Frascati, 24 June 2022
Note: **ACCDIV-01-2022**

FREE ELECTRON LASER SEEDED BY BETATRON RADIATION

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Abstract

In this short note the use of betatron radiation as a seed for the Free Electron Laser (FEL) is presented. The scheme shown can be adopted from all FEL driven by plasma accelerated electron beams via Particle or Laser Wake Field Acceleration.

Indeed intense broad spectrum radiation in the region of X ray, the betatron radiation, is produced in the plasma acceleration process from the electron passing through the ionized gas. It is proposed to use this radiation, suitably selected in wavelength and properly synchronized, to stimulate the emission of the Free Electron Laser on the fundamental frequency and on the higher harmonics.

Introduction

The possibility of using a plasma accelerated electron beam to generate Free Electron Laser (FEL) radiation has recently been proven [1]. The European EuPRAXIA project aims to develop FEL facilities using laser wake field acceleration and particle wake field acceleration (PWFA) techniques. In particular, in the INFN Frascati Laboratories, the headquarters of the EuPRAXIA project, an infrastructure will be built that will use the PWFA to generate FEL radiation in X-rays region. The electron beam produced by a low emittance injector is accelerated by an X-band linac and a plasma acceleration section. Due to the intense transverse forces generated in the plasma wave, the electrons of the bunch oscillate emitting the so called betatron radiation.

The radiation is emitted on a wide bandwidth in the X ray region and the basic idea is to select a narrow portion of the betatron radiation spectrum with a monochromator and send this radiation superimposed on the electrons, that generated it, towards the magnetic undulator, see Fig.1.

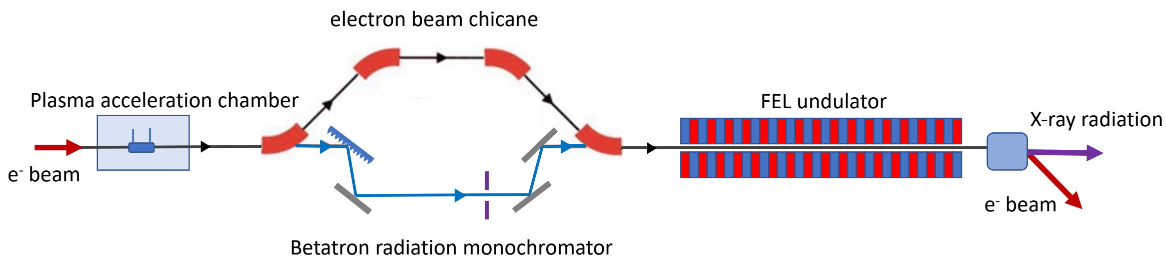

Figure 1: Betatron radiation seeding FEL scheme.

The betatron radiation acts as seed of the Free Electron Laser emission: in EuPRAXIA if the selected photon energy is matched with undulator fundamental wavelength (4nm) the seeding scheme improves the number of photons per pulse and pulse to pulse temporal stability as happens in the FEL self-seeding scheme [2].

If the chosen photons energy is harmonic frequency of undulator, for instance 620 eV, the FEL emission is stimulated to emit at 2nm wavelength with high gain.

Experimental set up

In the particle wake field plasma acceleration a high charge electron bunch, the *driver* bunch, generates the plasma shape, losing energy, and the following low charge bunch, the *witness* bunch, is accelerated.

Before entering in the FEL undulator, at the plasma chamber exit, the *driver* and *witness* bunches are dispersed, due to the different energy, in a dispersive section composed by dipole magnets in a chicane configuration.

The deviation angle in the first chicane dipole is large enough to separate the witness from the driver bunches and place a collimator, or beam scraper, to stop the driver bunch.

The betatron radiation continues straight into the vacuum chamber and as soon as the electron beam is deflected from the straight path the first optical element of the monochromator is installed.

The betatron radiation is selected in bandwidth and reflected back in the direction of the undulator overlapping the electrons that are leaving the chicane, in the first part of the undulator.

Because of the very short electron bunch a perfect synchronization at the entrance of the undulator, at level of tens of femtosecond, is needed. The electron and photon beams started automatically synchronize because generated from the same electron beam.

The trajectory length of the photons must compensate the path of the electrons that pass through the magnetic chicane and the delay of the electron, that travel with relativistic factor γ=2000, respect to the photon arrival time.

The monochromator has the purpose not only to select the energy of the betatron radiation that is sent to the undulator but also to delay it by the same time necessary for the electrons to travel the chicane at a speed slightly lower than the speed of light.

Conclusion

In the Free Electron Laser driven by plasma accelerated electron beams it is proposed to use the betatron radiation produced in the acceleration process as a seed to stimulate the emission on the fundamental frequency and on the higher harmonics.

References

[1] R. Pompili et al. "Free-electron lasing with compact beam-driven plasma wakefield accelerator", *Nature* volume 605, pages 659–662 (2022).

[2 D. Ratner et al. "Experimentl Demonstration of a Soft X-Ray Self-seeded Free-electron Laser accelerator", PRL 114, 054801 (2015).