

THE STAR PROJECT

A. Bacci, D. Palmer, L. Serafini, and V. Torri, INFN/Milan, Italy;

V. Petrillo and P. Tomassini, Univ. of Milan, Milano, Italy;

Ezio Puppini, CNISM and Politecnico of Milan, Milano, Italy;

D. Alesini, M. P. Anania, M. Bellaveglia, F. Bisesto, G. Di Pirro, A. Esposito, M. Ferrario,
A. Gallo, G. Gatti, A. Ghigo, B. Spataro, C. Vaccarezza, and F. Villa, INFN/LNF, Roma, Italy;

A. Cianchi, Univ. Tor Vergata, Roma, Italy;

R. G. Agostino, G. Borgese, M. Ghedini, F. Martire, and C. Pace,

UNICAL, Arcavacata di Rende, Cosenza, Italy;

T. Levato, Czech Republic Academy of Sciences Institute of Physics;

G. Dauria, A. Fabris, and M. Marazzi, Elettra/Sinc. Trieste, Trieste, Italy

Abstract

We present an overview of the STAR project (Southern European Thomson source for Applied Research), in progress at the Univ. of Calabria (Italy) aimed at the construction of an advanced Thomson source of monochromatic tunable, ps-long, polarized X-ray beams, ranging from 20 to 140 keV. The project is pursued in collaboration among: Univ. della Calabria, CNISM, INFN and Sincrotrone Trieste. The X-rays will be devoted to experiments of matter science, cultural heritage, advanced radiological imaging with micro-tomography capabilities. One S-band RF Gun at 100 Hz will produce electron bunches boosted up to 60 MeV by a 3m long S-band TW cavity. A dogleg will bring the beam on a parallel line, shielding the X-ray line from the background radiation due to Linac dark current. The peculiarity of the machine is the ability to produce high quality electron beams, with low emittance and high stability, allowing to reach spot sizes around 15-20 microns, with a pointing jitter of the order of a few microns. The collision laser will be based on a Yb:Yag 100 Hz high quality laser system, synchronized to an external photo-cathode laser and to the RF system to better than 1 ps time jitter.

INTRODUCTION

Thomson Scattering (TS) X-Ray sources, nowadays, are attracting strong attention, mainly by a strong flexibility, compactness and less expensive, respect to the synchrotron sources. Several laboratories world-wide are pursuing projects to develop such advanced sources [1-3].

The TS [4] is the electromagnetic process in which each electron absorbs one (linear Thomson scattering) or more (nonlinear Thomson scattering) photons from a laser pulse, emitting one photon. If the electrons are ultra-relativistic the scattered radiation is frequency upshifted and it is emitted forward with respect to the particles motion, with a small aperture cone, proportional to the inverse of the Lorentz relativistic factor.

A TS source driven by high quality electron beams can work in different operating modes, e.g.: the high-flux-moderate-monochromaticity mode, suitable for medical

imaging when high-flux sources are needed; the moderate-flux-monochromatic mode, suitable to improve the detection/dose performance [5]; short-and-monochromatic mode, useful for pump-and-probe experiments; further the coherence properties of the radiation have been well investigated by phase contrast imaging and diffraction enhanced imaging [6-8].

Facility Layout

The STAR facility site is the Univ. of Calabria campus, in Rende (CS, Italy). The STAR source will be located in a new building expressly designed to host it in its present layout (fig. 2). The building is a 50x25x6.7h m hangar in which the bunker (37x12x3.5h m, see fig.1), the laser clean room and the μ Tomo experimental hutch are sited. Three satellite structures are connected to the Hangar to host the control room and the electrical and conditioning systems. The radiation shielding was designed for electron energies up to 350 MeV while several passive seismic monitoring experiments at different conditions were carried out allowing us to exhaustively characterize the seismic noise in terms of the power and space-time variability, both in frequency and wavelength [9].



Figure 1: The project Hangar and the STAR bunker.

The STAR LINAC is based on: a S-band 1.6 Cell RF Gun, with a Cu photocathode, followed by one S-band SLAC-type 3 m long Traveling Wave (TW) accelerating cavity. After the Gun, where the beam is charge dominated and laminar, a solenoid, coupled with a TW cavity (placed in ad hoc position) performs the emittance

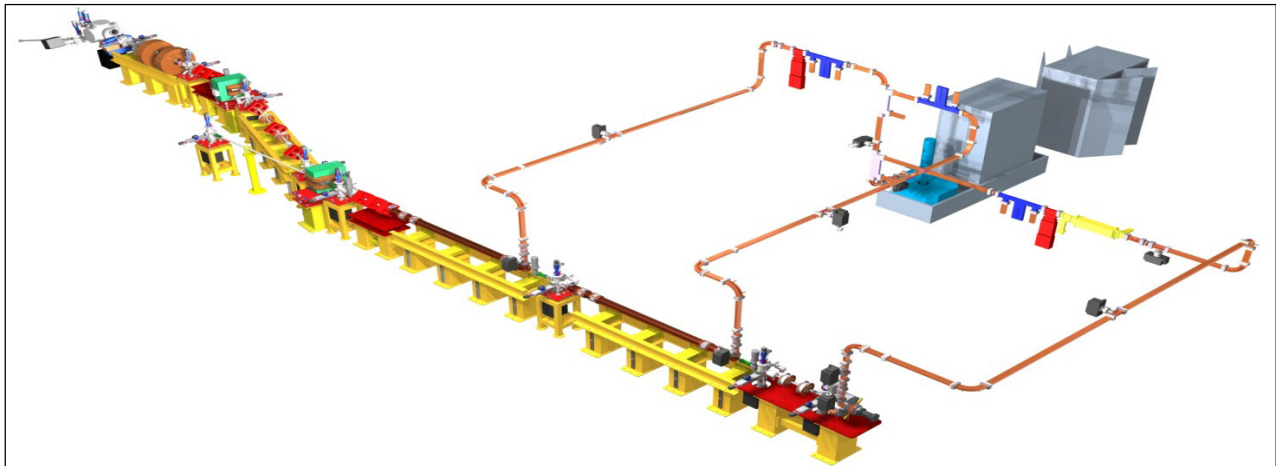


Figure 2: The STAR layout, with Acc. cavities, RF guides and beam optics, up to the IP vacuum chamber.

correction [10]. This schema, used by server labs and mainly studied and tested at SPARC lab. [11-12], is directly passed to the STAR project by the same people, involved in both the projects.

SIMULATIONS

Beam Dynamics

In order to produce a high quality TS source, accurate Star to End simulations has been performed. The acceleration stage, the DogLeg beam line and the final focus system, have been studied by using the following codes: Astra [13] (typically used in FEL community, for high brightness e-beams), which considers space-charge effects, Trace3D [14], which works on Twiss parameters giving fast starting configurations (DogLeg and final focus system), while the final optimizations was done by using Giotto [15]; this is a Genetic Algorithm based code, which performs optimizations of multi-dimensional highly non-linear problems. The use of these codes has permitted a fully optimization of the whole machine, up to the Interaction Point (IP).

The STAR LINAC is designed to be easily upgraded in two phases: “phase I”, which considers one TW acc. cavity, delivering a maximum electron energy of 60 MeV and “phase II”, which consists in the insertion of a second TW acc. cavity, reaching energy higher than 85 MeV. The easily with which the upgrade can be done lies in the beam line layout, which foreseen an “ad hoc” drift to insert the second acc. cavity and also by the planned Klystron power (directly from “phase I), enough to feed the Gun and the two TW cavities. All optics are designed to cover energies up to 110 MeV.

Two different Working Points (WPs), for the two phases, have been studied; one at 60 MeV and one at 85 MeV. A part for the second acc. cavity, the two WPs share

exactly the same beam line. In Tab. 1 are listed the main beam parameters, at cathode, at LINAC exit and at the IP, for the two WPs. The chosen charge is 500pC, a trade-off between TS flux (scaling linearly with bunch charge) and the space-charge effects, which degrade the emittance. As thermal emittance, considering a Cu cathode, has been chosen 1.2 mm-mrad per 1mm of rms laser spot, which is a conservative value historically used at SPARC (recent measures show 0.9 mm-mrad per 1 mm rms laser spot). Figure 3 shows emittances, envelopes and energy spread in to in the LINAC. For the 60 MeV case (solid lines), is possible to note the envelope rising caused by the long drift, it is a mild effect that don’t request additional optics.

Table 1: Electron Beam Main Parameters

WP	60MeV	85MeV
At the cathode: Q=0.5nC, $\epsilon_{th}=1.2 \mu\text{m}$ (1mm of σ_x)		
σ_t [ps] Gauss. Laser	3.4	3.7
σ_x [μm]	340	320
LINAC exit		
σ_x	0.7	0.6
ϵ_x	0.9	0.8
$\sigma\gamma/\gamma$ [%]	0.2	0.2
At the IP (18.7m)		
σ_x, σ_y [μm]	21.7, 22.5	18.8, 18.8
ϵ_x, ϵ_y [μm]	2.1, 1.3	2.1, 1.1

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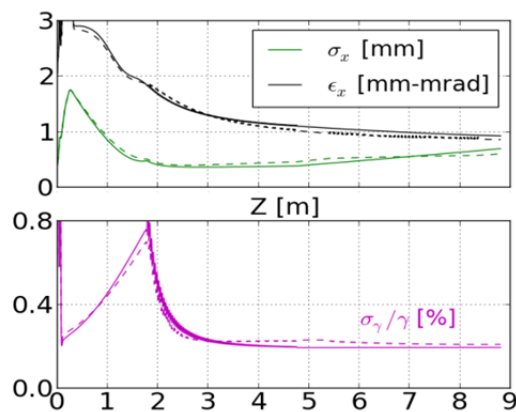


Figure 3: Envelopes, emittances and Energy spread for the two WPs; 85 MeV (solid line) and 60 MeV (dash line).

Despite the simple beam line (Fig. 2): a classical achromatic DogLeg, two triplets and two solenoids, the final IP focus value ($<23 \mu\text{m}$) and the beam stability are challenging items; as a consequence we were very conservative in our studies, e.g. the high thermal emittance value (see above) or the chosen to use sector dipoles, rather than rectangular ones. Moreover we have developed an algorithm to generate electron distributions, to be used in simulations, by the virtual cathode image, to consider real beam inhomogeneity, asymmetry and halos. This software, under testing on the SPARC LINAC, shows to be very important to tune the machine behaviour to the simulation results.

A jitters analysis of the machine has pointed out that feeding the dogleg dipoles, by using dedicated power suppliers (one for each), is produced a huge pointing instabilities, $\sigma_x=140 \mu\text{m}$ at the IP. The problem has been solved by feeding dipoles using only one power supplier, in this way the jitters cancel each other, reach a pointing instabilities two order of magnitude lower, $\sigma_x=1.4 \mu\text{m}$.

Laser/Electron Interaction

The Thomson Scattering process of the laser pulse by the entire electron beam has been simulated by using the TSST (Thomson Scattering Simulation Tools) code, which is based on analytical results of [2] but is suitable also for gaussian shaped pulses. TSST is able to treat each macroparticle of the bunch as an independent relativistic and nonlinear oscillator, avoiding the use of any superimposed statistical average on particles distribution.

The spectrum of the collected photons depends on geometry and laser photons/bunch phase space distributions. The peak energy ($E_{\text{max}}=4\gamma^2 E_{\text{ph}}$ where E_{ph} is the laser photons energy) is achieved by a full head-on collision with emission of a backscattered photon. In a cylindrical reference frame (θ, ϕ) pointing through the beam direction (i.e 180° of scattering angle) this is obtained on axis ($\theta=0$). Relativistic and nonlinear effects generate a reduction of the photons energy (see Fig. 4) when either multiphotons absorption (nonlinearities) or non-perfect backscattering occur.

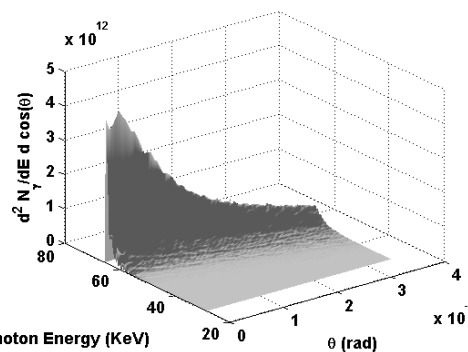


Figure 4: Local energy spectrum for a given scattering angle, 60MeV WP with waist of $18 \mu\text{m}$.

Simulations of the TS process involved scan in collimation angle θ_c , laser pulse waist size w_0 , bunch focusing size and pulse-bunch spatial jitter, with feedbacks to the electron dynamics modules. The optimization proceeded so as to increase the photon flux within the maximum bandwidth of 5% rms. Both are directly linked to the acceptance angle as it is apparent in Fig. 5 where we can infer that the goal energy spread of 5% is obtained with 1mrad of acceptance angle rms that is linked to a spectral density of 4000ph/eV.

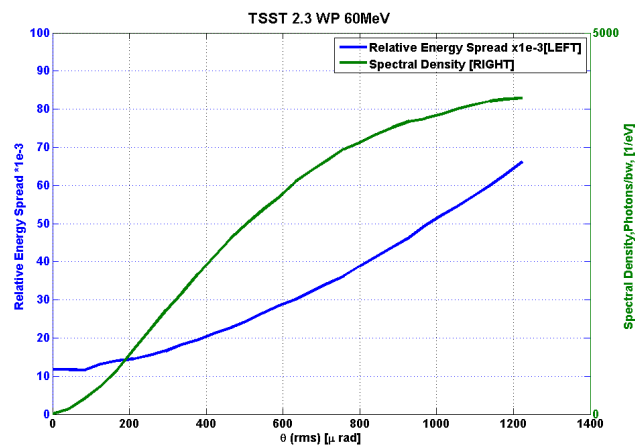


Figure 5: Relative energy spread (blue line, left) and spectral density of the collected photons [photons/eV] (green line, right) vs acceptance angle. 60MeV WP.

LASER SYSTEM

The STAR laser system will provide 5 ps (FWHM) pulses at 100Hz of repetition rate and an energy level of 130mJ. The entire laser system will be located in a dedicated Clean Room that will provide the required thermal stability to minimize the laser energy fluctuations. The expected rms laser energy stability is 3% with a long term peak-to-peak fluctuation below 5%. For the correct estimation of the X-ray photons flux the expected Strehl Ratio of 0.8 has been used.

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