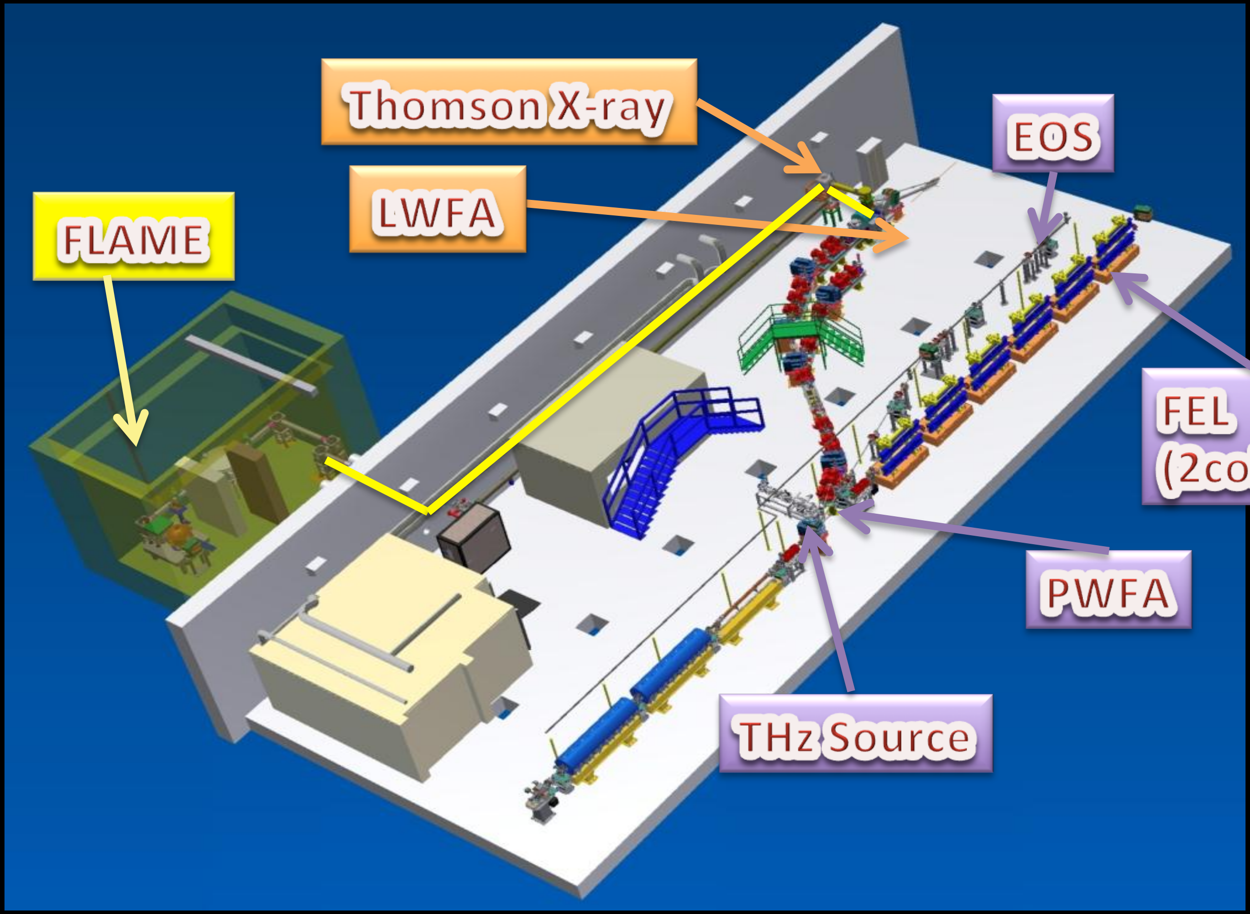
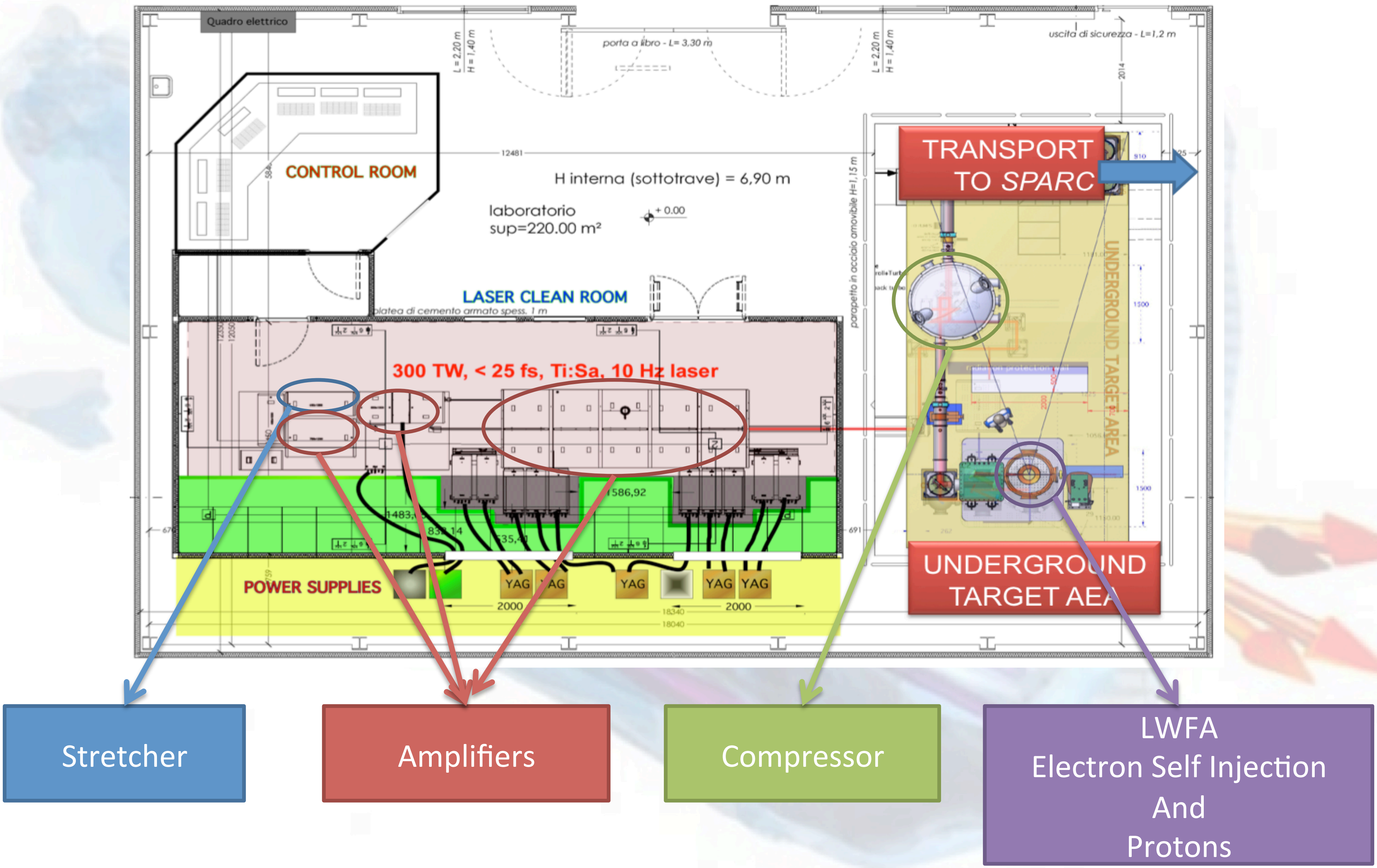
SPARC_LAB recent results

