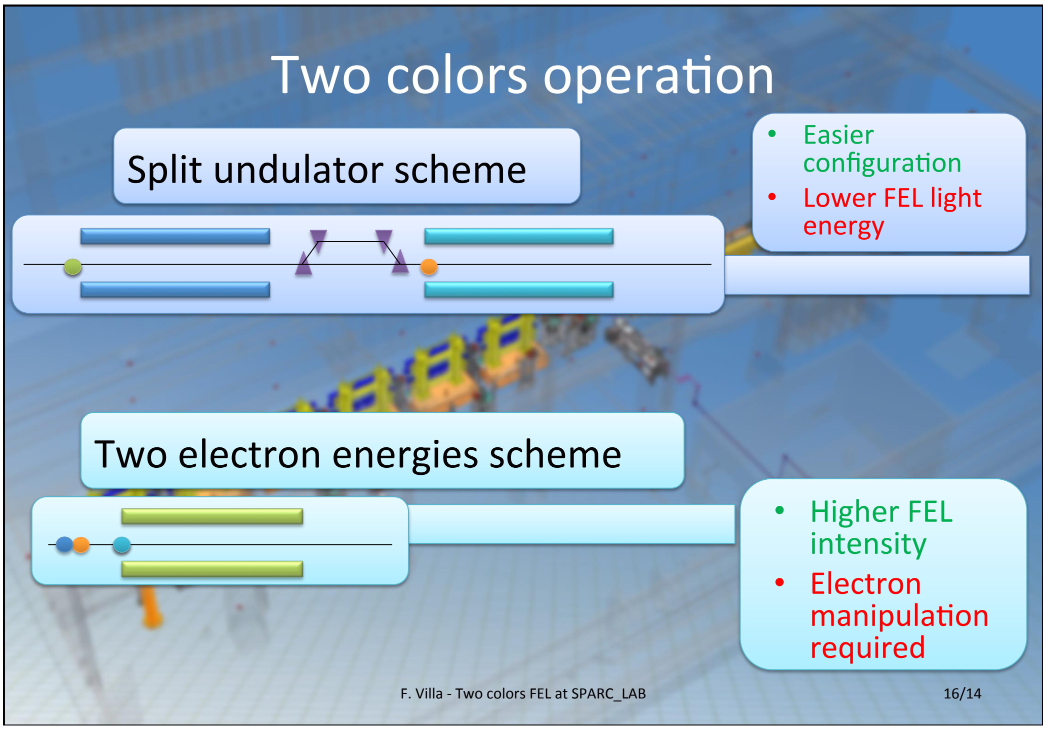
- Poor overlap conditions due to some misalignment of the interaction chamber can explain the difference between the measured number of photons for each pulse and the expected one.



Thomson x-rays signal in red, in black the electron background signal (without FLAME laser), integrated over 120 s (1200 pulses).

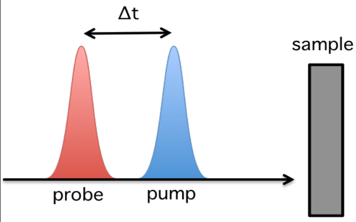
"THE SPARC_LAB THOMSON SOURCE COMMISSIONING" C. Vaccarezza et Al. IPAC 2014


TWO COLORS FEL


Two colors operation
Split undulator scheme
Easier configuration
Lower FEL light energy
Two electron energies scheme
Higher FEL intensity
Electron manipulation required
F. Villa - Two colors FEL at SPARC_LAB
16/14

2 Color Free-Electron Lasers

SLAC



2 pulses with

-tunable energy difference

-tunable arrival time

Many applications!

- x-ray pump/x-ray probe
- 2 color diffraction imaging

PRL **110,** 134801 (2013) PHYSICAL REVIEW LETTERS week ending 29 MARCH 2013

Experimental Demonstration of Femtosecond Two-Color X-Ray Free-Electron Lasers

A. A. Lutman, R. Coffee, Y. Ding,* Z. Huang, J. Krzywinski, T. Maxwell, M. Messerschmidt, and H.-D. Nuhn
SLAC National Accelerator Laboratory, Menlo Park, California 94025, USA
(Received 13 December 2012; published 25 March 2013)

PRL **111,** 134801 (2013) PHYSICAL REVIEW LETTERS week ending 27 SEPTEMBER 2013

Multicolor Operation and Spectral Control in a Gain-Modulated X-Ray Free-Electron Laser

A. Marinelli,[1,*] A. A. Lutman,[1] J. Wu,[1] Y. Ding,[1] J. Krzywinski,[1] H.-D. Nuhn,[1] Y. Feng,[1] R. N. Coffee,[1] and C. Pellegrini[2,1]

