Compact FEL SOURCES?

G. Dattoli
&
E. Di Palma, I. Spassovsky

Webinar CLS
November 10 (2021)

? A Definition of Compact and Low cost FEL has not been given yet?

Such a definition is not even straightforward (wave-length range, brightness (peak and average), choice of the accelerating devices, undulator architecture…)

Solutions

- High gradient accelerators
- «New» acceleration mechanisms
- «New» undulator Solutions,
- «Smart» Use of the higher harmonic generation mechanism
- Poli-Harmonic Undultors…

High Gradient (Plasma…)
Physics Reports 937 (2021) 1–73

- Undulator design for a laser-plasma-based free-electron-laser

- Ghaith; Couprie, ;Oumbarek-Espinos; Andriyash; Massimo; Clarke; Courthold; Bayliss; Bernhard; Trunk; Valléau; Marcouillé; Chancé; Licciardi; Malka; Nguyen; Dattoli.
- The design criteria for these FEL devices have been fixed …but…In the following we will not report on FPAD

Special Issue "Oscillator-Amplifier Free Electron Lasers an Outlook to Their Feasibility and Performances"

MDPI SPECIAL ISSUE

DATTOLI, CURCIO and GIULIETTI EDS.

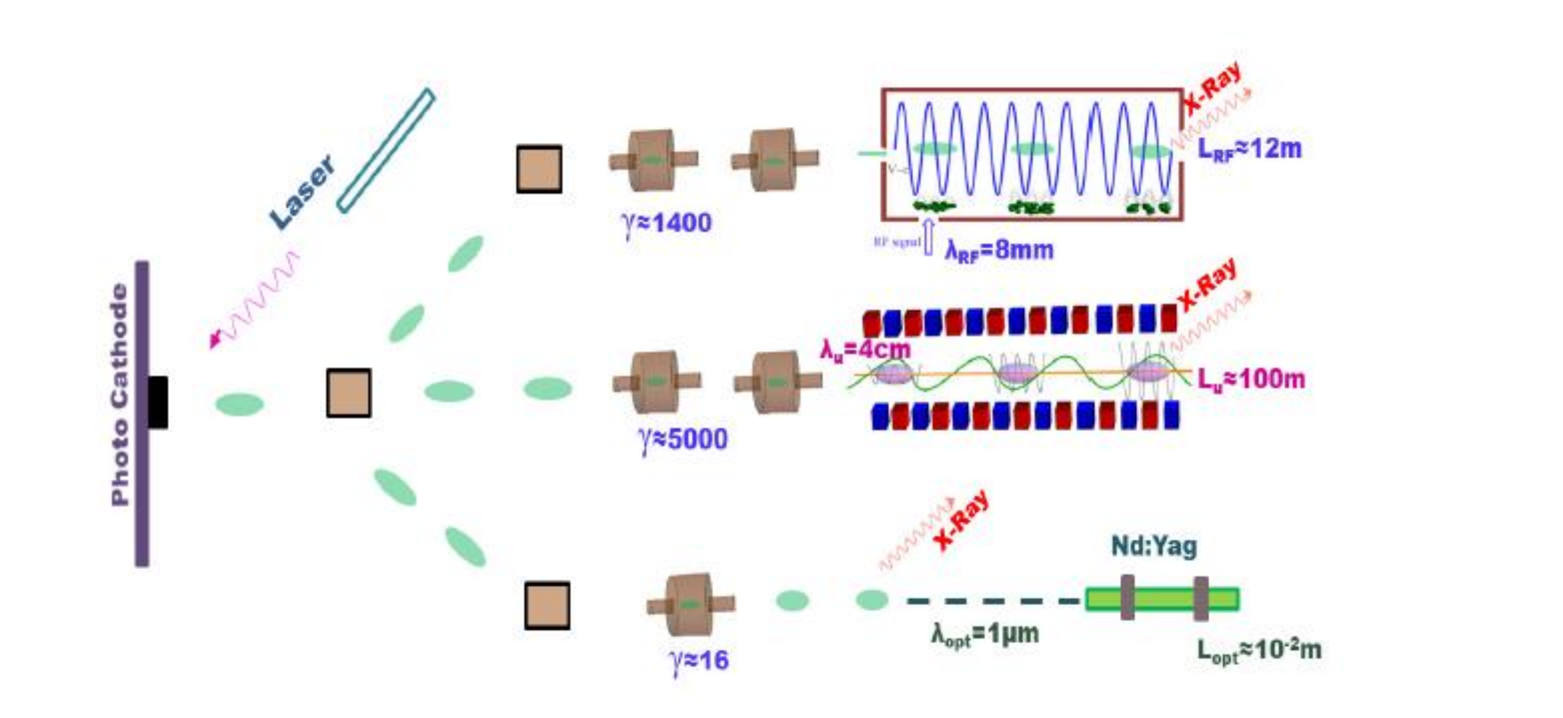
https://www.mdpi.com/journal/applsci/special_issues/Oscillator-Amplifier_Free_Electron_Lasers

