THE PLASMONX PROJECT FOR ADVANCED BEAM PHYSICS EXPERIMENTS

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Abstract

The Project PLASMONX is well progressing into its design phase and has entered as well its second phase of procurements for main components. The project foresees the installation at LNF of a Ti:Sa laser system (peak power > 170 TW), synchronized to the high brightness electron beam produced by the SPARC photo-injector. The advancement of the procurement of such a laser system is reported, as well as the construction plans of a new building at LNF to host a dedicated laboratory for high intensity photon beam experiments (High Intensity Laser Laboratory). Several experiments are foreseen using this complex facility, mainly in the high gradient plasma acceleration field and in the field of mono-chromatic ultra-fast X-ray pulse generation via Thomson back-scattering. Detailed numerical simulations have been carried out to study the generation of tightly focused electron bunches to collide with laser pulses in the Thomson source: results on the emitted spectra of X-rays are presented.

CPA 100 TW-CLASS LASER SYSTEM

While the SPARC Project is in its commissioning phase at LNF, where the first high brightness electron beams produced by the SPARC photo-innjector are under characterization [1], its long term upgrade, based on the project PLASMONX, has entered its acquisition phase, after completion of the design of the system [2]. The first phase, after approval by INFN, is aimed at building at LNF a 100 TW-class laser system as the core system of a High Intensity Laser Laboratory (HILL), and a final goal of constituting a national facility merging advanced technologies and expertises in high brightness electron beams and high intensity laser beams, as well as plasma wave formation, control and diagnostics. Under this respect, the collaboration between INFN and CNR-IPCF is considered to be strategic to the realization of the final phase of the facility, where synchronized electron and photon beams of ultra-high performances, in terms of brightness, intensity and brevity will be driven to interact in several fashions, in order to allow investigations of high gradient acceleration techniques and/or X-ray production via Thomson back-scattering in the spontaneous incoherent mode or, eventually, in the coherent collective mode. The proposed time schedule for this initiative is tightly correlated with the progress of the SPARC project: according to this schedule, final completion of the SPARC&PLASMONX facility is foreseen by the year 2009.

The proposed laser system [3] must have unique performances in terms of power, pulse duration, flexibility and reliability: it will be installed inside the dedicated HILL building at LNF, located just outside the underground SPARC bunker. The laser system, based upon the C.P.A. technique, will deliver < 50 fs, 800 nm, >100 TW, laser pulses at 10 Hz rep. rate. The 5 J laser pulses will be transported uncompressed from the HILL laboratory down into the SPARC bunker. The proposed system combines the reliability of established Ti:Sa technology with novel additional devices aimed at overcoming known issues typical of large Ti:Sa systems.

One of these issues concerns the power contrast ratio, namely the ratio between the main CPA pulse and the so-called "pedestal", a spurious precursor radiation arising from amplified spontaneous emission (ASE) by amplifiers. The block diagram of Figure 1 shows the main components of the system, including the devices necessary for ensuring the high quality of the final output.

The oscillator produces a 10 fs pulse that is stretched and pre-amplified by a two stage amplifier up to the 30 mJ level per pulse. Approximately half of this energy is extracted and compressed to provide a low energy beam for probing/diagnostic purposes. The remaining part of the pulse is further amplified to the 8 J level and finally compressed under vacuum. Besides the standard vacuum spatial filter necessary for beam cleaning, we plan to insert an adaptive optics before the vacuum compressor. This device will enable us to remove aberrations on the beam which may result in a poor performance of the compressor as well as poor quality of the focal spot after focusing. Concerning the control of the pulse duration, the system includes a Dazzler device which will enable correction of the spectral features of the pulse prior to stretching. These corrections are necessary in order to keep the final pulse-length well below the 100 fs level. In fact, we aim at reaching the < 50 fs pulse-length which is now regarded as the minimum pulse duration achievable in a multi-joule Ti:Sa laser system. The main beam characteristics after the vacuum compressor are foreseen to be: pulse energy 5 J, peak power > 100 TW, contrast ratio < 10^{-5} .

We plan to conduct R&D on the OPCPA technique, that exploits the non-linear properties of some crystals for the amplification of optical pulses: we aim at an inherently low ASE system in which the ASE level is drastically reduced in the initial amplifier stages. In fact, it is estimated that with an OPCPA system in place, the final pulse length could be as short as 30 fs, thus leading to a peak power as high as 170 TW on target and a contrast ratio smaller than 10^{-8} .

