EuPRAXIA Doctoral Network

Theoretical and Technological Studies into Femtosecond Synchronization

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INFN-LNF

UK Research and Innovation

EuPRAXIA@SPARC_LAB User Facility

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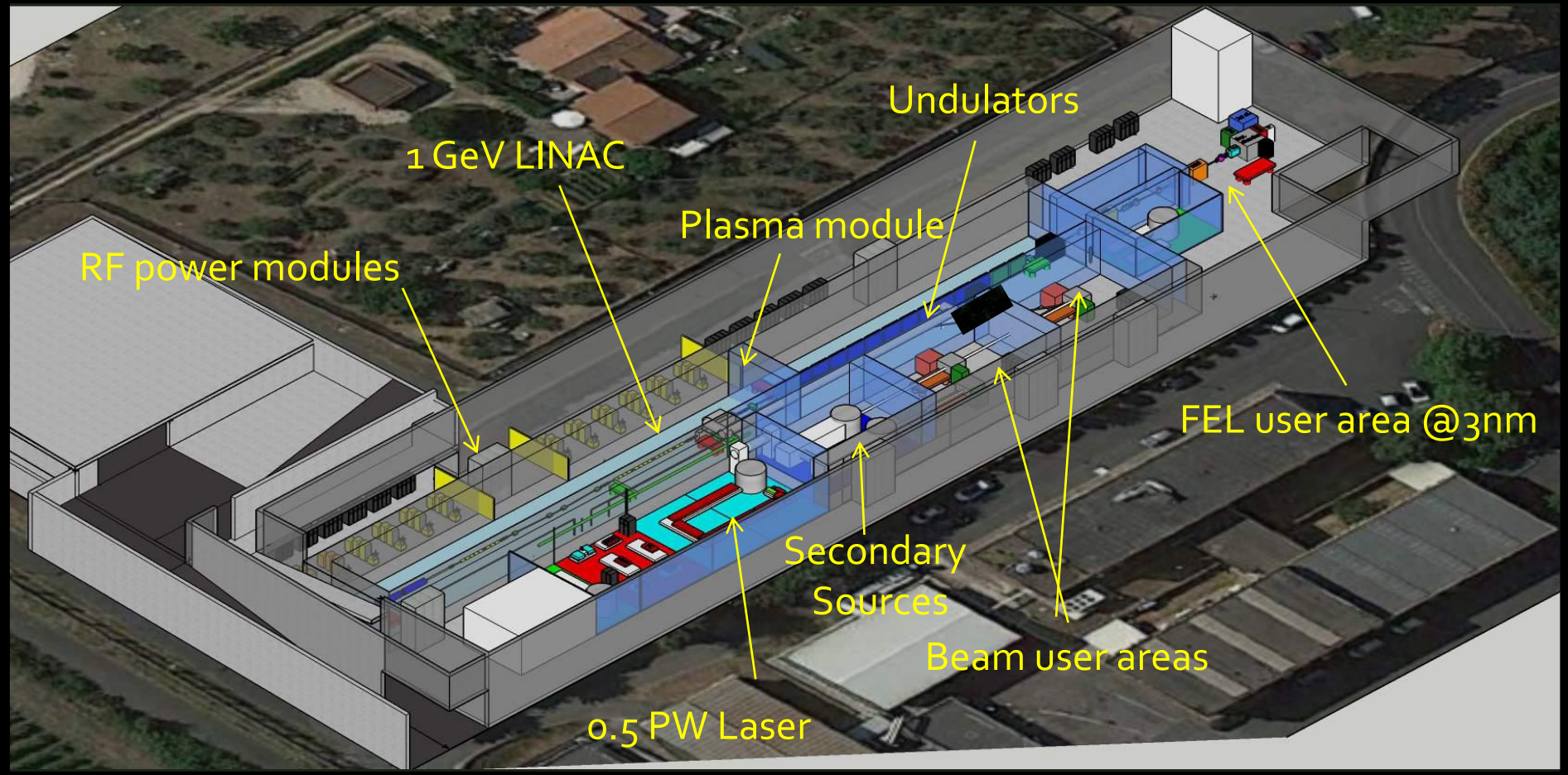