PRL **110,** 064801 (2013) PHYSICAL REVIEW LETTERS week ending 8 FEBRUARY 2013

Chirped Seeded Free-Electron Lasers: Self-Standing Light Sources for Two-Color Pump-Probe Experiments

Giovanni De Ninno,[1,2] Benoît Mahieu,[1,2,3] Enrico Allaria,[2] Luca Giannessi,[2,4] and Simone Spampinati[2]

ARTICLE

Received 8 Sep 2013 | Accepted 12 Nov 2013 | Published 4 Dec 2013 DOI: 10.1038/ncomms3919

Two-colour hard X-ray free-electron laser with wide tunability

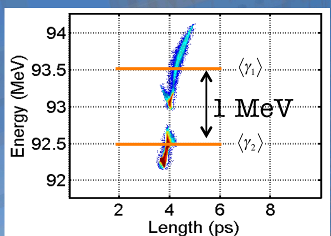
Toru Hara[1], Yuichi Inubushi[1], Tetsuo Katayama[2], Takahiro Sato[1,†], Hitoshi Tanaka[1], Takashi Tanaka[1], Tadashi Togashi[2], Kazuaki Togawa[1], Kensuke Tono[2], Makina Yabashi[1] & Tetsuya Ishikawa[1]

PRL **111,** 114802 (2013) PHYSICAL REVIEW LETTERS week ending 13 SEPTEMBER 2013

Observation of Time-Domain Modulation of Free-Electron-Laser Pulses by Multipeaked Electron-Energy Spectrum

V. Petrillo,[1] M. P. Anania,[2] M. Artioli,[3] A. Bacci,[1] M. Bellaveglia,[2] E. Chiadroni,[2] A. Cianchi,[4] F. Ciocci,[3] G. Dattoli,[3] D. Di Giovenale,[2] G. Di Pirro,[2] M. Ferrario,[2] G. Gatti,[2] L. Giannessi,[3] A. Mostacci,[5] P. Musumeci,[6] A. Petralia,[3] R. Pompili,[4] M. Quattromini,[3] J. V. Rau,[7] C. Ronsivalle,[3] A. R. Rossi,[1] E. Sabia,[3] C. Vaccarezza,[2] and F. Villa[2]

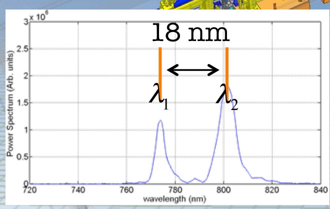
A train of fs FEL pulses



two bunches with
a two-level energy distribution
and time overlap (Laser COMB tech.)

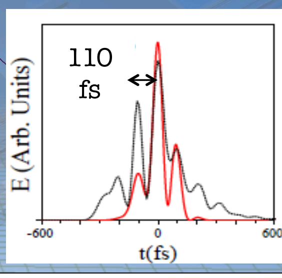
$$\lambda_r = \frac{\lambda_u}{2\gamma^2}\left(1 + K_{rms}^2\right)$$

$$\frac{\Delta\lambda_r}{\langle\lambda_r\rangle} = 2\frac{\langle\gamma_1\rangle - \langle\gamma_2\rangle}{\langle\gamma\rangle}$$

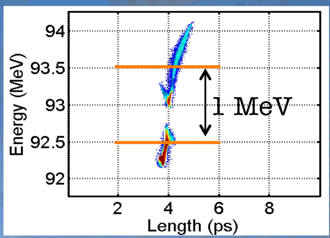


produce two wavelength
SASE -FEL radiation
with time modulation

$$\Delta t = \frac{\lambda_u\left(1 + K_{rms}^2\right)}{4c\langle\gamma\rangle\left(\langle\gamma_1\rangle - \langle\gamma_2\rangle\right)}$$