The conception of FEL compact device developed in the issue belong to

NFAT

(NEXT FUTURE AVAILABLE TECHNOLOGIES)

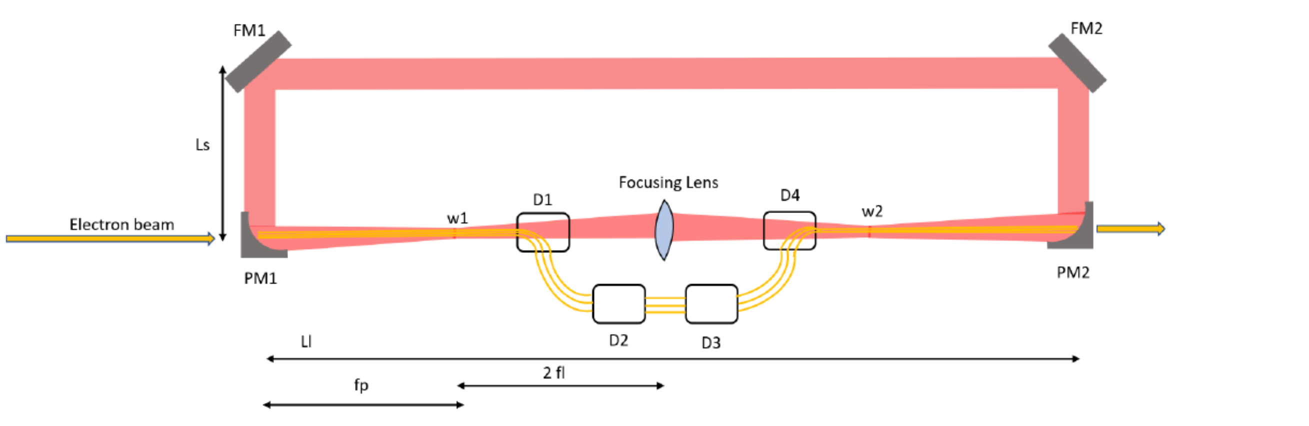
Scenario



Laser
Photo Cathode
X-Ray
L_{RF}≈12m
RF signal
λ_{RF}=8mm
γ≈1400
X-Ray
λ_u=4cm
L_u≈100m
γ≈5000
X-Ray
Nd:Yag
λ_{opt}=1μm
L_{opt}≈10^{-2}m
γ≈16

A. Curcio

Recirculated Wave Undulators for Compact FELs



$I_p = 4.2 \times 10^{18}\ \mathrm{W/m^2}$ $(\lambda_0 = 10.6\ \mu\mathrm{m})$ energy per pulse of 40 J in 300 ps $(P_L = 130\ \mathrm{GW})$