FEL requirement

$$\frac{\Delta\lambda}{\lambda} \propto \frac{\Delta E}{E} \propto \rho \approx 10^{-3}$$

Plasma density

$$\left.\frac{\Delta E}{E}\right|_p = \frac{\Delta n_p}{n_p}$$

Bunch charge/length

$$\left.\frac{\Delta E}{E}\right|_Q = \frac{\Delta I_d}{2(I_d)} + \frac{\Delta I_w}{2(I_w)}$$

Driver/Witness separation

$$\left.\frac{\Delta E}{E}\right|_{DW} = \frac{a\omega_p}{2\pi}\Delta t_{DW}$$

$2 \le a \le 4$

INFN-LNF synchronization activity overview

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The synchronization activity @ LNF is carried out by the RF group of the accelerator division. It covers many topics involving electronics, optics, software development, simulations:

- Synchronization system of particle accelerators in both electrical (coaxial cable reference distribution) and optical (fiber optics reference distribution) architecture
- Fast feedbacks to lock clients (LLRF system, lasers, …) to the reference signal
- Fast intra-pulse feedbacks to stabilize the phase inside a single RF pulse (some µs)
- Slow feedbacks to correct machine drifts, by means of LLRF modules
- Diagnostics on the synchronization system using dedicated instrumentation and LLRF modules (absolute and relative jitter measurements)
- Jitter studies on different accelerator working points using simulation codes

Proposed topic for the PhD thesis

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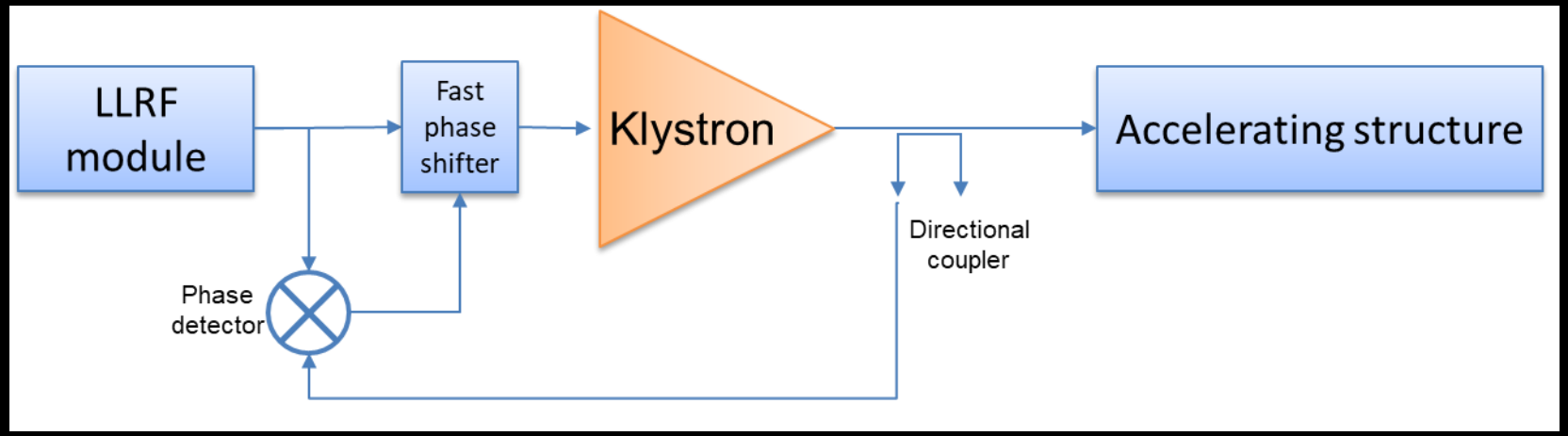
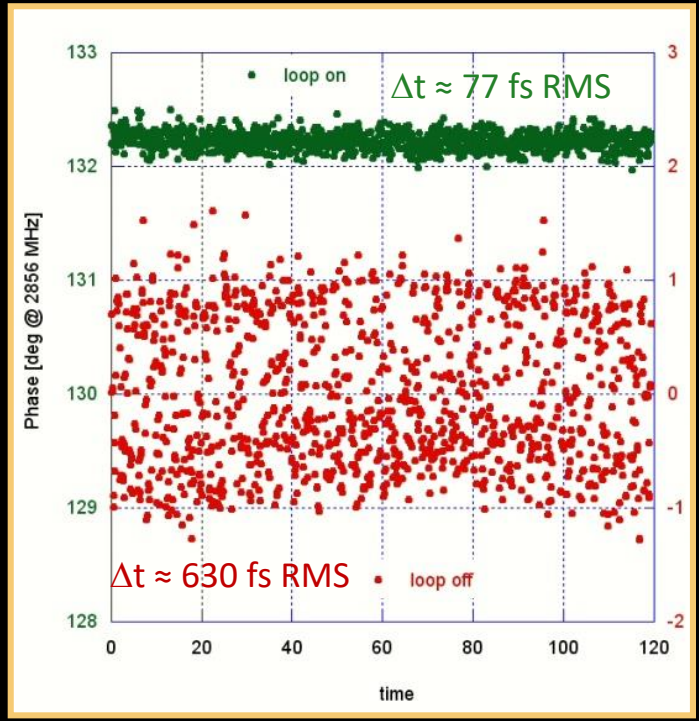
The proposed topic is centered on the RF intra-pulse fast feedback to stabilize the phase of the accelerating fields inside a single klystron pulse.
We illustrate the working principle below.