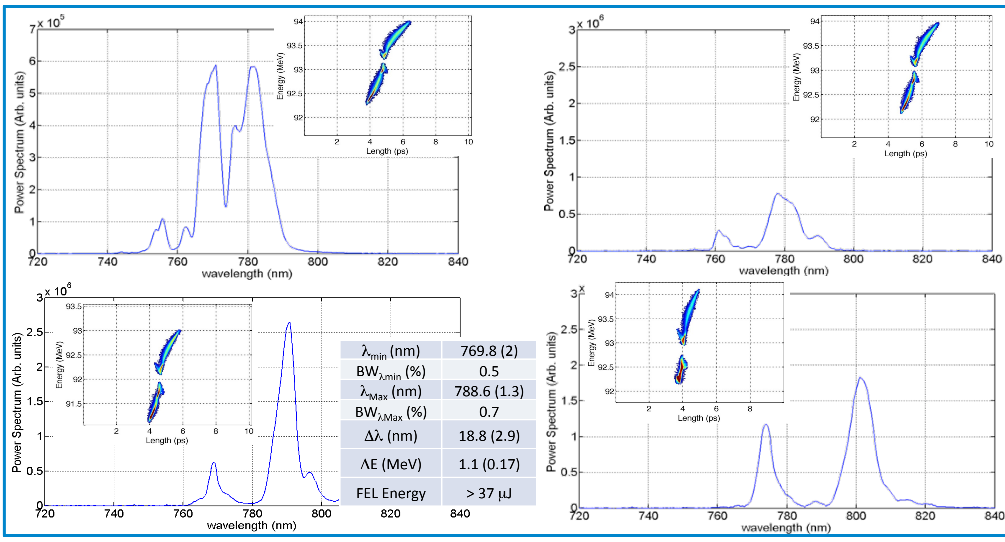
Electron beam requiremetns



two bunches with
a two-level energy distribution
and time overlap (Laser COMB tech.)

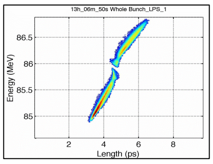
- Lasing condition: $\frac{\delta\gamma_{1,2}}{\langle\gamma_{1,2}\rangle} < \rho$
- To prevent mode competition: $\frac{\langle\gamma_1\rangle - \langle\gamma_2\rangle}{\langle\gamma\rangle} > \rho$
- Single spike condition: $l_b \approx L_{coop} = \frac{\lambda_r}{4\pi\sqrt{3}\rho}$

FEL Experiments: Two-levels radiation spectra

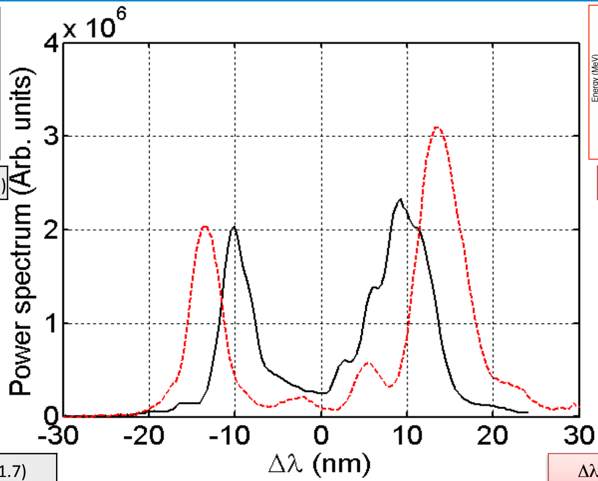


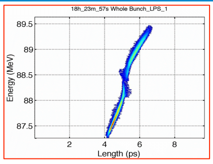
λ_{min} (nm)	769.8 (2)
$BW_{\lambda min}$ (%)	0.5
λ_{Max} (nm)	788.6 (1.3)
$BW_{\lambda Max}$ (%)	0.7
$\Delta\lambda$ (nm)	18.8 (2.9)
ΔE (MeV)	1.1 (0.17)
FEL Energy	> 37 μJ

FEL EXPERIMENTS: Two-color tunability



ΔE(MeV)	-1.01 (0.03)





ΔE(MeV)	-1.14 (0.06)

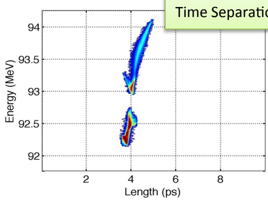
Δλ (nm)	20.7 (1.7)
ΔE (MeV)	1.066 (0.086)

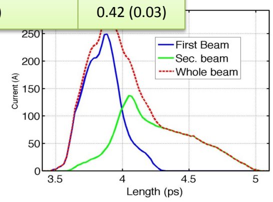
Δλ (nm)	26 (3)
ΔE (MeV)	1.35 (0.14)

FEL Experiments: Time-modulated pulses

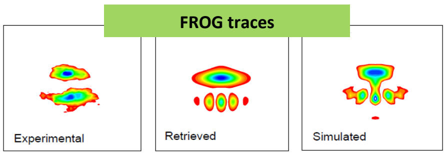
	Energy (MeV)	En. Spread (%)	Length (ps)	Charge (pC)
First Beam	92.515 (0.033)	0.174 (0.005)	0.147 (0.002)	82.15 (1.58)
Second Beam	93.588 (0.033)	0.317 (0.005)	0.283 (0.003)	77.85 (1.56)
Whole Beam	93.038 (0.032)	0.631 (0.003)	0.305 (0.004)	160.00 (3.10)