$\Sigma_0 = \pi w_0^2 \sim \pi \times 10^{-8}\ \mathrm{m}^2$

$$K = a_0 = 0.85 \times 10^{-5} \lambda_0[m] \sqrt{I_p(W/m^2)}$$

$K \sim 0.186.$

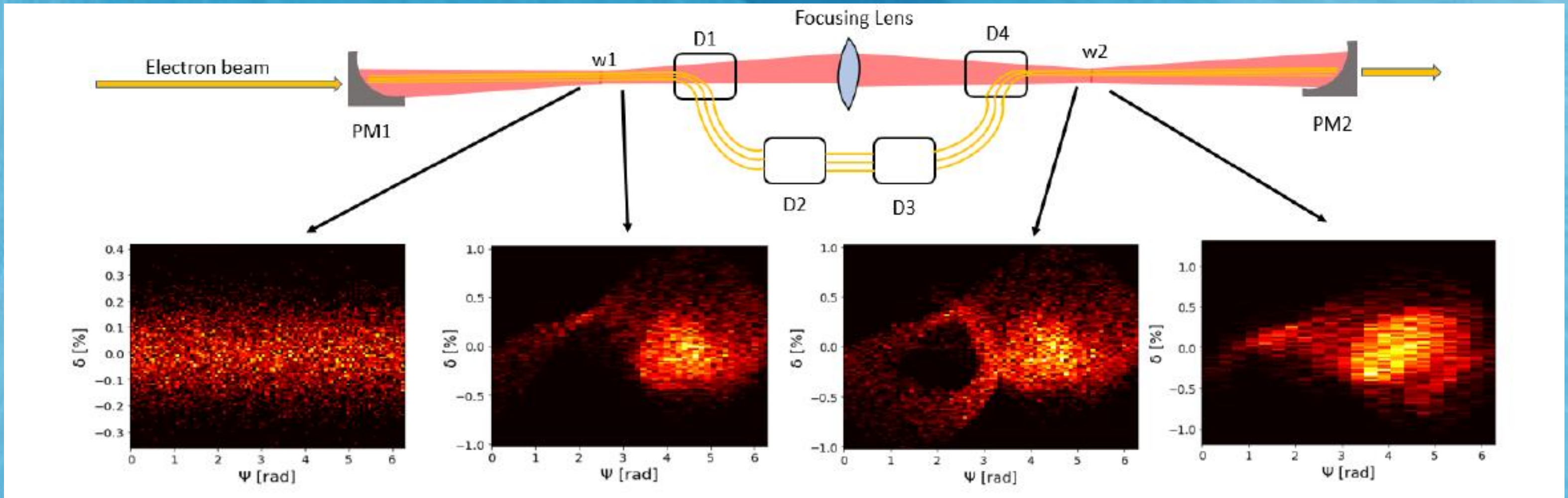
$\gamma_r \sim 70.$

$I_e = j_e \Sigma_e = 3\,\mathrm{kA}$, where $\Sigma_e = 0.075\Sigma_0$

$$\varrho = \frac{8.36 \times 10^{-3}}{\gamma_e} \left(j_e[A/m^2] \lambda_0^2[m] K^2 \right)^{1/3}$$

A. CURCIO

Recirculated Wave Undulators for Compact FELs



Centro de Laseres Pulsados (CLPU), Edificio M5, Parque Científico, C/Adaja, 8, 37185 Villamayor, Spain; acurcio@clpu.es

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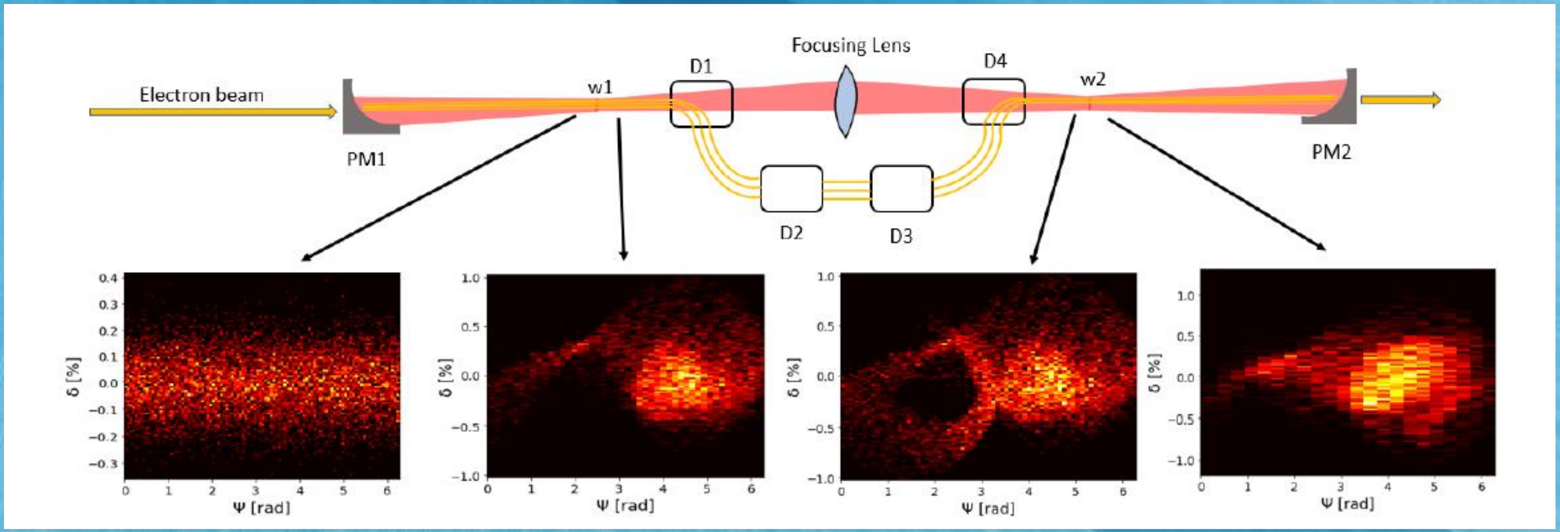
…A. Curcio
FEL 1d Python



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E. Di Palma et al.
ENEA

Radio-Frequency Undulators, Cyclotron Auto Resonance Maser and Free Electron Lasers

