STATUS OF THE STAR PROJECT

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Abstract

This paper reports on the final design and the work in progress on the STAR project (IPAC2014:WEPRO115), which is under construction at the Univ. of Calabria (Italy). The project is devoted to the construction of an advanced Thomson source of monochromatic tunable, ps-long, polarized X-ray beams, ranging from 40 up to 140 KeV. At present the buildings and main plants have been completed as the acquisition of main components: the RF photo-injector, the accelerating section, laser systems for collision and photo-cathode, RF Power Source and magnets are ready to start installation and site acceptance tests. The design of laser lines is complete and simulated by ZEMAX, aiming to minimize energy losses, optical distortions and providing a tunable experimental setup as well. The RF power network is close to be tested, it's based on a 55MW (2.5us pulse) S-band Klystron driven by a 500kV Pulse Forming Network based modulator and a Low Level RF system, running at 100 Hz. The Control System is been designed using EPICS and allows to manage easily and fastly each machine parameter. We expect to start commissioning the machine by the end of 2016 and obtain the first collisions within the first part of 2017.

INTRODUCTION

In the last few years worldwide different international labs have started Thomson Scattering (TS) X-Ray sources development. This is true for big facilities, as the one under development in Romania, Extreme Light Infrastructure-Nuclear Physics (ELI-NP), driven by a c-band linac booster and capable to deliver 20 MeV high quality gamma Ray [1], or smaller machines which permit to open very interesting research lines [2]. The interest in these kind of sources is so strong that small TS sources are nowadays commercially available [3-4], as proved by the recent acquisition of the Technische Universität München (TUM, Germany), able to reach up to 35keV X-Ray energy. It has to be clarified that if we consider the necessity to produce higher energy X-Ray, with very narrow bandwidth, as typical requests, these machines are still not commercially attractive.

The STAR facility site at Univ. of Calabria campus, in Rende (CS, Italy) is under construction in a building ad hoc designed

The STAR LINAC is composed by: one S-band 1.6 Cell RF Gun (Cu photocathode) based on a new design. It represents one of the first Gun, of this type, able to reach 100Hz rap. rate. The Gun is followed by a solenoid, a 1.8m drift and one S-band SLAC-type 3 m long Traveling Wave (TW) accelerating cavity. The solenoid and the TW cavity, placed in an ad hoc position where the beam is still space charge dominated, perform the emittance correction [5].

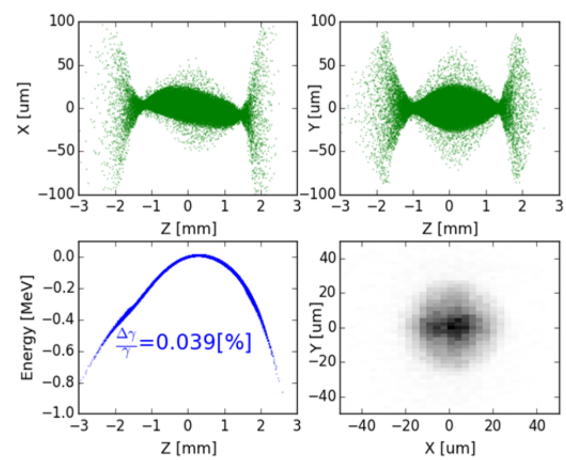

Figure 1: Upper line, in green dots, the X,Z and Y,Z beam projection at the IP. In the lower line, on the left the longitudinal phase-space (blue dots), on the right a 2D spot density.

This scheme, used by server labs, has been mainly studied and tested at the SPARC lab. [6-7]. Downstream the accelerating cavity is foreseen a long drift ad hoc to host an additional TW cavity (S-band SLAC type). The addiction cavity can be installed without any difficulty and will permit a fast upgrade, rising the final energy from 60 MeV up to 90-105 MeV (limit given by the RF power available). All the beam line has been studied, simulated

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and careful optimized, to host the log drift, to fully compensate the emittance and to minimize the energy-spread. Beam parameters and plots have been already presented in the reference [8]. The good beam quality at the linac exit, $\varepsilon_{n,x,y} = 0.9\mu m$, $\frac{\Delta\gamma}{\gamma} = 0.2\%$, for the quite high bunch charge of $Q_b = 500\ pC$, permits to pass through the dog-leg and to reach the Interaction Point (IP) with a very narrow final spot of $15\ \mu m$ (or smaller) on the both planes as shown by simulations in Fig. 1.

IP LASER LINE

The STAR laser system, based on a Yb:Yag, will provide 100Hz rep. rate pulses, about 5 ps long (FWHM), with an energy in the range of 400-500 mJ (with the final laser upgrade).The small bandwidth (1nm) and the pico-second temporal duration allow to use refractive optics to deal with the laser beam. In particular, the final focus on interaction point will be provided by a BK7 aspherical lens, 2” aperture, with 1500mm of focal length, placed out of the IP chamber.

The set-up optimization has been studied by performing physical optics simulations with Zemax software. In detail, taking into account diffraction effects due to any aperture (e.g. chamber optical viewport) the $F_{\#}$ has been found in order to avoid energy loss and the desired focal spot (20um rms). Moreover, since the laser beam goes through a window, its focusing has been evaluated as well. In Fig. 2 the focus spot at the IP.

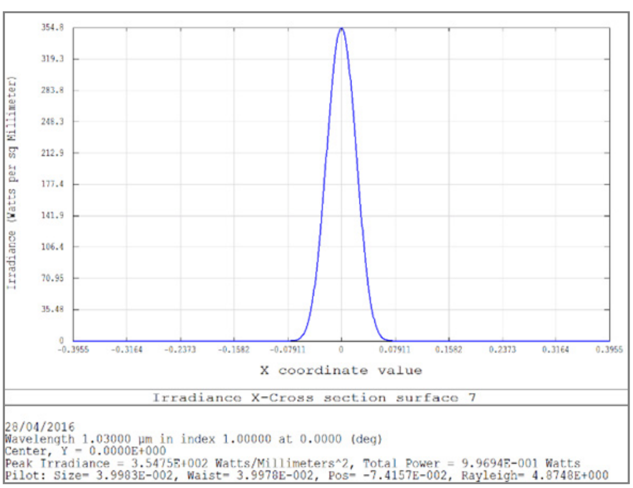

Figure 2: Simulation of the 2D laser spot at the IP.

IP REGION

The IP region, in the TS sources, is clearly of main importance. At STAR two different interaction schemes have been considered, both with an angle between laser and electron beams at the IP. In figure 3 is shown the effect of this angle on the source’s photon flux, as simulate by the code CAIN [9]. The head-on scattering, which is possible by using an on-axis holed focusing parabola and which should ensure a higher flux, has been considered unfavourable by previous experiences done at SPARC lab. A scheme with all the laser optics out of the electron beam line seems advantaged from alignment and operation point of view. The first IP scheme was based on the most advanced state of the art, for the Beam Position Monitors (BPM), by using “cavity” BPMs ($< 1\mu m$ res.) [10] and, for the focusing channel point of view, by using a movable high gradient Permanent Magnet Quadrupoles (PMQ) system, capable to focus the electron beam at $10\ \mu m$. Further a second identical focusing system was inserted to capture the beam, after the IP, and leads it through the dumper path to avoid background radiation from pipe-beam scattering (halo beam).

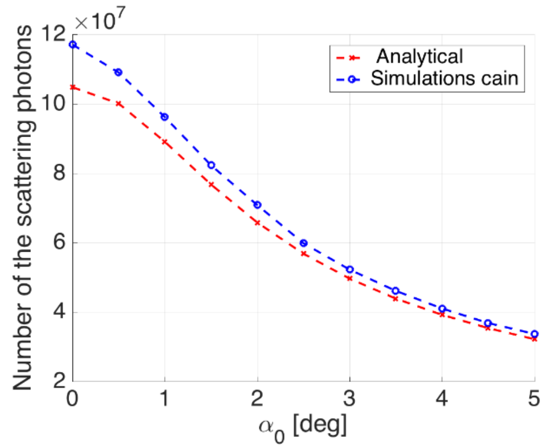

Figure 3: X-ray full photons flux by analytical formulas (dashed red line) and by a CAIN code simulation (dashed blue line).

The cavity BPM and the permanent quadrupoles focusing system are nowadays commercially available, but because of the forefront technology and the outstanding performances, the cost of these devices has a considerable impact on a STAR like machine. Then the short focusing length of the system, few centimetres, makes it necessary to embed the two PMQ focusing channels, and the laser focusing system, into a relative big vacuum chamber, together with the movements.

The second interaction IP scheme, that is now the frozen solution, is born together with a new injection scheme for the STAR photocathode laser. After an analysis of different laser cathode injection schemes, based on the SPARC team experience, on the solution adopted at Fermi [11] and also on the solution defined for the ELI-np facility, we have chosen to inject the laser, on the cathode, by using an ad hoc vacuum chamber (relatively small), with a dedicated entrance laser window (fig. 4). In this way the laser reaches the cathode with a small angle of 2.5 Deg. In a similar way, as mentioned at the paragraph “IP LASER LINE” the interaction laser can reach the IP entering from a small vacuum chamber, equal, or quasi, to the one in the Gun’s region. This solution is compatible with an angle, between the laser and the electron beam, of about 2.3 Deg.; angle that downgrade the X-ray flux around the 50%. This drawback is acceptable if one considers all the strong benefits: the laser and electron optics are out of the vacuum chambers, which give the possibility to moved and to optimized, them, without any complications; further there aren't complex laser optics (as the holed parabola mirror) on the electron beam path. All these are clearly great benefits not only from the laser point of view, but also for the electron beam line point of view. In order to fully optimize the final electron spot, an accurate adjustments, in term of positions of the final focus channel, which is an electromagnetic quadrupoles triplet, will be needed.

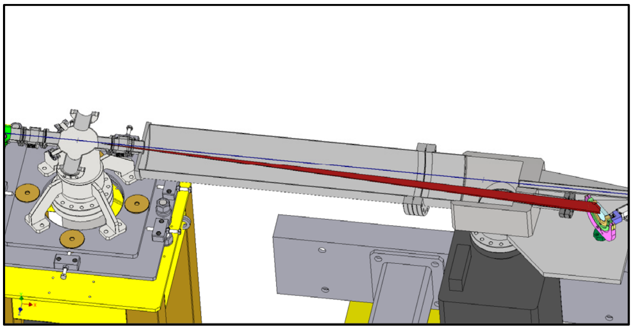

Figure 4: On the right the injection laser chamber, with the narrow electron beam pipe to accommodate the laser entrance windows. In red line is shown the laser envelope from the last mirror up to the IP, passing through the window. On the left the section of a typical diagnostic chamber, in this case used as the IP chamber.

As shown in Fig 4, by this last scheme, the interaction chamber is small, indeed it is a STAR diagnostic chamber. The small dimensions, about 20 cm between the entrance and exit flanges, permit to move the last quadrupole, of the final focusing triplet, very close to the IP (chamber's centre), shortening the triplet focal length and giving the capability to reach the same performances, or very similar ones, to the permanent quadrupoles system previously discussed. Because the IP chamber is a diagnostic chamber, we did not support any project or constructions costs, and further the beam target naturally hosted by the chamber is needful to optimize the laser and the electron beam focusing performances and to overlap the two beams in a proper way.

CONTROL SYSTEM

In order to control the STAR machine and to manage the whole facility, an EPICS-based control system [12] has been designed. Its architecture is shown in Fig. 5. There are three system layers: presentation layer (PL), supervision/monitoring layer (SML) and device interface layer (DIL). The PL contains accelerator operation and monitoring activities, the SML is made of two mirrored redundant CS Server that provide the central coordination for all Input/Output Controllers (IOCs) in the plan. This level will be used for computer services that, irrespective of user's activities, need to run continuously. The DIL hosts Input/ Output Controllers (IOCs), which in turn interface with specific equipment through point-to-point protocols. It provides an abstract representation of equipment to higher layers through which the equipment can be monitored and controlled. The STAR Control System Software infrastructure is based, as already said, on an EPICS architecture. A typical EPICS structure follows the client/server model and considers several Operator Interfaces (OPIs) which, using a Local Area Network (LAN), send requests and acquire data (one or more process variables) to/ from the IOCs. There are many subsystems, such as: beam diagnostic (DIAG1), magnet power supply (PS), vacuum subsystem (VACUUM), Machine Protection System and Personnel Protection System interface (SAFETY), timing system (MTG). The STAR control system has been designed to monitor, control and convey the computed data from the accelerator, facility, experimental, safety and operation subsystems to allow supervisory control, automation and operational analysis. In addition, thanks to its well-known flexibility and modularity, it will be possible to extend and improve its analysis/computing capability, interfacing easily new IOCs, such as several kind of custom parallel multicore elaboration platforms (FPGA-based, SoC-based or Raspberry-based) [13], [14], [15].

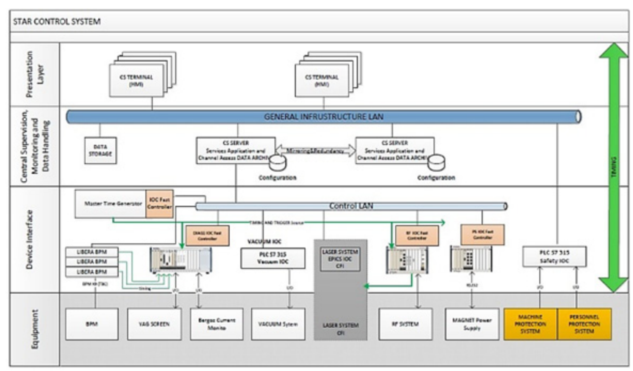

Figure 5: The physical architecture of the STAR control system.

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