Energy Separation (MeV)	1.07 (0.05)
Time Separation (ps)	0.42 (0.03)

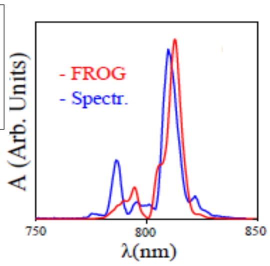


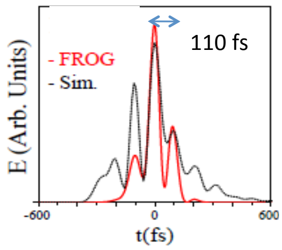


FROG traces

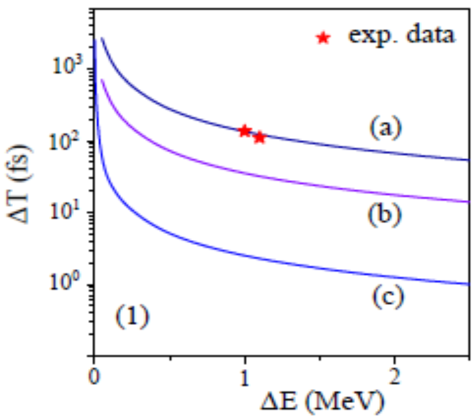


Δλ(nm)	BW (%)	RMS Time duration (fs)	Time separation (fs)
18	0.86	80	110





Expected time modulation at shorter wavelength



$$\Delta t = \frac{\lambda^2}{c(\lambda_2 - \lambda_1)} = \frac{\lambda_u(1 + K_w^2/2)}{4c\gamma\Delta\gamma}$$

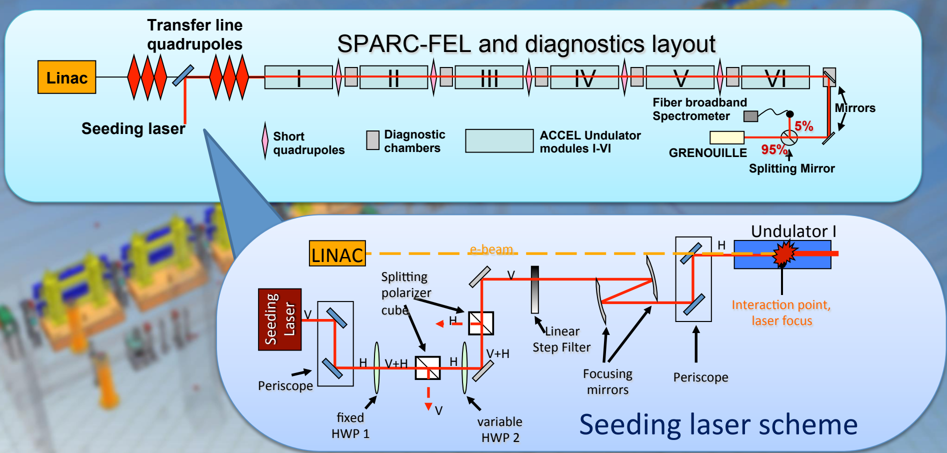
(a) SPARC case.

(b) $\lambda = 30\,nm$

(c) $\lambda = 0.15\,nm$

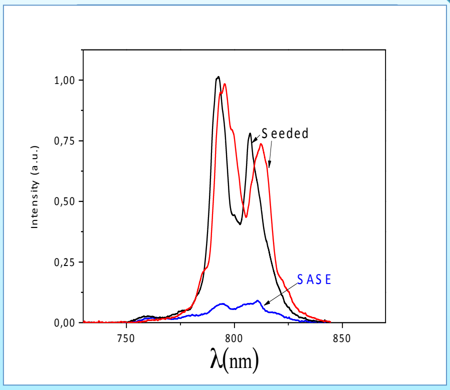
Two colors FEL: seeding

- To increase stability as well as intensity we added a laser seed at a wavelength at the average of the two FEL colors

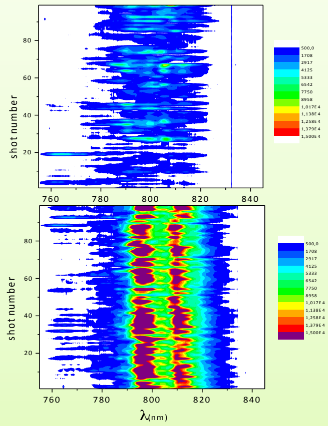


Two colors FEL: seeding

- With seeding we achieved increase stability and intensity



SASE (green) and seeded FEL (black)