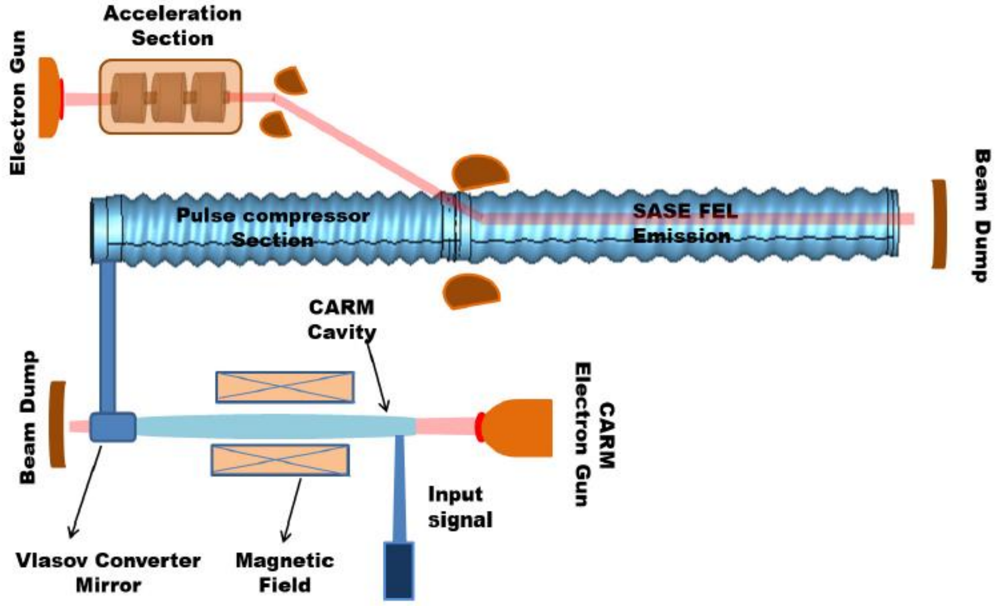
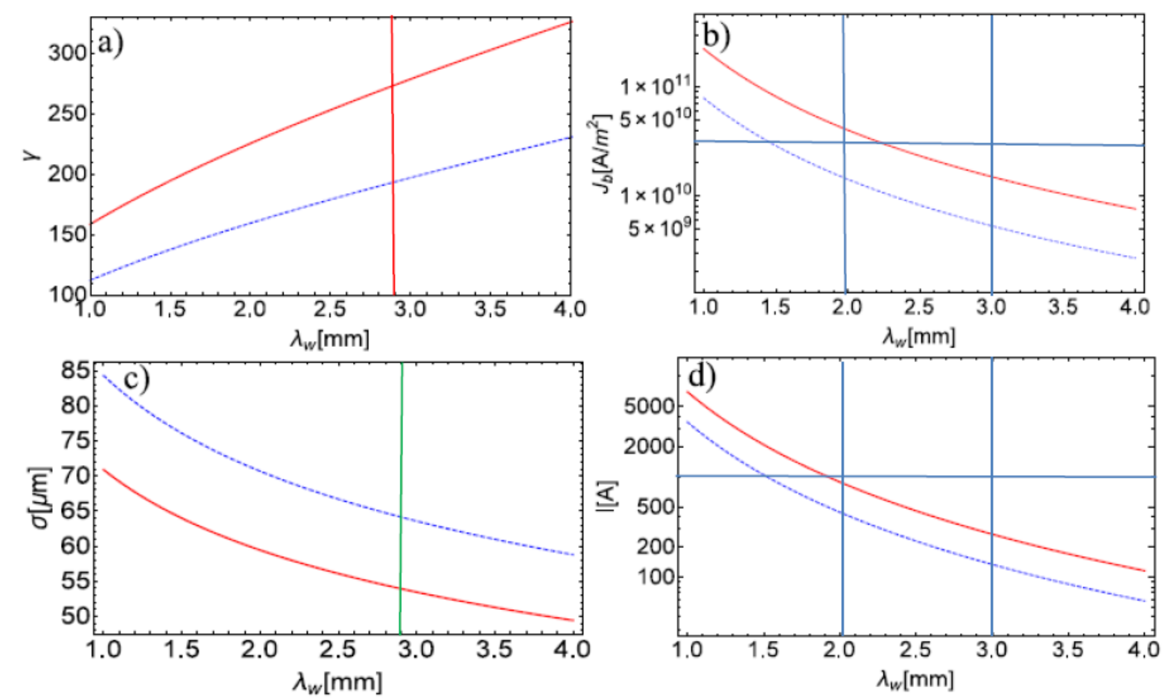


Figure 17. CARM-Undulator, SASE-FEL layout. Lower part: CARM generator and radiation transport system. Upper part: consecutive helical waveguides, the first acts as RF power compressor, the second, feeded with an external e-beam, realizes the SASE interaction region.