Sources for Plasma Accelerators and Radiation Compton with Lasers And Beams

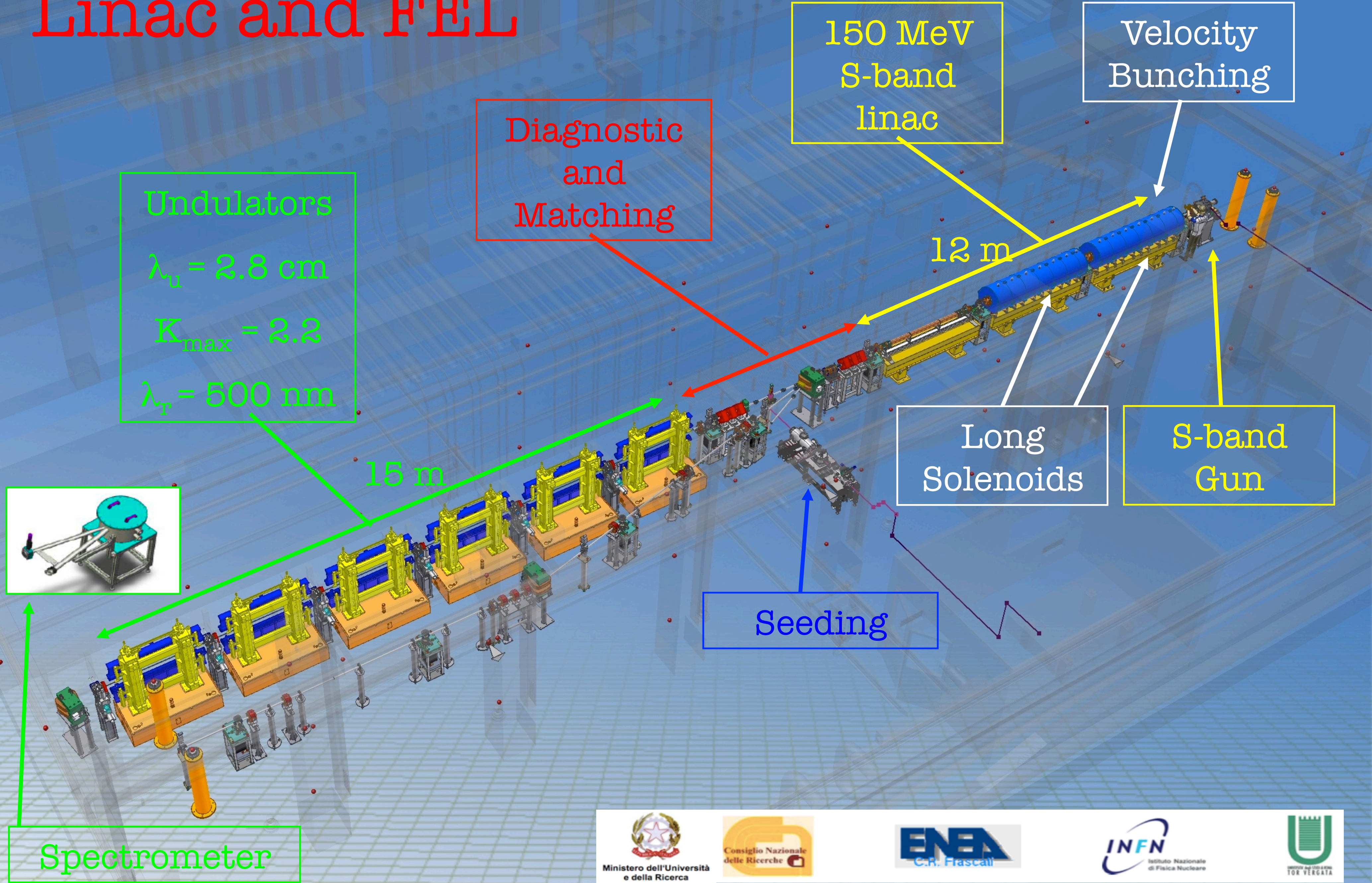
Massimo.Ferrario@LNF.INFN.IT



Ti:Sa FLAME laser

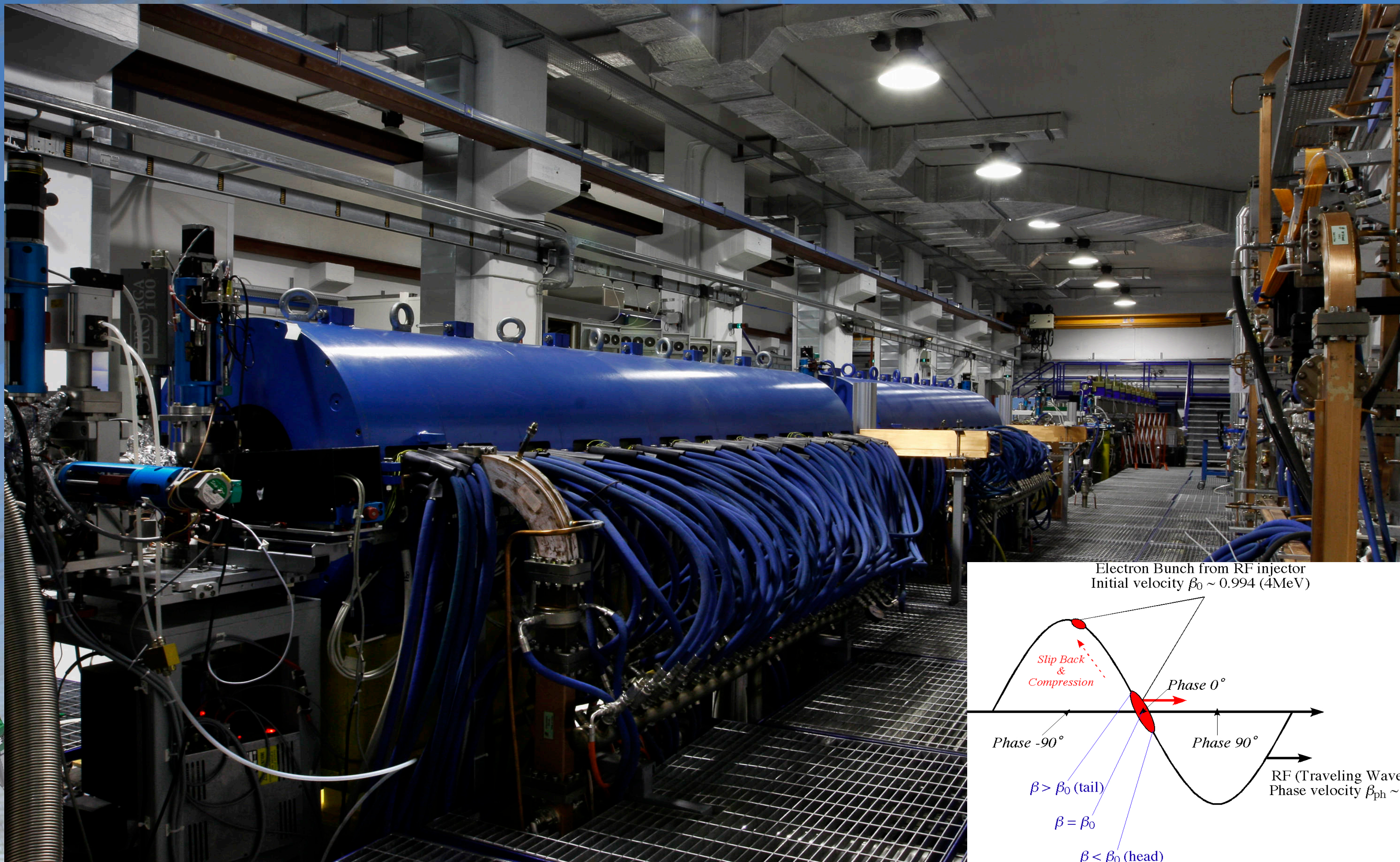


Linac and FEL

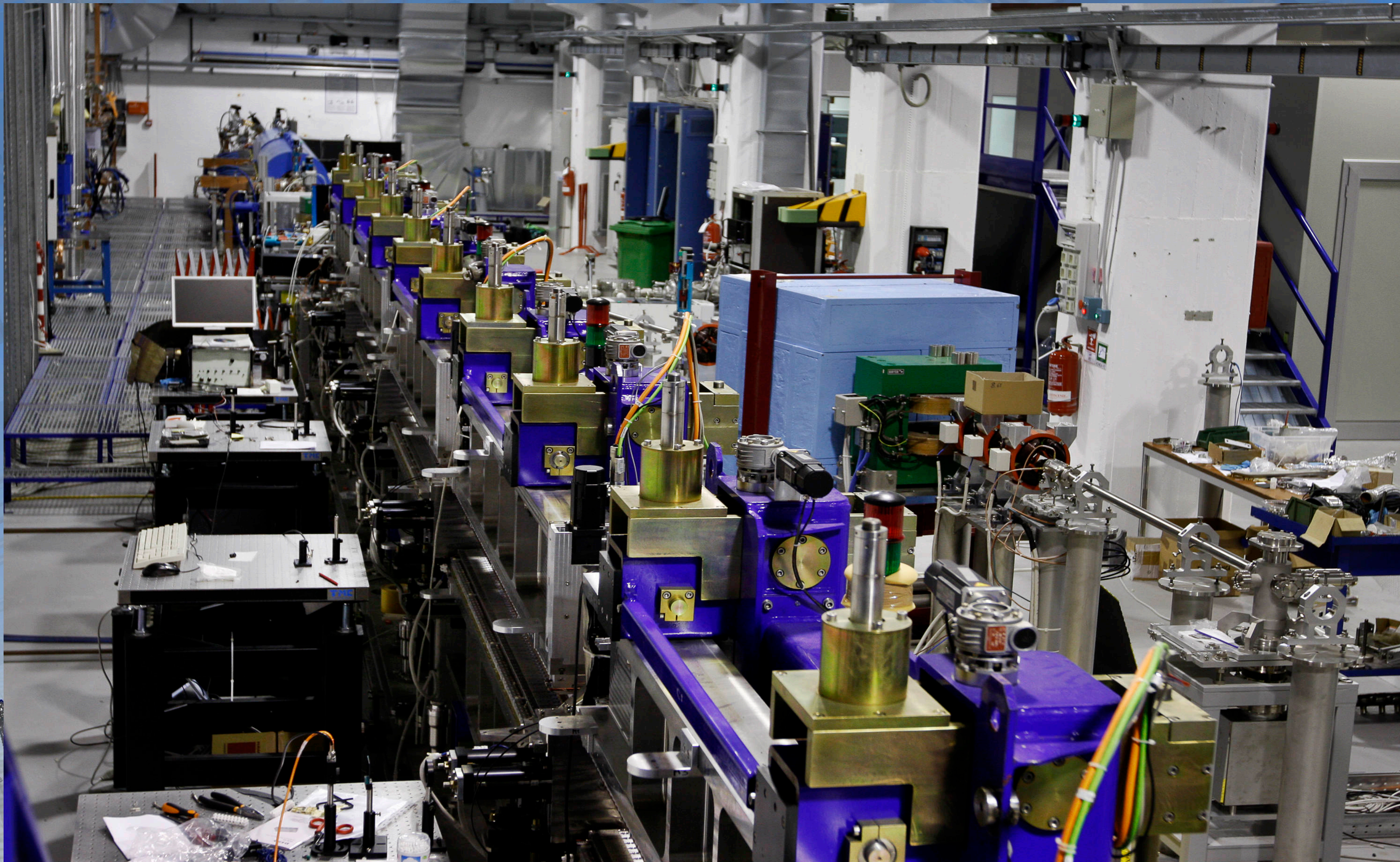


Ministero dell'Università e della Ricerca
Consiglio Nazionale delle Ricerche
ENEA C.R. Frascati
INFN Istituto Nazionale di Fisica Nucleare

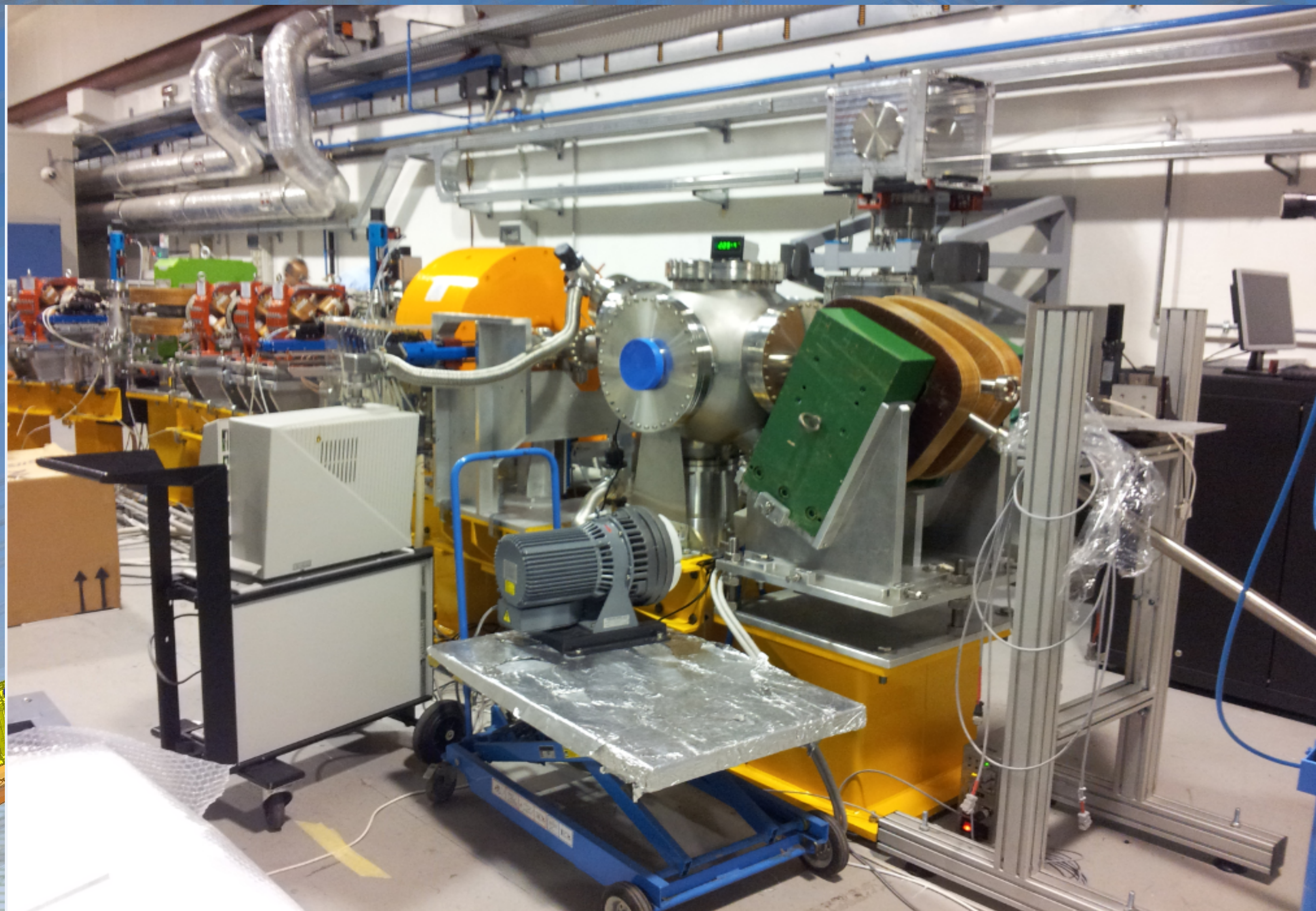
HB photo- injector with Velocity Bunching



Undulator chain



Thomson back-scattering source



SPARC_LAB: Some achievements

Beam Dynamics

Direct Measurement of the Double Emittance Minimum in the Beam Dynamics of the SPARC High-Brightness Photoinjector
M. Ferrario et al., PRL **99**, 234801 (2007)