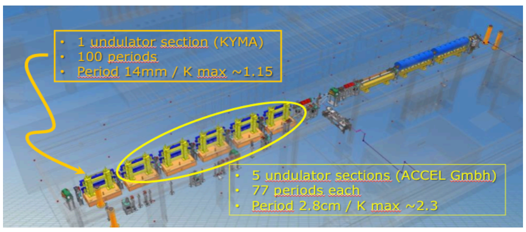
Spectral stability in time of SASE (top) and seeded FEL (bottom)

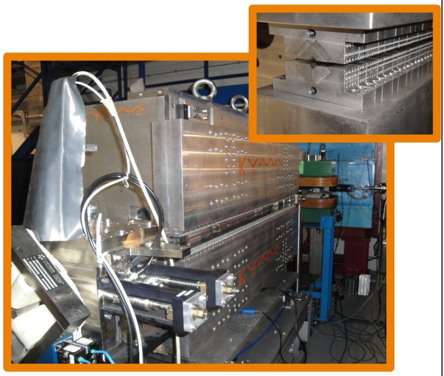
Test of multistage cascade FEL at SPARC *F. Ciocci*

- Installation and first test of short period undulator.
- Simulation work
- Preliminary report ready

DELTA like undulator λ_u = 14 mm, gap 5mm, Br = 1.22T

Undulator tested in two stage SASE-FEL: 630nm to 315 nm



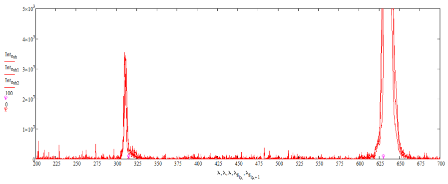


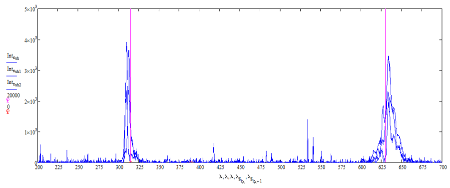
High-quality insertion devices
for light sources

Experiment. Example:
Short period section used as "afterburner"

ENEA INFN

Two different group of spectra in the same acquisition run: the intensity of the emission from the first five undulators seems to marginally affect the intensity in the last undulator.



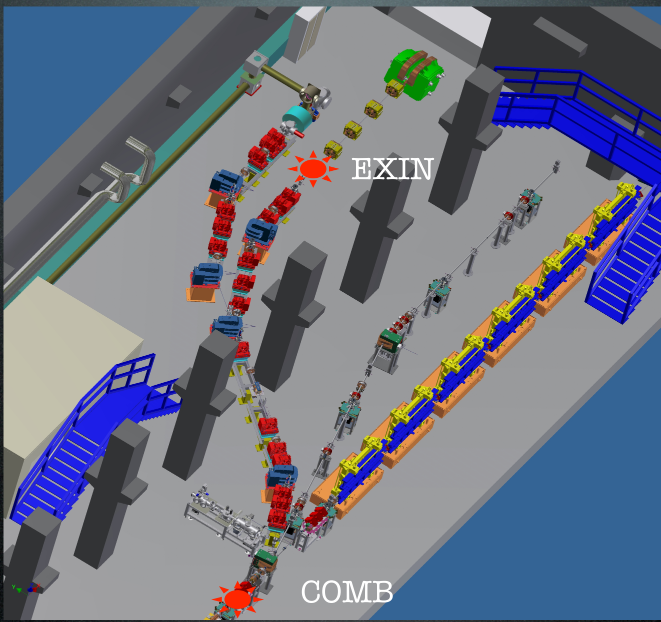


May be explained as an effect of electron beam mismatch in the first five sections connected to machine temporal drifts;

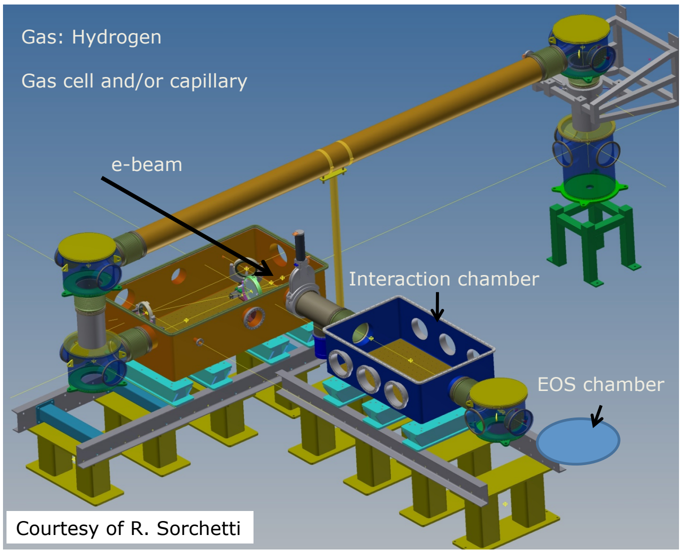
In the last section, the beam is always strongly focused in both directions and a mismatch at the entrance of this short section do not produce a significant reduction of the signal. Simulations show that other effects, such as variation of energy spread or electron bunches duration (with consequent variation of peak current) reduce in the same ratio both signals