Operating Region



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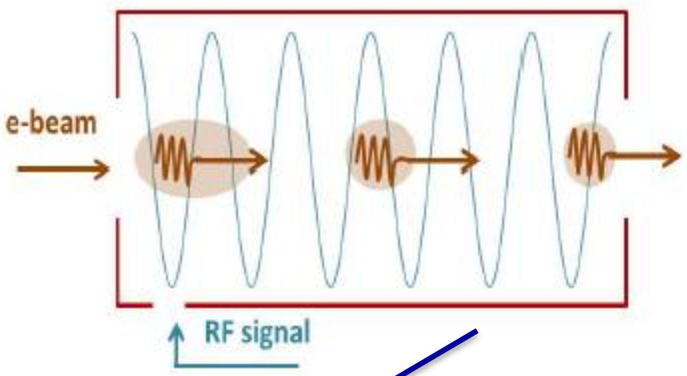
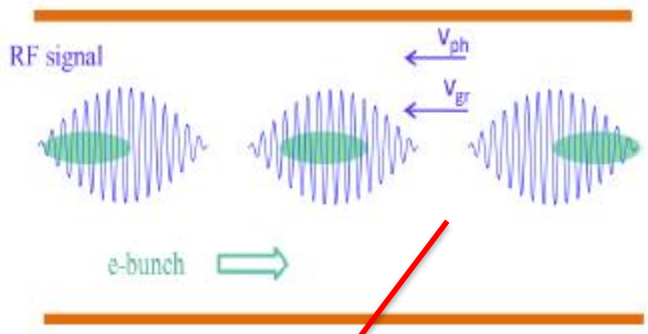
…

- Flying undulators/ Pulse compression





$$L_{eff} = \frac{v_g \tau}{1 + \frac{v_g}{c}}$$

$$L_{c,eff} = \frac{v_g \tau}{1 - \frac{v_g}{c}}$$

Flying und.

- ...

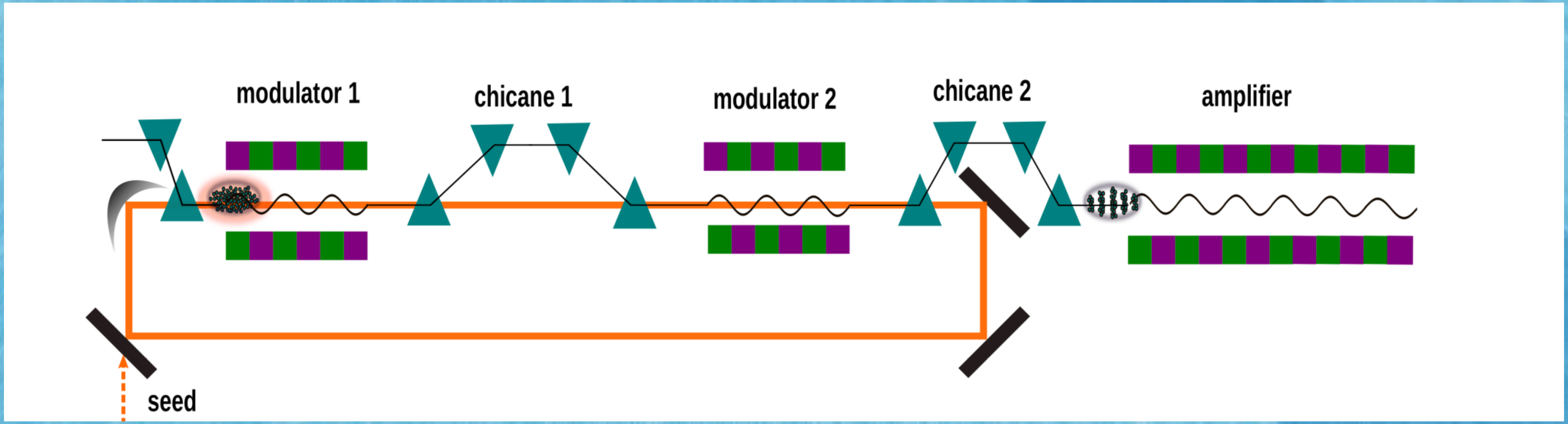
Samsonov, S.V.; Phelps, A.D.; Bratman, V.L.; Burt, G.; Denisov, G.G.; Cross, A.W.; Ronald, K.; He, W.; Yin H. Compression of frequency-modulated pulses using helically corrugated waveguides and its potential for generating multigigawatt rf radiation. *Phys. Rev. Lett.* **2004**, *92*, 118301, doi:10.1103/PhysRevLett.92.118301 [CrossRef]
Zhang, L.; Mishakin, S.V.; He, W.; Samsonov, S.V.; McStravick, M.; Denisov, G.G.; Cross, A.W.; Bratman, V.L.; Whyte, C.G.; Robertson, C.W.; et al. Experimental Study of Microwave Pulse Compression Using a Five-Fold Helically Corrugated Waveguide. *IEEE Trans. Microw. Theory Tech.* **2015**, *63*, 1090–1096. doi:10.1109/TMTT.2015.2393882. [CrossRef]
McStravick, M.; Samsonov, S.V.; Ronald, K.; Mishakin, S.V.; He, W.; Denisov, G.G.; Whyte, C.G.; Bratman, V.L.; Cross, A.W.; Young, A.R.; et al. Experimental results on microwave pulse compression using helically corrugated waveguide. *J. Appl. Phys.* **2010**, *108*, 054908, doi:10.1063/1.3482024. [CrossRef]