Experimental Demonstration of Emittance Compensation with Velocity Bunching
M. Ferrario et al., PRL **104**, 054801 (2010)

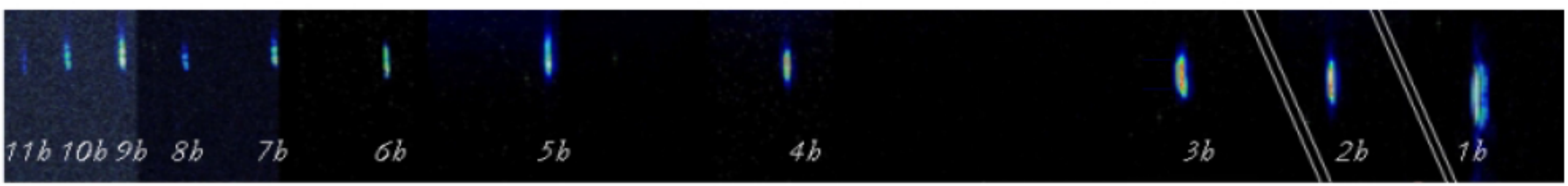
FEL

Self-Amplified Spontaneous Emission Free-electron Laser with an Energy-Chirped Electron Beam and Undulator Tapering
L. Giannessi et al., PRL **106**, 144801 (2011)

Seeded FEL

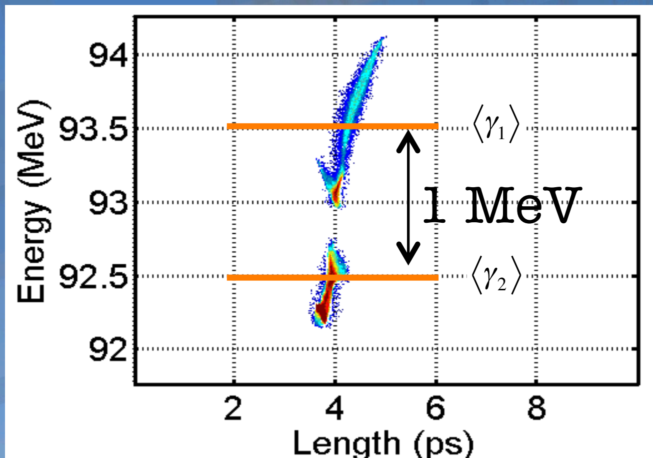
High-Gain Harmonic-Generation and Superradiance Free-electron Laser Seeded by Harmonics Generated in Gas
M. Labat et al., PRL **107**, 224801 (2011)

High-Order- Harmonic Generation and Superradiance in a Seeded Free-electron Laser
L. Giannessi et al., PRL **108**, 164801 (2012)



Superradiant Cascade in a Seeded Free-electron Laser
L. Giannessi et al., PRL **110**, 044801 (2013)