SPARC

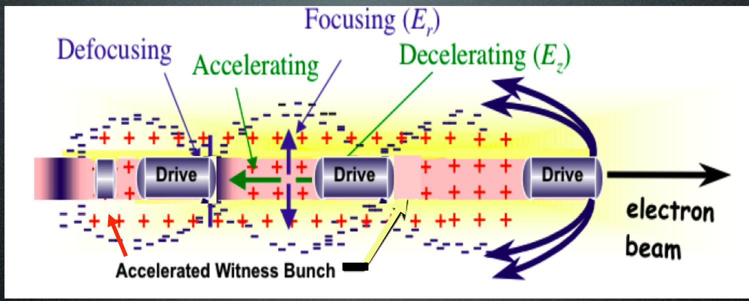
Plasma Wake Field Acceleration



Interaction Layout

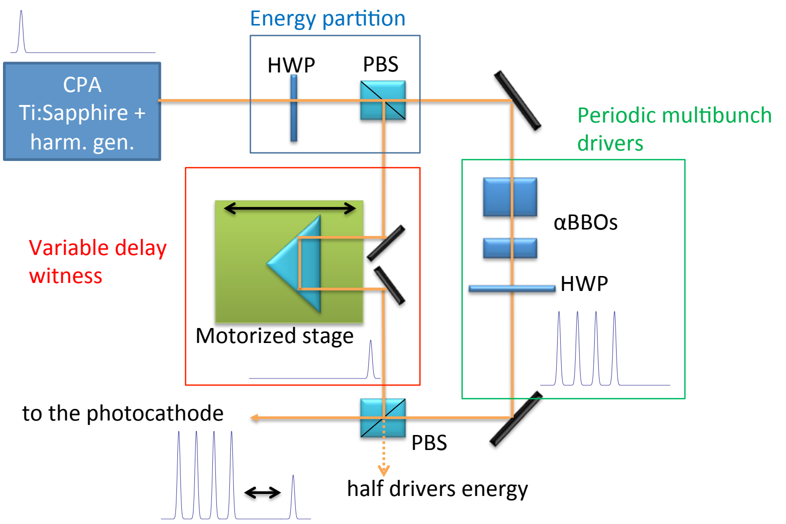


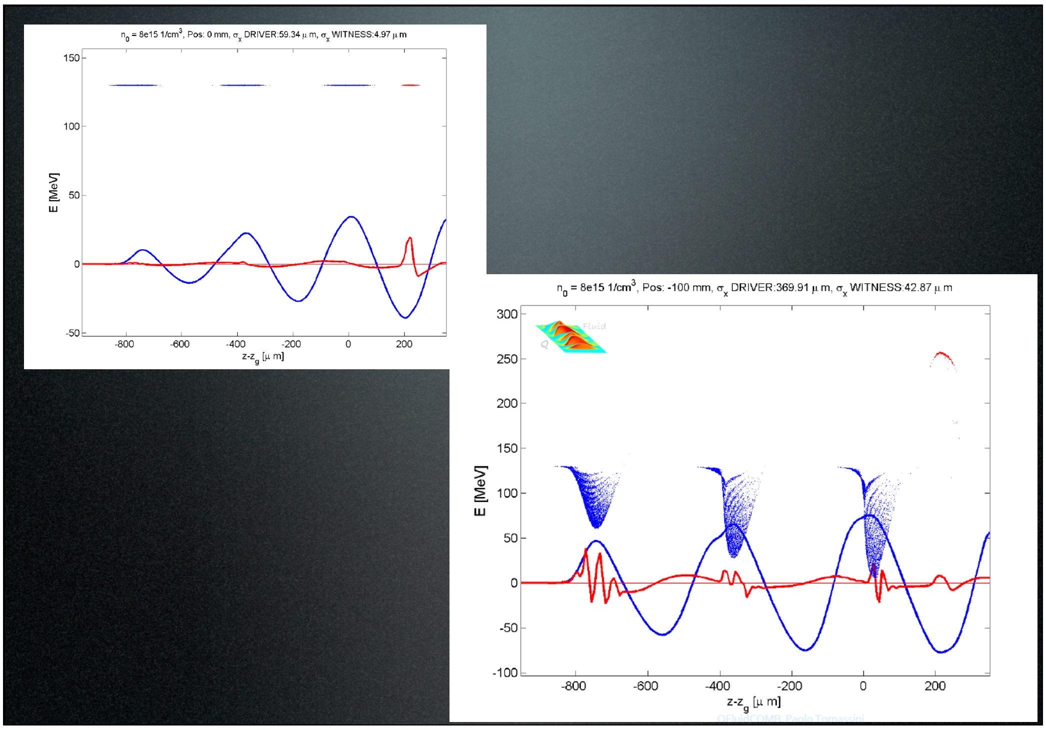
Resonant plasma excitation by a Train of Bunches