Georgia Paraskaki et al. (DESY)

Oscillator Amplifier Schemes and NLHG

Advanced Scheme to Generate MHz, Fully Coherent FEL Pulses at nm Wavelength

Current FEL development efforts aim at improving the control of coherence at high repetition rate while keeping the wavelength tunability. Seeding schemes, like HGHG and EEHG, allow for the generation of fully coherent FEL pulses, but the powerful external seed laser required limits the repetition rate that can be achieved. In turn, this impacts the average brightness and the amount of statistics that experiments can do. In order to solve this issue, here we take a unique approach and discuss the use of one or more optical cavities to seed the electron bunches accelerated in a superconducting linac to modulate their energy. Like standard seeding schemes, the cavity is followed by a dispersive section, which manipulates the longitudinal phase space of the electron bunches, inducing longitudinal density modulations with high harmonic content that undergo the FEL process in an amplifier placed downstream. We will discuss technical requirements for implementing these setups and their operation range based on numerical simulations



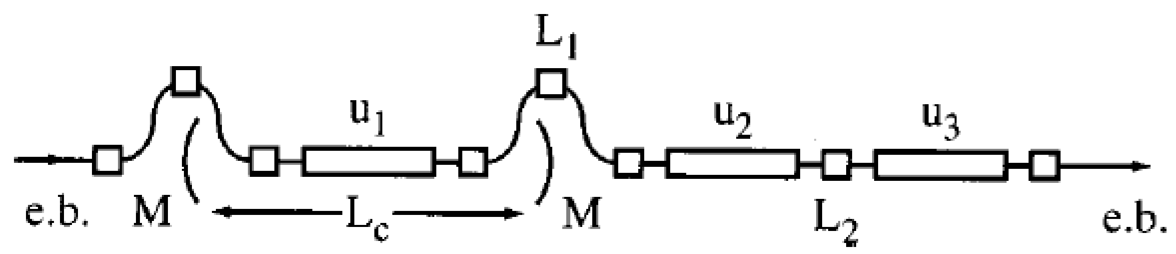
…From the past

- Design considerations for x-ray free electron lasers

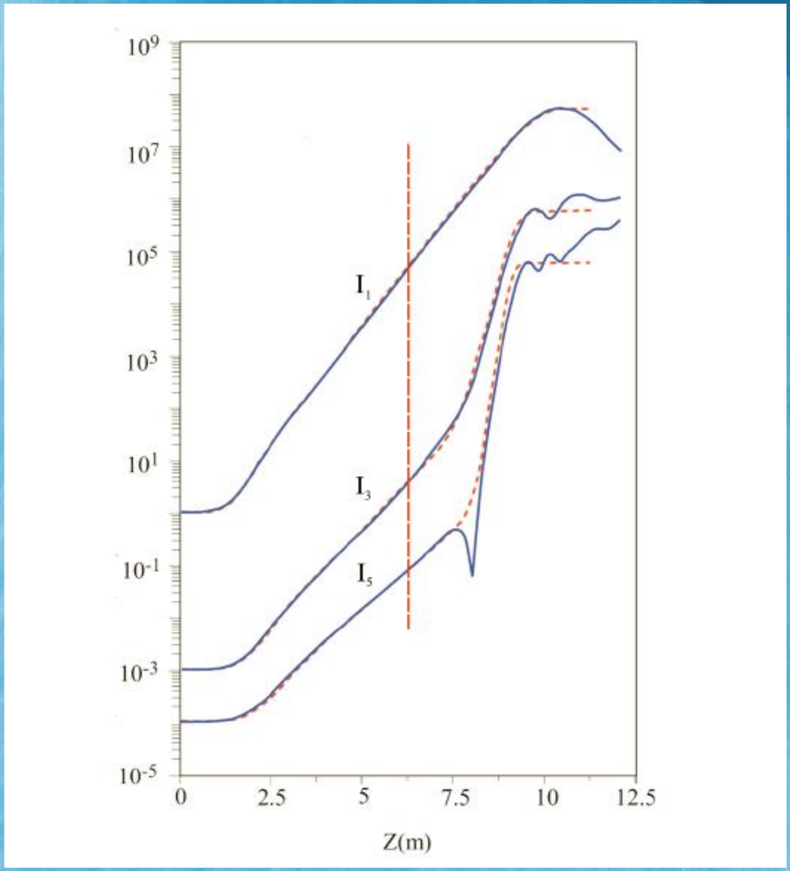
G. Dattoli and P. L. Ottaviani[a)]