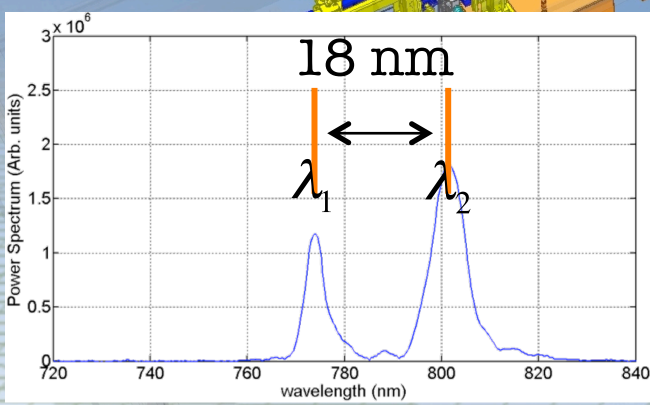
NEW: TWO COLORS SASE FEL



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

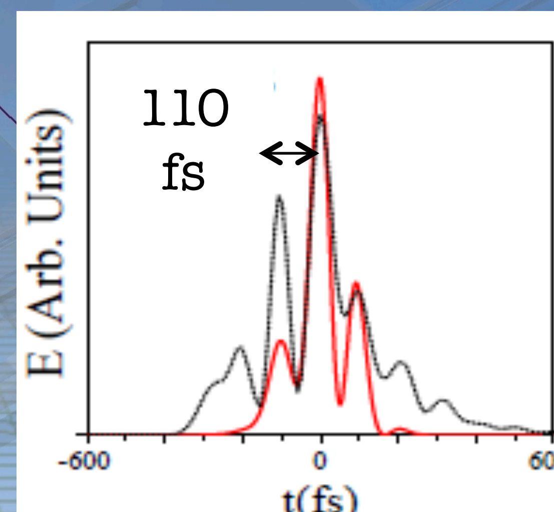
$$\lambda_r = \frac{\lambda_u}{2\gamma^2}\left(1 + K_{rms}^2\right)$$

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

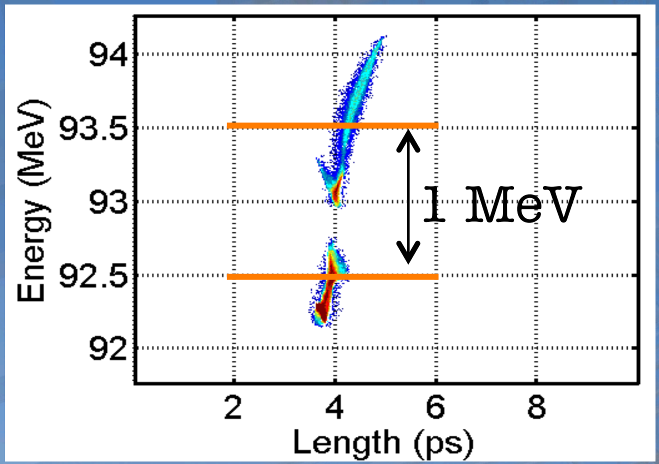


produce two wavelength
SASE –FEL radiation
with time modulation

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



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: $$l_b \approx L_{coop} = \frac{\lambda_r}{4\pi\sqrt{3}\rho}$$

Laser Comb technique: generation of a train of short bunches

(Parmela code)

Charge vs. Time

Energy vs. Time

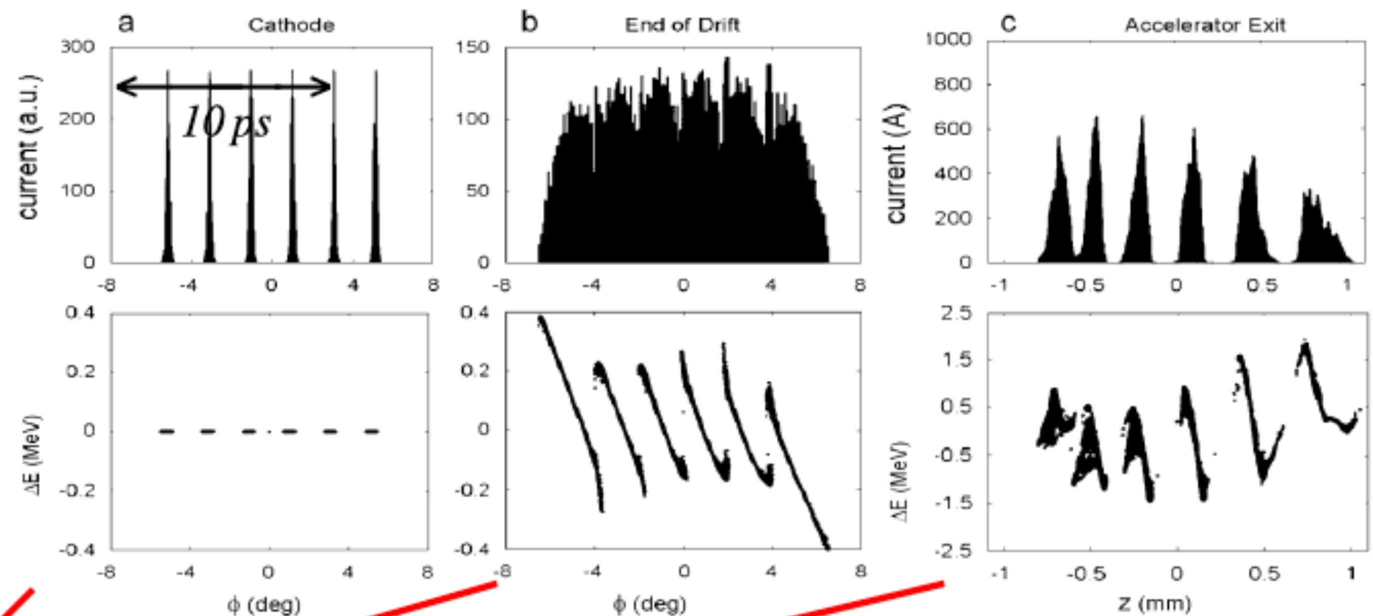
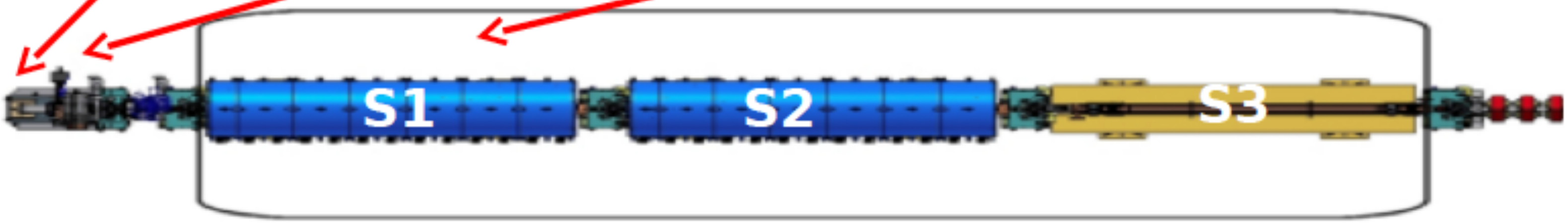
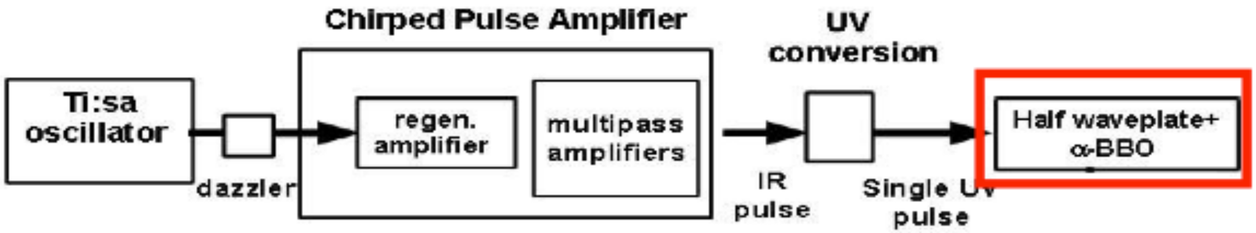


Fig. 1. Evolution of a six bunches electron beam train: the columns from left refer, respectively, to (a) the cathode, (b) the end of the drift at 150 cm and (c) the end of linac at 12 m far from cathode. The rows from top refer, respectively, to longitudinal profile and to energy modulation ΔE (MeV).