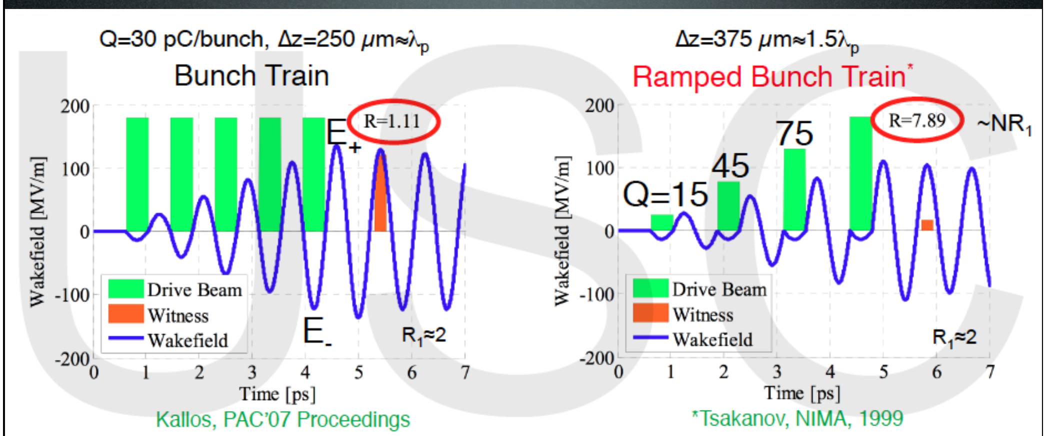
- **Weak blowout regime** with resonant amplification of plasma wave by a train of high Brightness electron bunches produced by **Laser Comb** technique?
- **Ramped bunch train configuration** to enhance tranformer ratio?
- **High quality bunch** preservation during acceleration and transport?