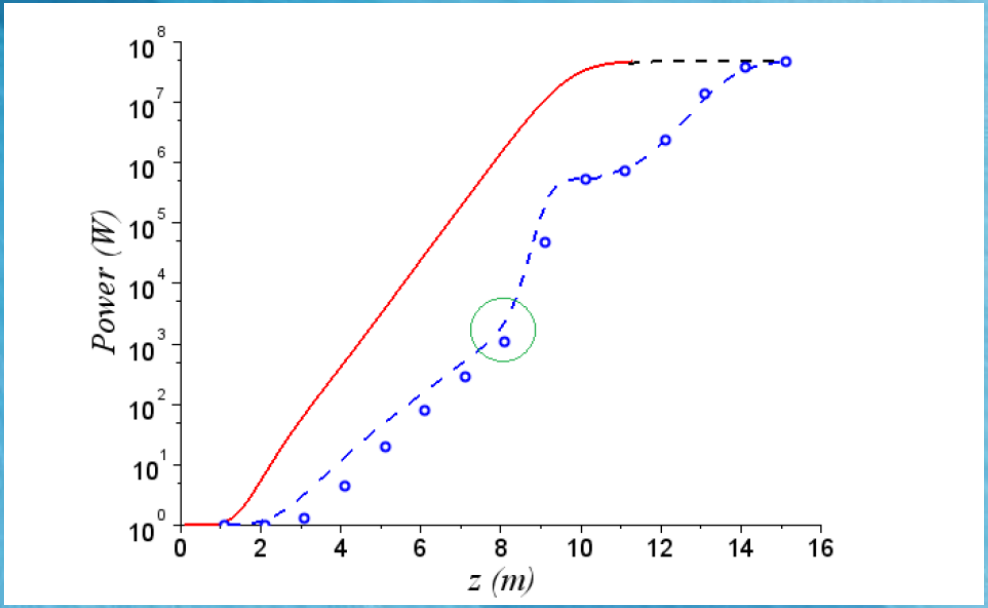
JOURNAL OF APPLIED PHYSICS

15 NOVEMBER 1999



Non Linear Harmonic generation





Two Harmonic Coupled beams

- .

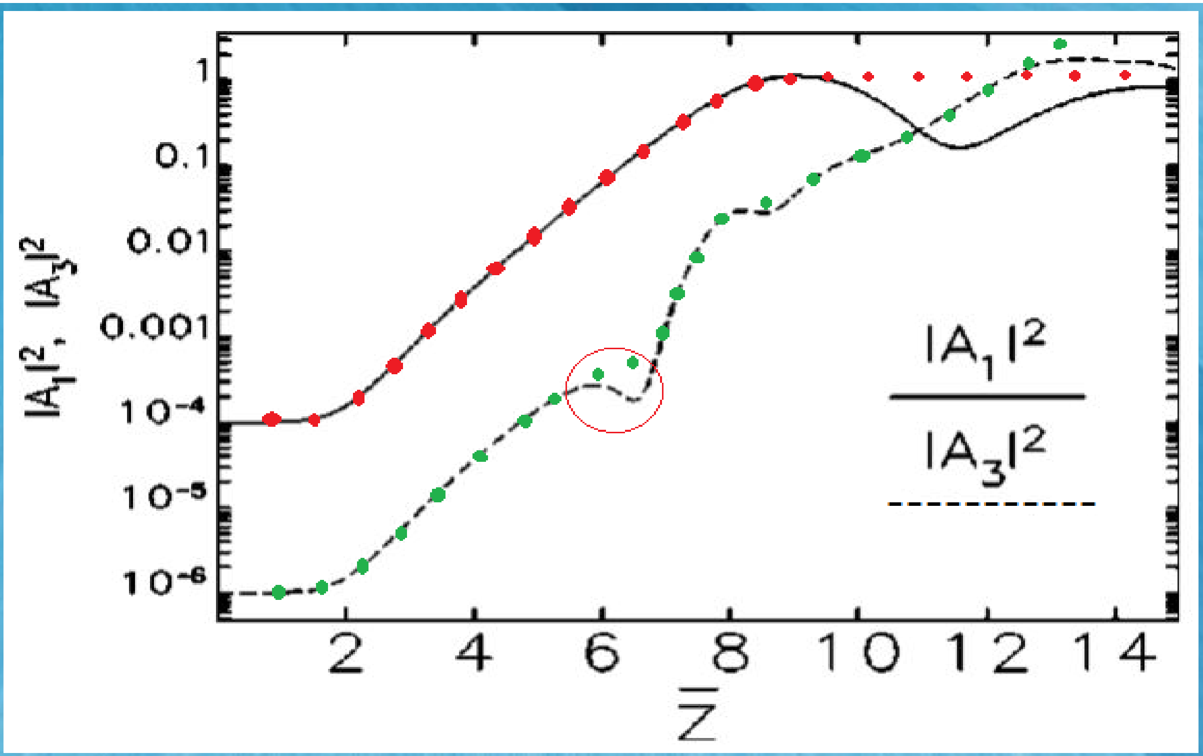
A further possibility, suggested by McNeil, Robb and Poole [24] is that of the harmonically coupled 2-beam FEL (HCB). In their proposal, it is foreseen the use of two beams operating at different energies, passing through a linearly polarized undulator, to run an FEL operating at different harmonics. The relativistic factor of the higher energy beam is chosen in such a way that $\gamma_2 = \sqrt{n}\gamma_1$.