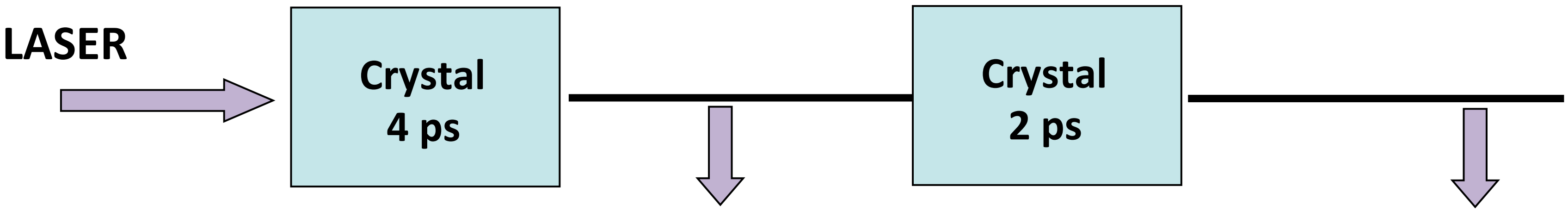


- P.O.Shea et al., Proc. of 2001 IEEE PAC, Chicago, USA (2001) p.704.
- M. Ferrario, M. Boscolo et al., Int. J. of Mod. Phys. B, 2006