Most of the proposed programme relies on the synchronisation of the laser system with the SPARC Linac and, in particular, with the photoinjector laser system. This can be done either using an electro-optics based approach or optically. In the first way the laser oscillator is synchronized with an external rf signal, by changing dynamically the oscillator cavity length: a jitter between the rf and the laser pulse of less than 1ps is typically achieved. The fully optical approach consists in synchronising the two laser systems. This can be done either by using the same oscillator for both lasers or by measuring the change in delay between the two laser pulses (*i.e.* using a single shot second order cross correlator) with a precision of tens of femtoseconds, and then adjust dynamically a delay line in one of the two laser system.

X-RAY THOMSON SOURCE

We studied the head-on collisions between the SPARC electron beam and the FLAME photon beam with the aim of producing mono-chromatic Thomson X-rays with energy tunable in the range 20-900 keV. We report here the result of the optimization study performed with start-to-end simulations starting from the photocathode and producing the angular and frequency spectra of the emitted X-rays. Only the case of 20 eV photons is reported, which is of interest for a planned experiment of digital mammography using mono-chromatic X-rays.

The main challenge regarding the electron beam generation is to focus down a high charge beam (1-2 nC) to focal spot sizes below 10 microns in the collision point, which in turns implies to accurately take under control emittance and energy spread of the beam itself [4].

This is necessary in order to reach high fluxes in the X-ray beam, which scales like the inverse of the square of the spot size. 10^{10} photons/sec is the goal of the mammography experiment, which means 10^{9} photons per collision at the SPARC rep rate of 10 Hz (the FLAME laser has similar rep rate as well).

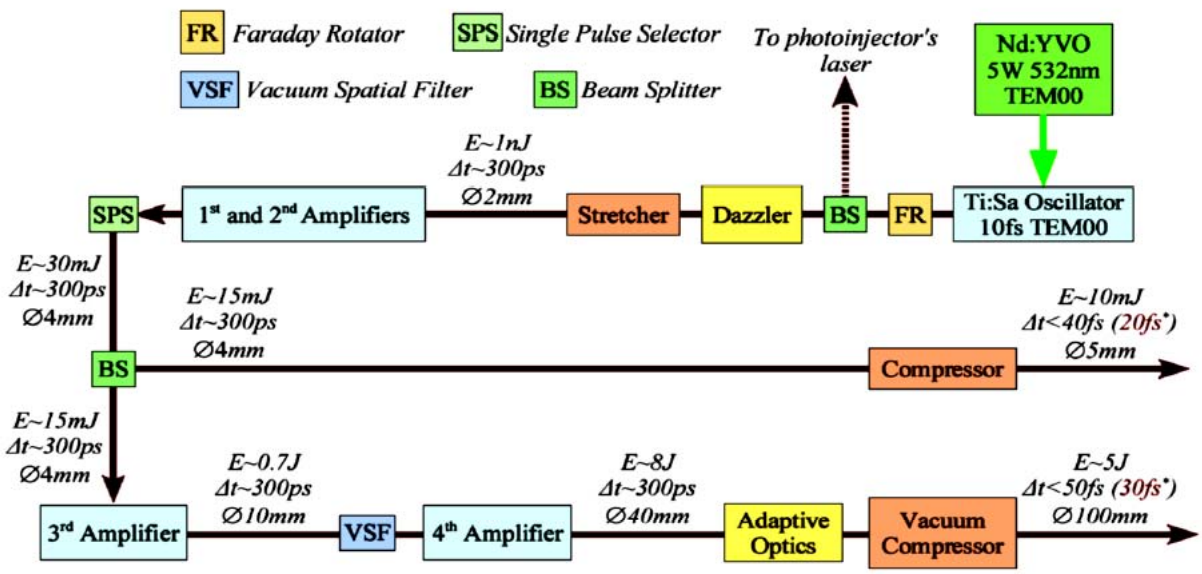

Figure 1: Lay-out of the FLAME Laser System.

ASTRA simulations of the SPARC photo-injector operated to produce a 30 MeV electron beam to the collision point show that by properly correcting the correlated energy spread with the use of a 4-th harmonic cavity we can reach a longitudinal phase space distribution as shown in Figure 2, displaying a rms energy spread smaller than $2 \cdot 10^{-4}$.