Driving and witness bunches generation

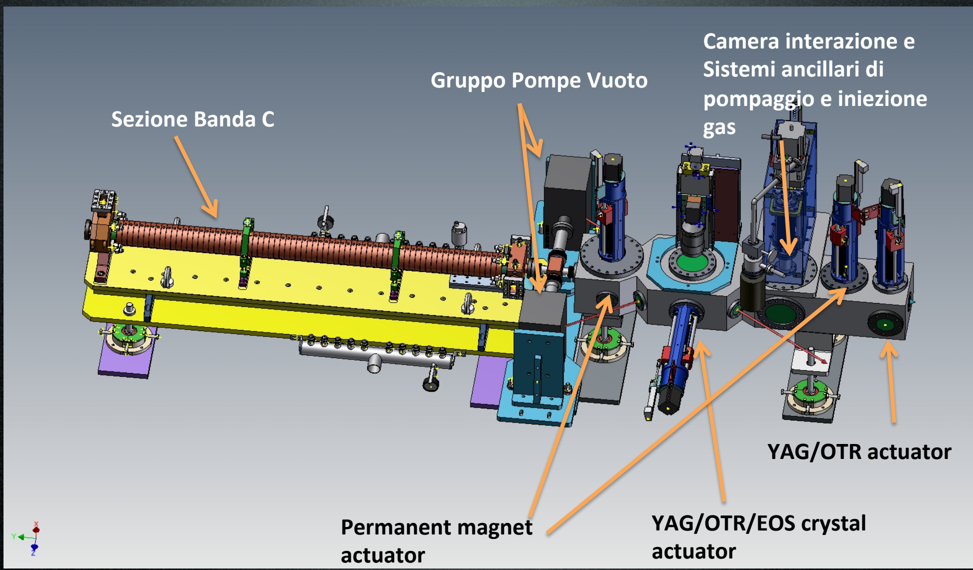


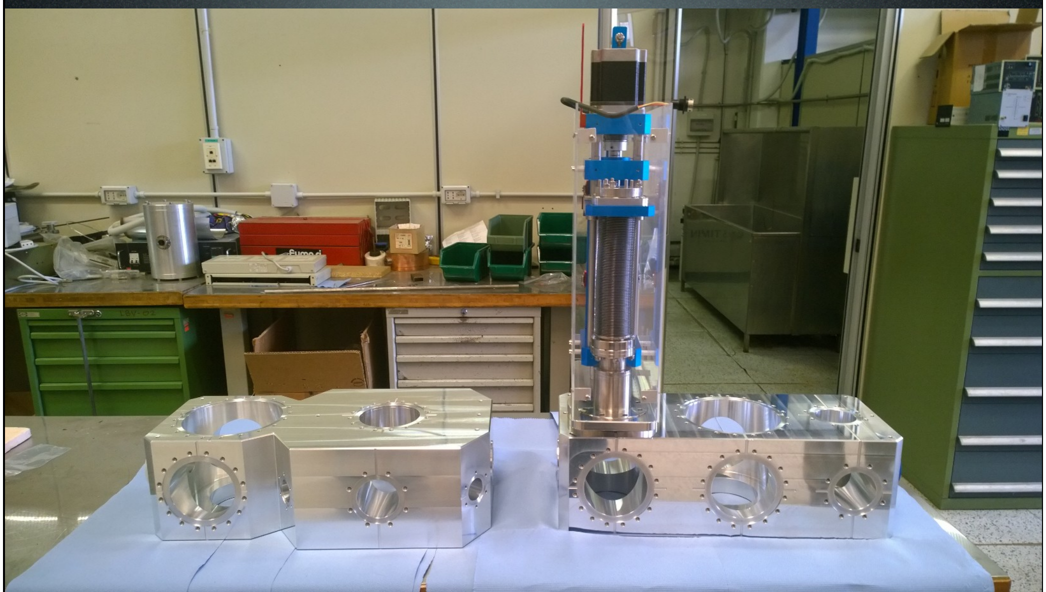


Ramped Bunch Train → longer active length

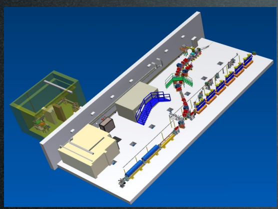


COMB plasma interaction chamber

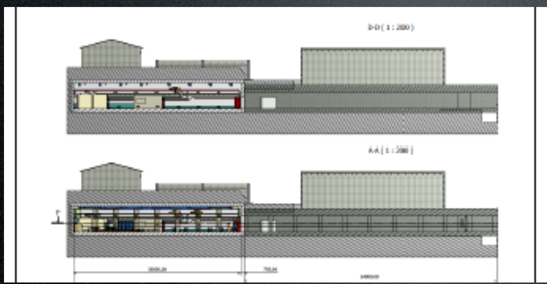




Some future



Consolidation

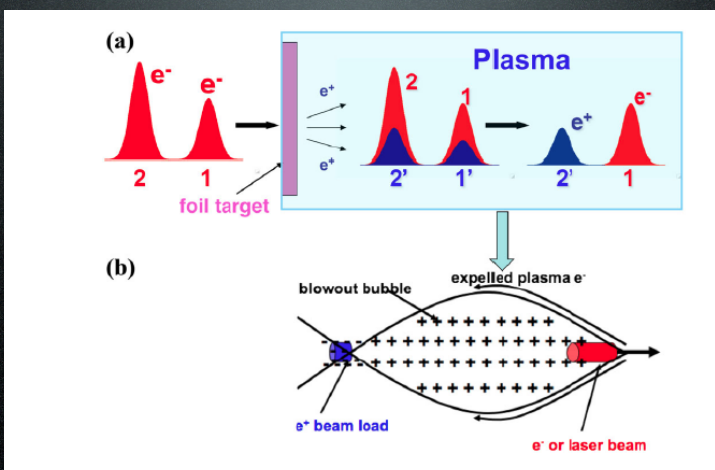


Upgrade 1 GeV

PHYSICAL REVIEW SPECIAL TOPICS - ACCELERATORS AND BEAMS **12**, 051303 (2009)

Optimization of positron trapping and acceleration in an electron-beam-driven plasma wakefield accelerator

X. Wang,[1] P. Muggli,[1] T. Katsouleas,[1] C. Joshi,[2] W. B. Mori,[2] R. Ischebeck,[3] and M. J. Hogan[3]

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