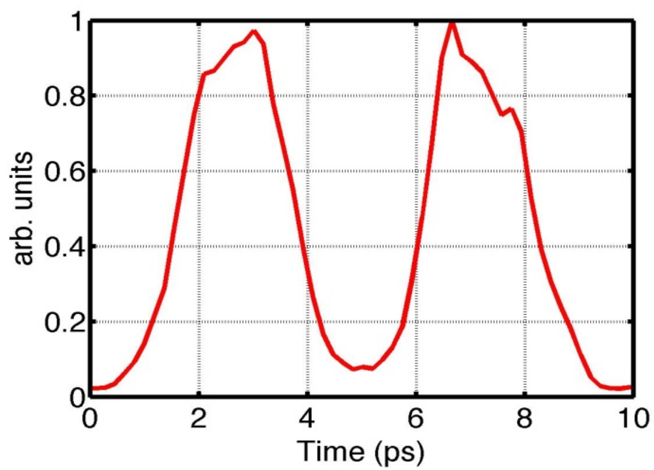
Laser Pulse Train Generation



$$\Delta\tau = \left| \frac{1}{v_{ge}} - \frac{1}{v_{go}} \right| L_{crystal}$$

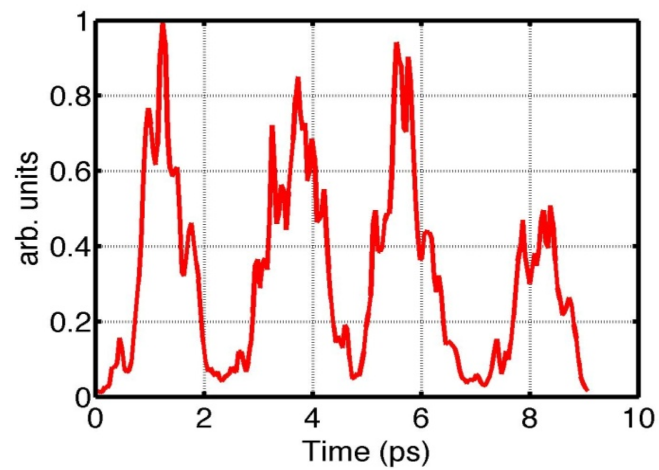


UV pulses



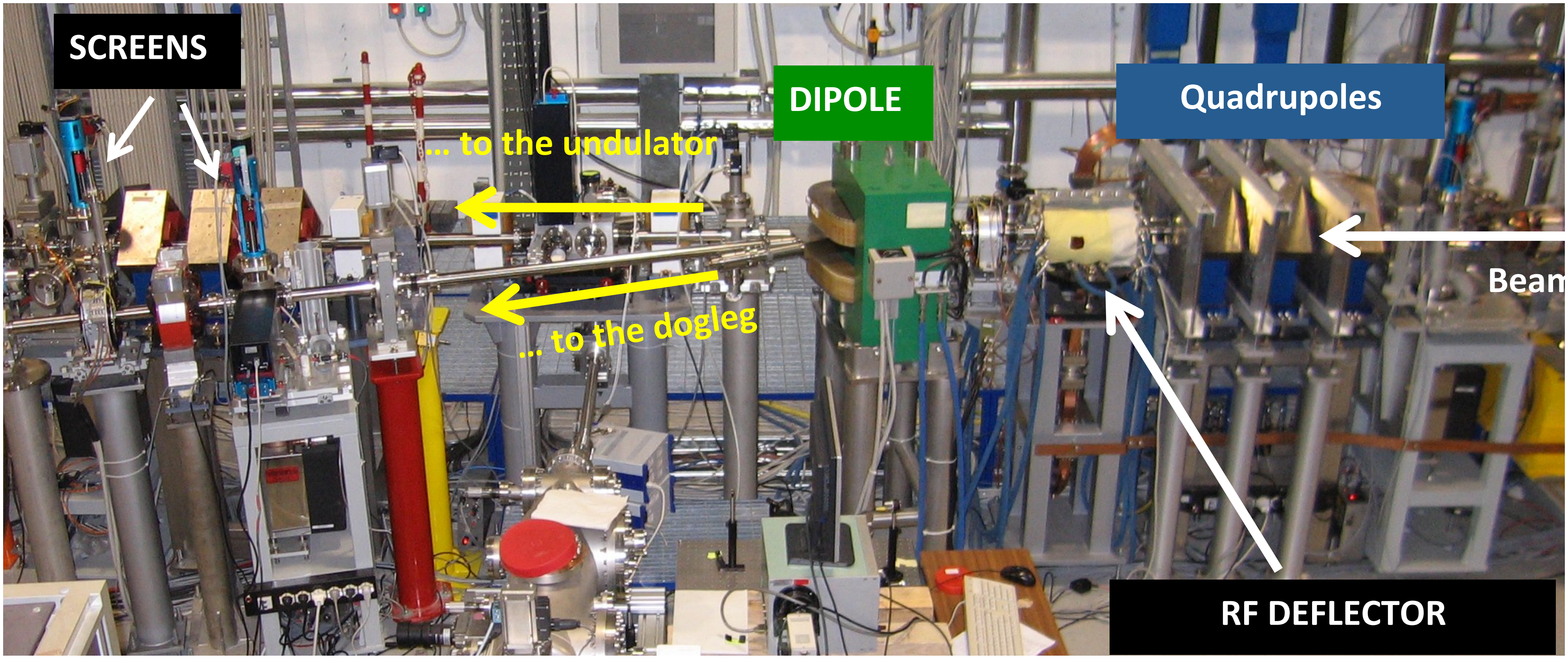
Streak camera

UV pulses

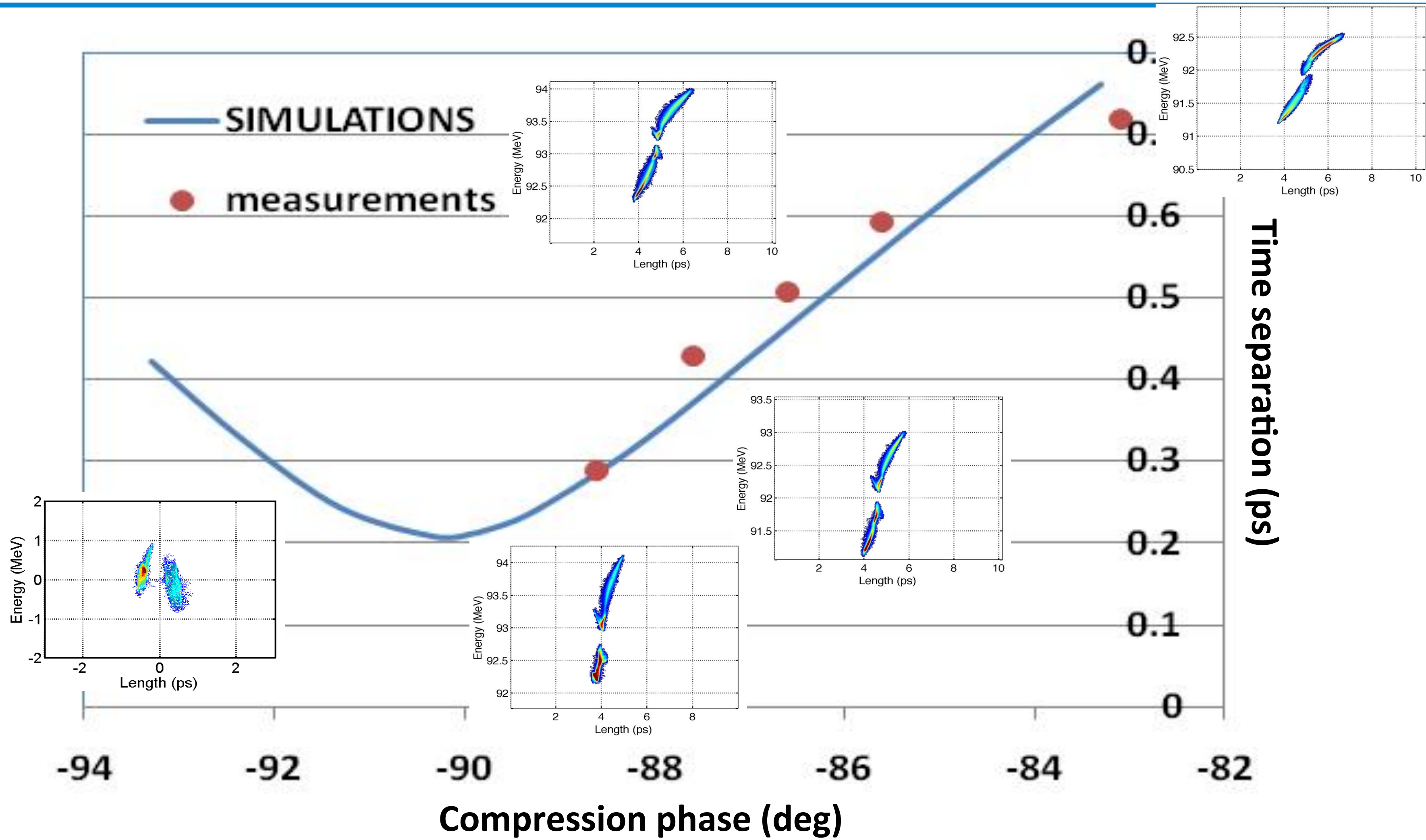


Streak camera

Electron beam diagnostics



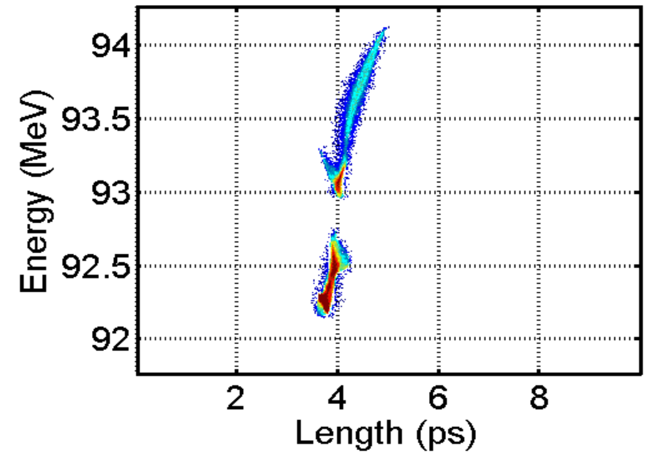
Measured 2 bunches distance versus VB phase



Achieved Electron Beam Performances

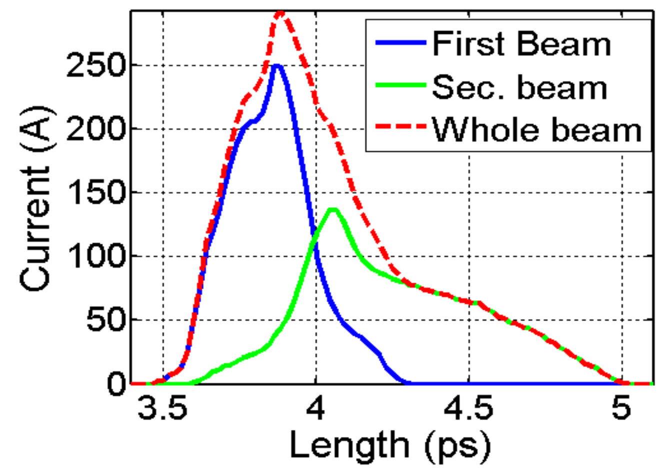
Whole beam

- Peak current: 300 A (with 160 pC)
- Bunch duration: 300 fs
- Normalized emittance: 1.7 (0.1) mm mrad
- Energy spread: 0.6%
- Energy: 93.04 (0.03) MeV