- Part of the output signal of the klystron is picked up using a waveguide directional coupler and is phase-compared with the driving signal.
- The phase difference is used as error signal to correct the phase inside a pulse by means of a fast phase shifter and a custom error amplifier.



Performance of the present system

- The intra-pulse fast feedback has already been implemented on the S-band PFN modulators in operation at LNF in the SPARC_LAB facility
- The results show a reduction of the jitter of the klystron output relative to the RF reference of about an order of magnitude.
- The jitter has been reduced from hundreds to tens of femtoseconds
- The bandwidth of the loop is around 1 MHz, so that the loop can go to regime in about 1 µs. Since the S-band klystron has a RF pulse lasting 4.5 µs, this system can work properly.
- In case of RF pulse compressor, however, the last microsecond of the pulse jumps to a different phase (180° shift). Also, higher frequency klystrons can have pulses lasting less than 1 µs. In this cases, this systems shows its limitation, and an upgrade is necessary



PhD scope and timetable

The proposed PhD topic aims to extend the bandwidth of intra-pulse feedback and to make it work at higher frequencies (C- and, if possible, X-band) where the RF pulses are shorter.
A new technical design and implementation of the electronics is necessary together with tests in laboratory and on a real accelerator environment. Also, a preliminary theoretical study is foreseen

	T0 + 12 months	**T0 +24 months**	**T0 + 36 months**
Deliverable	**D12** Minimization of jitter in SPARC_LAB working points	**D13** Fast intra-pulse feedback system prototype	**D14** paper on demonstrated performance at SPARC_LAB

Education and secondments

Education

- Particle accelerator international schools (JUAS, CAS,…)
- PhD courses at «Sapienza» University of Rome
- EuPRAXIA DN Schools and camps
- International Conferences and Workshops (IPAC, LLRF Workshop, ...)
- INFN-LNF RF laboratory experience (electronics, optics, e.m. fields measurements)

Secondments

- Instrumentation Technology (Slovenia)
  - Particle accelerator electronic devices (LLRF, BPM,…)
  - Industry, research, automotive, test and measurements
  - R&D in collaboration with public institutions and industry

Contact and Further Details

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