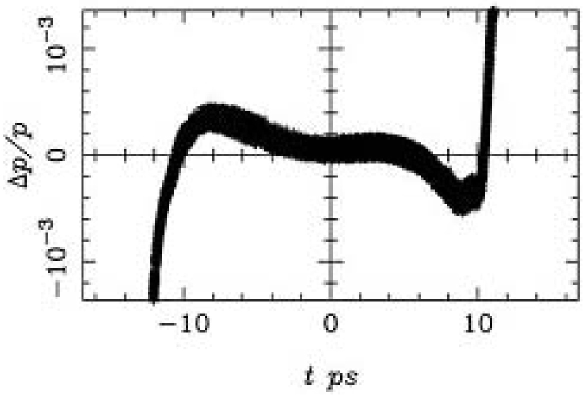

Figure 2: Longitudinal phase space distribution at Linac exit.

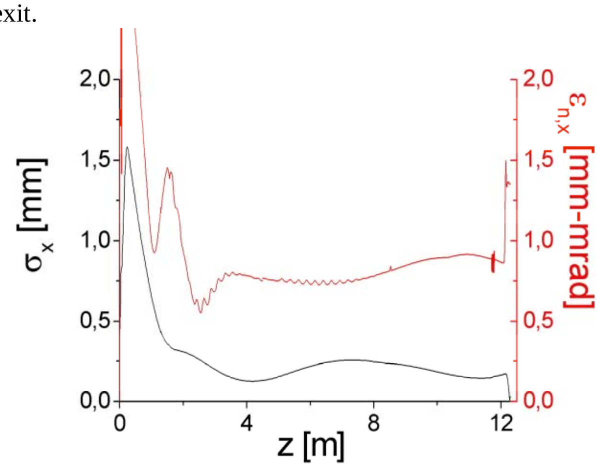

Figure 3: Beam emittance and envelope along z

A careful emittance compensation performed through the injector leads to a sub-micron rms normalized transverse emittance at the final focus, as shown in Fig.3. The resulting rms focal spot size is 9 microns. This allows

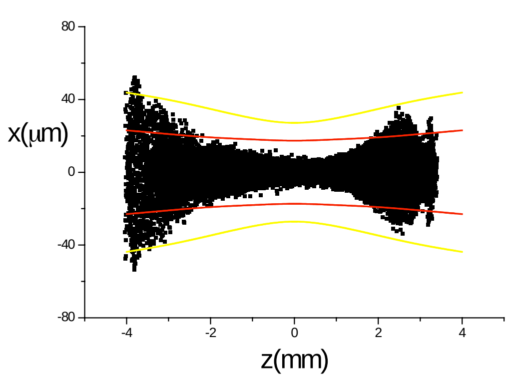

Figure 4: Electron bunch and laser pulse overlap at the final focus in the collision point

in turns to maximize the number of X-ray photons generated in the collision. The frequency spectrum is shown in Figure 5 at different angle of collimation [5].

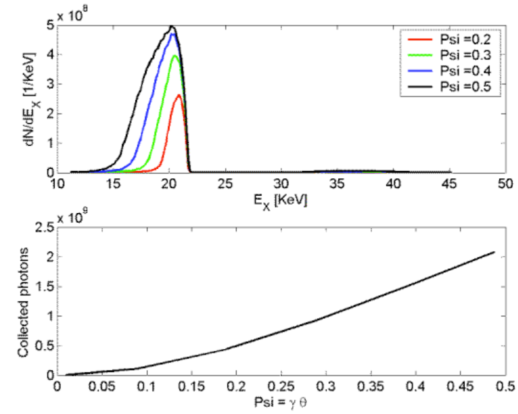

Figure 5: X-ray spectra for different solid angle collimation

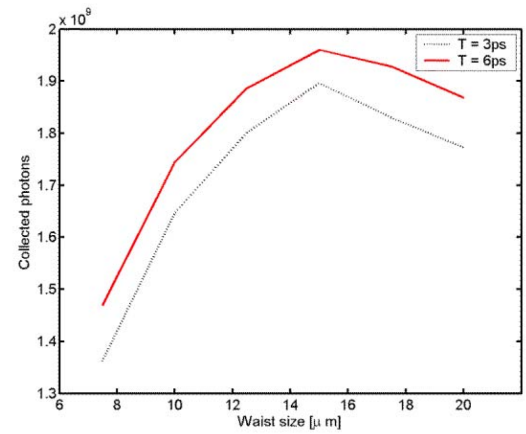

Figure 6: X-ray yield vs. laser spot size and pulse length

The total number of emitted photons within a frequecy bandwith of 5% rms is given in Fig.6 as a function of the laser spot size and for 3 and 6 ps, respectively, of laser pulse length. We can reach about $2 \cdot 10^{9}$ photons per pulse, which is considered, at 10 Hz rep rate, a satisfactory flux to perform advanced radiological imaging with monochromatic X-rays [6].

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