Single bunch

- Energy spread: 0.2% / 0.3 %
- Bunch duration: 100 fs / 250 fs



Energy separation: 1.07 (0.05) MeV

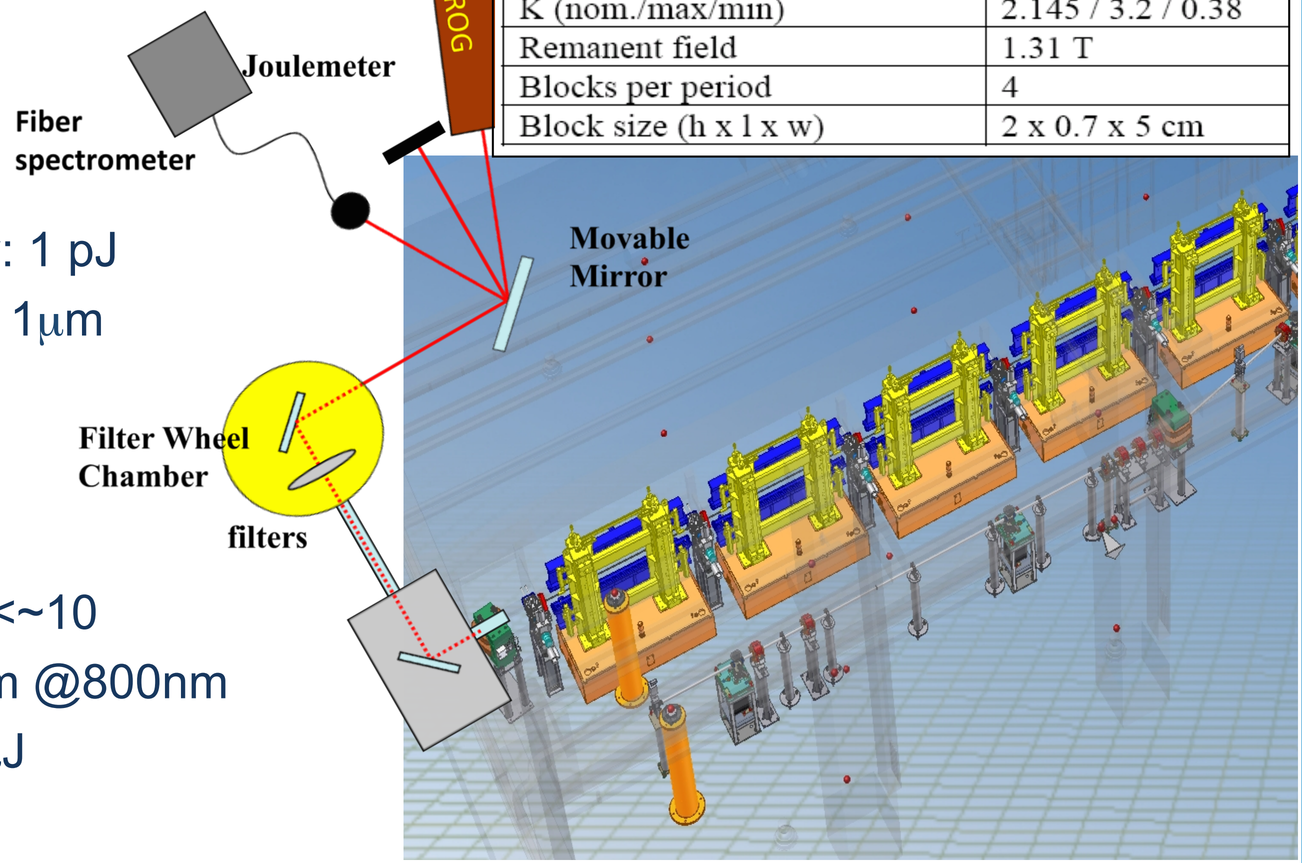
Time separation: 0.42 (0.03) ps

FEL parameter ρ: 6.7×10^{-3}

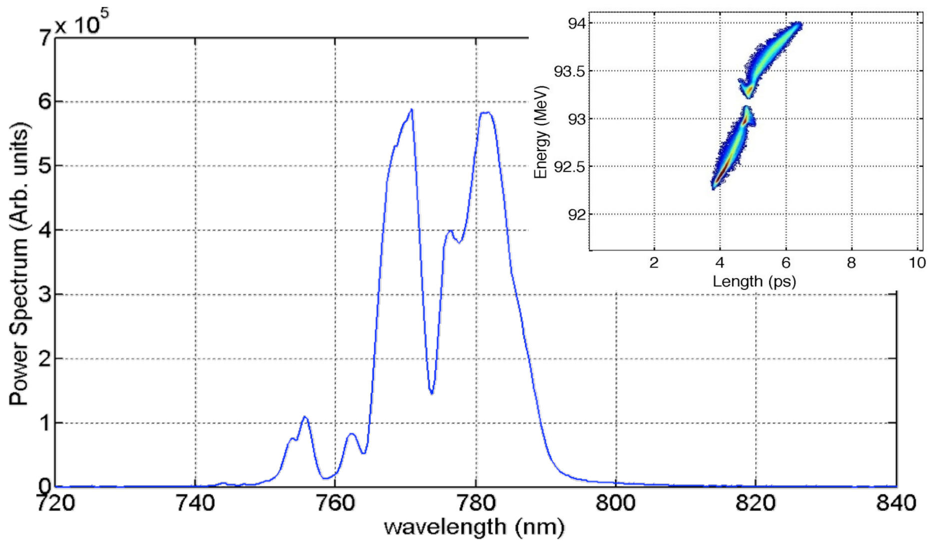
FEL Photon Diagnostics

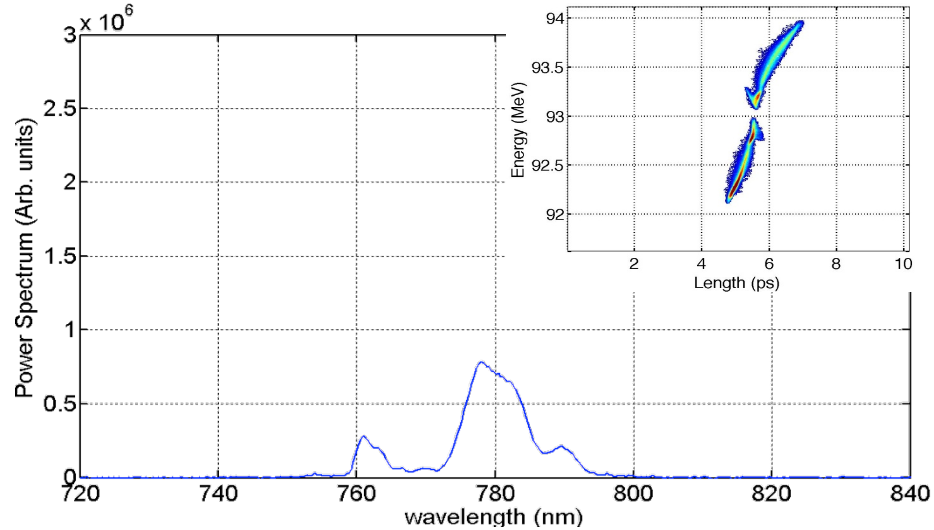
- **Fiber Spectrometer**
  - Resolution: 1.2 nm @ 800 nm
  - Window: 200-840 nm
- **Joulemeter**
  - Minimum detected energy: 1 pJ
  - Calibration: 5.96e8 V/J @ 1μm
  - Optical density filters
- **FROG:** NIR-Grenouille
  - Time-bandwidth product: <~10
  - Spectral resolution: 0.7 nm @800nm
  - Single shot sensitivity: 1 μJ

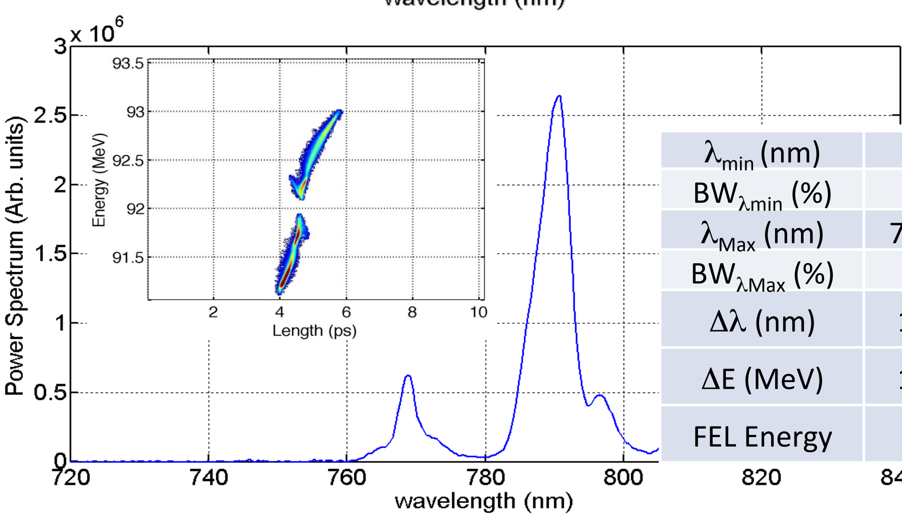
Period	2.8 cm
Undulator length	2.156.m
No of Periods	77
Gap (nom./min/max)	0.958 / 0.6 / 2.5 cm
K (nom./max/min)	2.145 / 3.2 / 0.38
Remanent field	1.31 T
Blocks per period	4
Block size (h x l x w)	2 x 0.7 x 5 cm



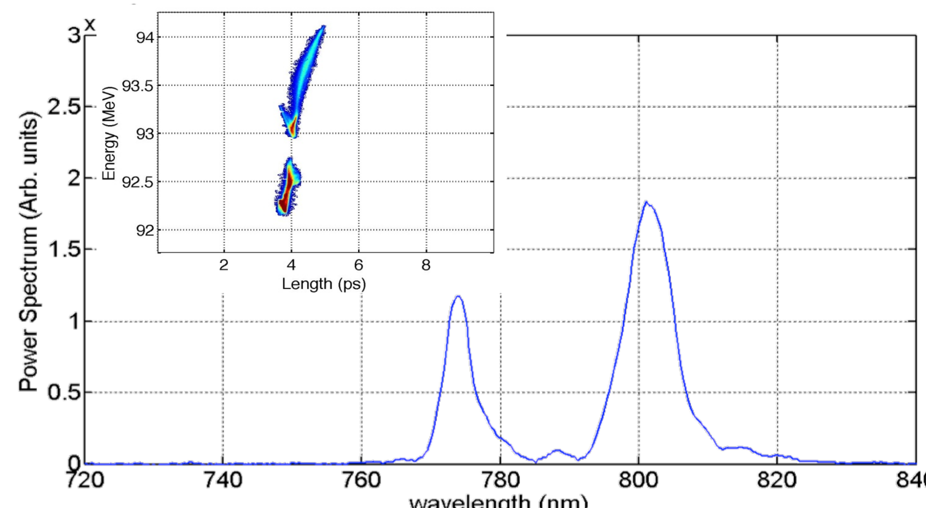
FEL Experiments: Two-levels radiation spectra



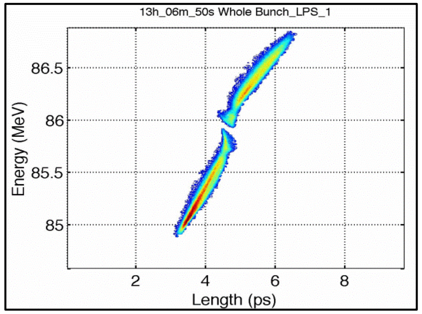




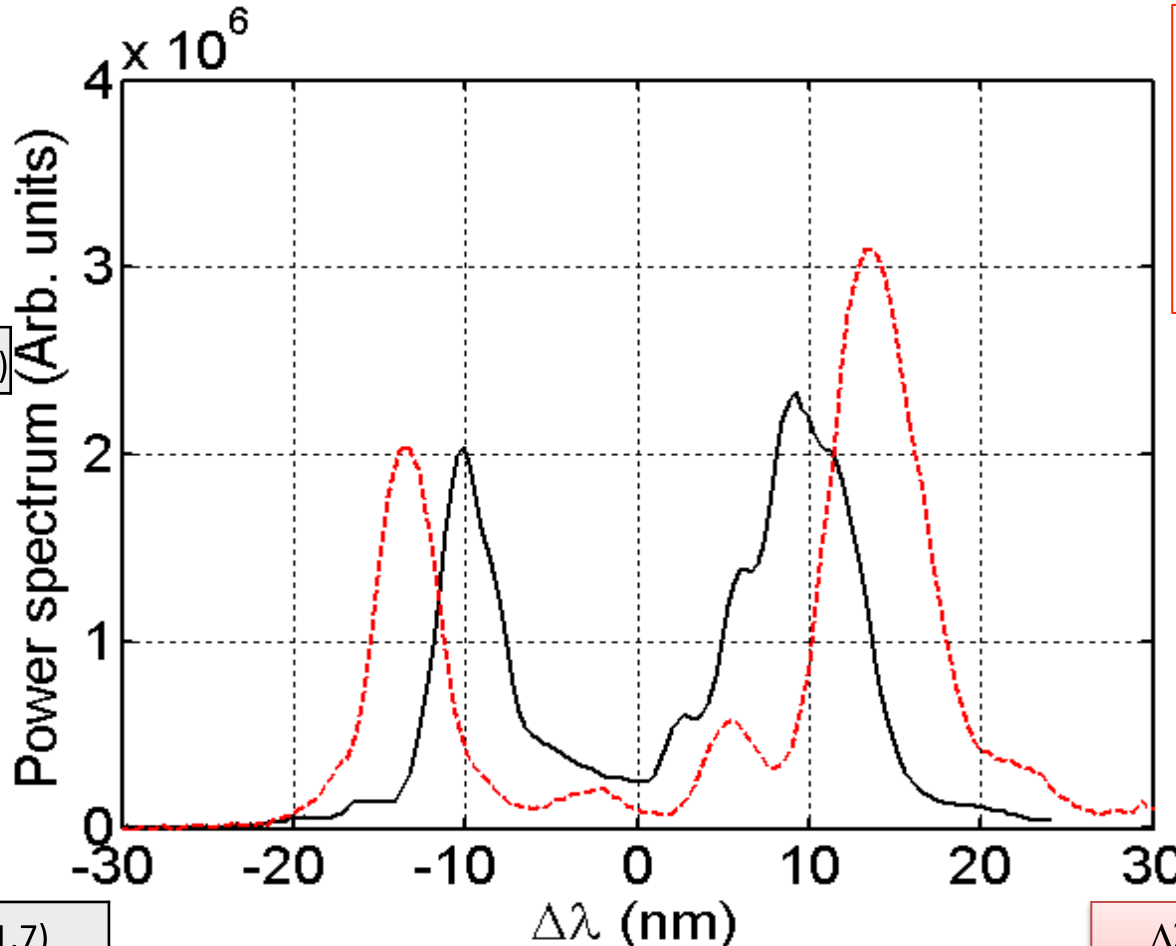
λ_{min} (nm)	769.8 (2)
$BW_{\lambda min}$ (%)	0.5
λ_{Max} (nm)	788.6 (1.3)
$BW_{\lambda Max}$ (%)	0.7
$\Delta\lambda$ (nm)	18.8 (2.9)
ΔE (MeV)	1.1 (0.17)
FEL Energy	> 37 µJ

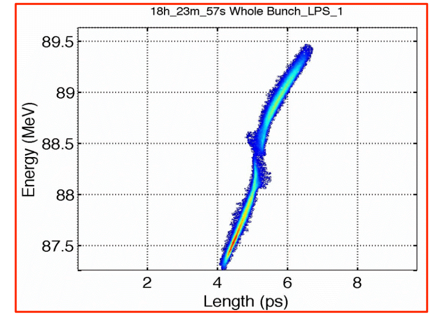


FEL EXPERIMENTS: Two-color tunability



ΔE(MeV)	-1.01 (0.03)





ΔE(MeV)	-1.14 (0.06)

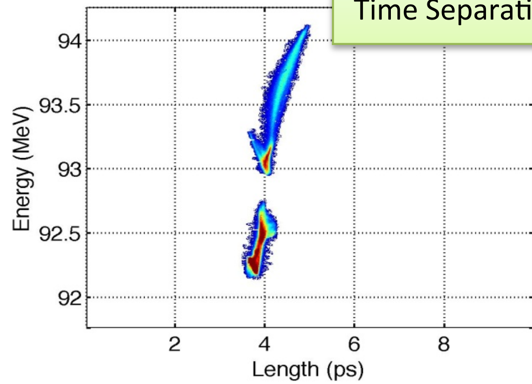
Δλ (nm)	20.7 (1.7)
ΔE (MeV)	1.066 (0.086)

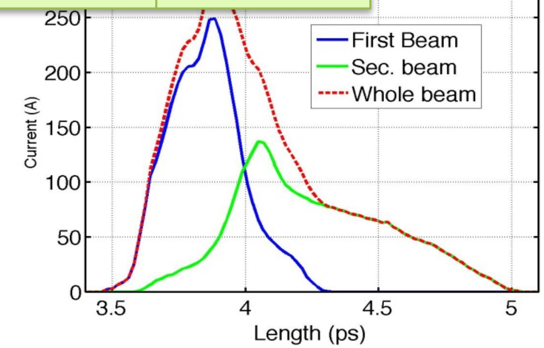
Δλ (nm)	26 (3)
ΔE (MeV)	1.35 (0.14)

FEL Experiments: Time-modulated pulses

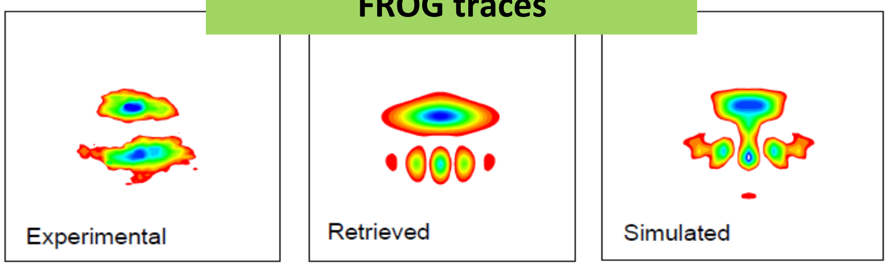
	Energy (MeV)	En. Spread (%)	Length (ps)	Charge (pC)
First Beam	92.515 (0.033)	0.174 (0.005)	0.147 (0.002)	82.15 (1.58)
Second Beam	93.588 (0.033)	0.317 (0.005)	0.283 (0.003)	77.85 (1.56)
Whole Beam	93.038 (0.032)	0.631 (0.003)	0.305 (0.004)	160.00 (3.10)

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



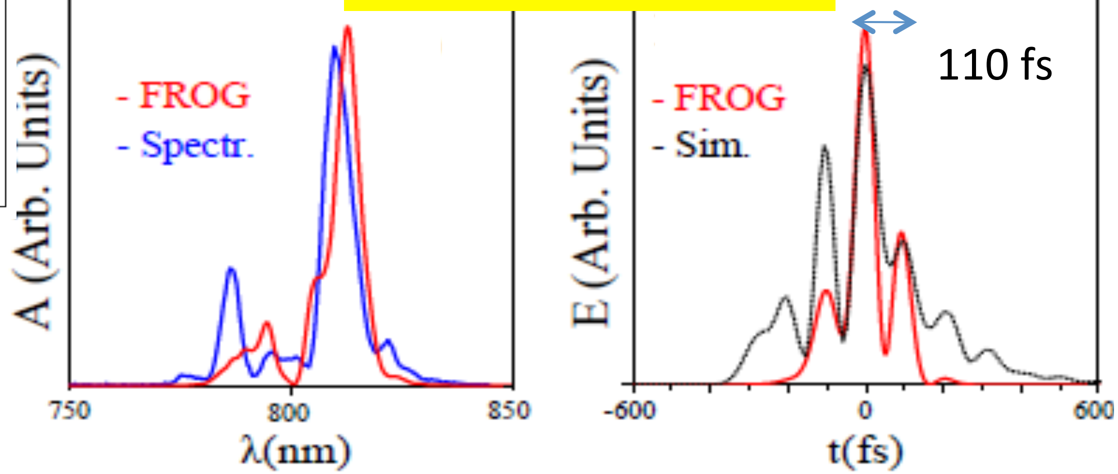


FROG traces

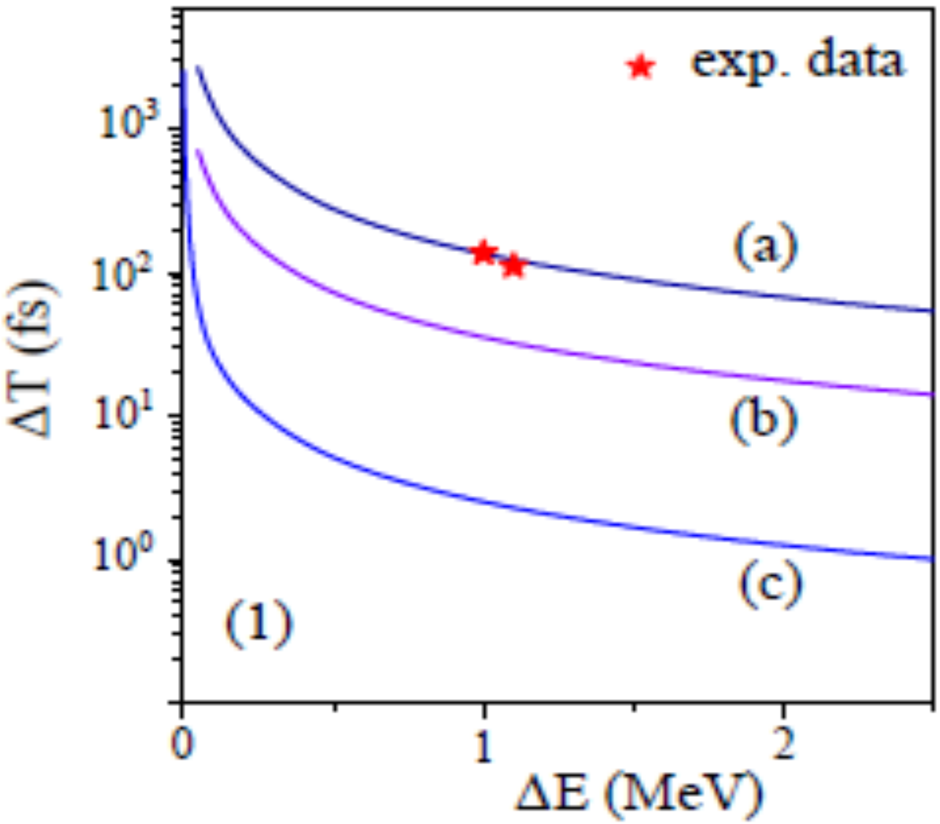


Δλ(nm)	BW (%)	RMS Time duration (fs)	Time separation (fs)
18	0.86	80	110

Simulation by GENESIS



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) $\lambda = 0.15\,nm$

CONCLUSIONS

- Production of a two-pulse beam with **time and energy separation tunable** with linac settings

- Demonstration of the possibility to control time and energy separation

- Achievement of beam quality necessary for FEL applications

- Generation of a two-pulse beam, each pulse shorter than the L_c, acting as independent radiation source in a quasi-single spike regime
  - Production and characterization of a two-color FEL spectrum and of a train of short FEL pulses
- Different techniques:
  - Chirped seeding ➔ G. De Ninni et al., PRL 110, 064801 (2013)
  - Alternate K undulator → A. A. Lutman et al., PRL 110, 134801 (2013)

Acknowledgement

- ALL OF YOU FOR THE ATTENTION

- SPARC collaboration
  - INFN,
  - ENEA
  - Univ. of Milano
  - Univ. of Rome La Sapienza (SBAI)
  - Univ. of Rome Tor Vergata
  - CNR
  - UCLA