

DOGLEG DESIGN FOR THE SINBAD LINAC

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Abstract

The SINBAD facility (Short and INnovative Bunches and Accelerators at DESY) is foreseen to provide sub-fs to tens of fs electron bunches for the R&D of novel acceleration concepts and applications, e.g. Laser Wake-Field Acceleration (LWFA), