SINBAD - A PROPOSAL FOR A DEDICATED ACCELERATOR RESEARCH FACILITY AT DESY

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Abstract

A dedicated accelerator research and development facility SINBAD (Short INnovative Bunches and Accelerators at DESY) is proposed. This multi-purpose research facility is initially aimed at promoting three major goals: (1) Short electron bunches for ultra-fast science. (2) Construction of a plasma accelerator module with useable beam quality (3) Setup of an attosecond radiation source with advanced technology. Research and development on these topics is presently ongoing at various places at DESY, as add-on experiments at operational facilities. The two research goals are intimately connected: short bunches and precise femtosecond timing are requirements for developing a plasma accelerator module with external injection or staging. The scientific case of a dedicated facility for accelerator research at DESY is discussed. Further options are mentioned, like the use of a 1 GeV beam from Linac II for FEL studies. The presently planned conversion of the DORIS accelerator and its central halls into the SINBAD facility is described. The available space will allow setting up several independent experiments with a cost-effective use of the same infrastructure (for example a central high power laser, a central timing and synchronization lab, etc.). National and international contributions and proposals can be envisaged. A preliminary, possible layout and the design work plan are discussed.

SINBAD CONCEPT

The accelerator research and development program at DESY has been expanded since 2011 in the framework of the Helmholtz ARD program. ARD establishes accelerator R&D as a research field in the Helmholtz program with dedicated resources [1]. In this context, plasma acceleration of electrons (PWA) has been defined as one of the new research fields at DESY.

While there are already now several PWA experiments being set up at DESY (see below), the SINBAD facility will provide a long-term home to PWA and other accelerator R&D experiments providing the necessary space, the required beam infrastructure, maximum synergy and independence of user operation. Initial studies show that a longitudinal space of about 60 m is required plus space for RF infrastructure, for a Peta-Watt laser lab, for FEL user tests and for downstream dispersive diagnostics lines. The SINBAD facility shall also provide opportunities for experiments with third-party funding. It shall reuse existing equipment whenever possible, including for example the 200 TW laser that will be moved from the initial LAOLA-REGAE experiment to SINBAD.

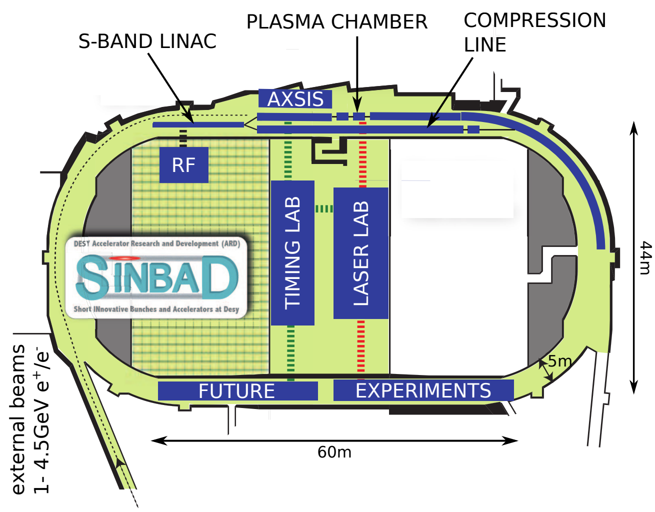

Figure 1: A schematic facility layout illustrating the available premises (green) and the experiments AXSIS and ARES that will be installed in the first stage of SINBAD. The available space indicated in the lower long straight section is available for future experiments like FEL seeding tests. The option to reuse the beam line element of one arc as spectrometer is indicated as well as the possibility to deliver externally produced beams.

The SINBAD facility will be located in the premises of the former DORIS synchrotron which was shut down at the beginning of 2013 after 40 years of operation as a high-energy physics e^+e^--collider and later as a synchrotron light source. It is foreseen to reuse the existing infrastructure like the radiation protection shielding tunnel, the associated halls, the technical infrastructure (water cooling plant, cranes, ...) and possibly a few parts of the beam line elements for SINBAD. For this purpose, the old DORIS beam line elements in the two long straight sections will be removed, creating two free areas of approximately 70 m length with 5 and 9 m width, respectively. The beam line in the arcs will be kept in place initially. One of the arcs can be used for the injection of externally produced beams while the other will serve either as spectrometer or an additional bunch compressor stage. In addition to the halls housing the old power converters and klystrons, the central hall - formerly used by the DORIS experiments Argus/Olympus - is available. It will be used

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to house additional required items like the 200 TW laser and timing labs. This central arrangement is ideal for efficient sharing of expensive technology between the various experiments.

In the first stage, the facility will host three independent experiments (Figure 1): (1) AXSIS, a fully coherent attosecond X-ray source based on coherent inverse Compton scattering off an atto-second electron beam; (2) ARES, a 100 MeV electron linac delivering high quality beam into a magnetic bunch compression line for femto-second bunch generation; (3) a PWA R&D line taking the ARES beam and accelerating it further. At a later stage, additionally available space will be used to house further experiments. The foreseen SINBAD location is fully integrated in the DESY accelerator chain. This might later be made use of for bringing higher energy electrons or positrons to the proposed facility, allowing for example to perform FEL seeding studies or positron injection into a PWA. The connections to existing accelerators also allow, in principle, injecting a plasma-accelerated beam into a synchrotron for testing injection applications for high energy physics.

The work on plasma acceleration will be performed in the context of the LAOLA collaboration, bringing together DESY Hamburg, DESY Zeuthen and the University of Hamburg. The collaboration has already set up several experiments at DESY which will start beam operation soon: (1) The LAOLA-REGAE experiment aims at studying laser driven plasma acceleration of electrons with external injection of a 5 MeV beam with record-short bunches (down to 7 fs) [2]. The 200 TW laser for this experiment is also used for tests on free-electron laser with a laser-generated electron beam, the so-called LAOLA-LUX experiment (2) The LAOLA-PITZ experiment aims at studying the self-modulation (transverse size, beam energy) of long bunches and the generation of high transformer ratios for electron beams (25MeV) that are injected into a plasma channel. [3]. (3) The LAOLA-FLASHForward experiment aims at studying beam-driven PWA with internal as well as external injection using the 1GeV beam of the FLASH user facility [4]. At a later stage, it is envisaged to demonstrate FEL operation with the plasma-accelerated beam. (4) Present research on femto-second long bunches is performed at various facilities, including the REGAE and FLASH accelerators at DESY in Hamburg and in a collaboration with KIT and PSI at the FLUTE project at KIT in Karlsruhe [5]. As the exploratory phase of experiments is limited, either in time, space, scope or accessibility, being attached to existing facilities at DESY, SINBAD will offer the premises to perform research without these restrictions. The SINBAD PWA experiment will profit from the experience gained in these experiments and the lessons learned will culminate in its design.

ARES - FS BUNCHES FROM CONVENTIONAL ACCELERATORS

ARES (Accelerator Research Experiment at Sinbad) will consist of a compact photo-injector providing ultra-short electron bunches of 100 MeV kinetic energy to one of two connected beam lines. A photo-cathode S-band RF-gun, similar to the one operating at REGAE at DESY, will produce a 5 MeV beam which is subsequently velocity compressed [6] and at the same time accelerated to 100 MeV. It is foreseen to produce beams with between 0.5 and few tens of pC charge within sub-femto to few fs second length. At the moment, there are three alternative layout options for the linac being investigated: the first one uses two long traveling wave S-band RF-structures similar to the ones used in the DESY linac II, the second one consists of three shorter, frequency scaled S-band TW SLAC-type ones, the third one uses L-band structures. Furthermore, it is envisaged to use a X-band cavity to compensate nonlinear distortions of the longitudinal phase-space distribution. One of the two beam lines connected to the linac is a bunch compression line. There are two magnetic layouts under study in order to relax the tolerances of the compression and eventually deliver a shorter bunch duration with respect to the pure velocity bunching compression. The first layout foresees a magnetic chicane with a slit placed in the middle of the it. The gap will select only the central longitudinal slice of the electron bunch and reduce the effective mean energy jitter of the beam [7]. The second layout under study foresees the presence of a magnetic arc at the exit of the photo-injector to stabilize the arrival time jitter [8].

PLASMA ACCELERATOR R&D TOWARDS NOVEL FEL'S

Plasma-wakefield acceleration has proven to be a technology which can successfully be used to generate accelerating fields with gradients up to 100 GV/m, with bunches produced in a single stage reaching energies up to several GeV [9, 10]. While the quality of those beams has improved tremendously, some key parameters (such as energy spread of a few %) are significantly worse than those produced in conventional accelerators. This is due to laser stability issues, limited control over the internal injection process and the intrinsic growth of correlated energy-spread in plasma accelerators.

The initial focus of the plasma experiments at SINBAD will be on controlled external injection of a 100 MeV electron bunch into a laser-driven plasma wakefield [11]. At 100 MeV the propagation speed of the electrons is well matched to the phase velocity of the plasma wakefield [12]. External injection allows for precise tailoring of the injected 6D phase-space and therefore provides the possibility to optimize the evolution of bunch parameters during the acceleration process.

In order to minimize the induced energy spread during acceleration, the bunch length must be short compared to the plasma wavelength. External injection of ultra-short bunches requires fs-synchronization and good matching of the transverse beam parameters into the plasma focusing fields. In order to relax some tolerances it is beneficial to operate at low plasma densities. A set of 2D particle-in-cell simulations were performed with the code OSIRIS

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[13, 14] for SINBAD. Parameters close to the existing 200 TW LAOLA laser were used: normalized vector-potential $a_0 = 1.8$, pulse length 25 fs RMS, spot size 50 μm RMS, 800 nm wavelength, 5 J energy corresponding to 196 TW peak power. It can be seen in Figure 2 that gradients drop rapidly for lower plasma densities. Defining 200 MV/m as a minimum goal for SINBAD, a minimum feasible plasma density of about 10^{16} cm^{-3} is found. If the laser would be upgraded to 200 fs long pulses at an increased spot size of 100 μm and peak power of 0.8 PW the minimum interesting plasma density would be 10^{15} cm^{-3}. Starting from these initial values, plasma densities and gradients can then be subsequently increased, once good beam quality has been achieved and measured behind the plasma. At a later stage, it is considered to produce comb beams [15] with ARES, allowing experiments on multi-bunch driven plasma acceleration with resonantly excited wakes.

Figure 2: Accelerating gradients from OSIRIS simulations and theory versus plasma density, showing results for the existing 200 TW laser and a potential 0.7 PW laser upgrade.

AXSIS - ATTO-SECOND SCIENCE

The third baseline experiment at SINBAD is AXSIS (Attosecond X-ray Science: Imaging and Spectroscopy), which was recently funded through a Synergy Grant of the European Research Council (ERC). This project - a collaboration between the Hamburg University, DESY and Arizona State University - aims at developing a fully coherent attosecond X-ray source based on coherent inverse Compton scattering off an atto-second electron beam. An ultra-short and cold electron bunch is generated in a nano-emitter photocathode and accelerated to 20 - 40 MeV in THz driven waveguides. Related studies can be found in [16] and [17]. The SINBAD setup will provide an adequate beamline tunnel, space for a diagnostics beamline, a location for the foreseen user station and general accelerator infrastructure.

ADDITIONAL POSSIBILITIES

Located in the former DORIS premises, the SINBAD facility will be well integrated into the DESY accelerator chain. This opens the possibility to bring externally accelerated electron beams to SINBAD at a later stage. While the DESY linac II is currently used to provide 450 MeV electrons for DESY II, it is capable to accelerate electrons to 800 MeV or alternatively positrons to 400 MeV. Currently a new DC gun is being installed in parallel to the existing DC-gun. Once the new source has proven to operate reliably, the old gun could in principle be replaced with a photo-cathode RF-gun for the production of short bunches. There are currently two alternatives being investigated for transporting the beam from the linac to SINBAD: While the first option uses an existing, empty tunnel (blue line in Figure 3), the second option (red line in Figure 3) would use the original injection path into DORIS via the DESY II synchrotron and the still fully equipped existing transfer-line ("R-Weg"). In the latter case, the DESY II synchrotron (which is used only about 10% of the time for top-up operation of the PETRA III synchrotron light source) can either be used as a simple transfer-line or - at the cost of sacrificing the short bunch length - it is used to accelerate to beam energies of 4.5 GeV. In case the beam is to be injected into a plasma chamber, the tight timing synchronization requirements will have to be mastered.

Figure 3: Integration of SINBAD into the DESY accelerator chain with two possible options (red and blue) for transporting beam from linac II to the facility.

CONCLUSION & OUTLOOK

Due to the available technical infrastructure and good integration into the DESY accelerator chain, the former DORIS premises at DESY offer unique possibilities for a dedicated accelerator research facility. The detailed design studies on three initial experiments have started, one of them funded through an ERC Synergy Grant. The initial scientific case includes fs electron bunches from conventional accelerators, plasma accelerator R&D towards novel FEL's and attosecond technology and science. The overall facility layout will be optimized in future studies. Significant space remains available for future ideas and proposals, also providing opportunities for additional third-party projects. Construction should start in 2016 with first experiments in 2017. SINBAD completion is foreseen for 2020.

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