In loose terms, the mechanism of growth of the FEL signal can be described as reported below. The first beam induces the bunching conditions to trigger the third harmonics, if $n = 3$, which eventually seeds the first harmonic emitted by the higher energy beam.

In the forthcoming section we model the dynamics of the harmonically coupled beams FEL, using the already quoted semi-analytical procedure [14].

E. SABIA et al.
(ENEA)

Two-Beam Free-Electron Lasers and Self-Injected Nonlinear Harmonic Generation



McNeil, B.W.J.; Poole, M.W.; Robb, G.R.M. Two-beam free-electron laser. *Phys. Rev. E* **2004**, *70*, 035501.

MULTI-BEAM ENERGY PROPOSAL

- . Shine

Zhu, Z.Y.; Zhao, Z.T.; Wang, D.; Liu, Z.; Li, R.X.; Yin, L.X.; Yang, Z.H. SCLF: an 8-GeV CW SCRF Linac-based X-ray FEL Facility in Shangai. In Proceedings of the International Free Electron Laser Conference (FEL'17), Santa Fe, Mexico, 20–25 August 2017; No. 38; JACoW: Geneva, Switzerland, 2018; pp. 182–184.

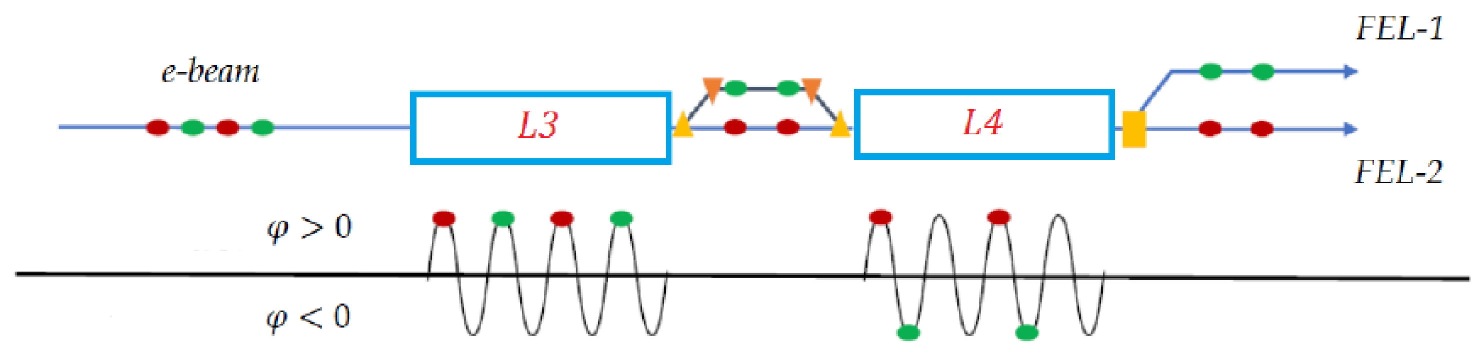


Figure 8. Sketch of multi-beam energy device proposed at SHINE ($\varphi \equiv$ accelerating phase).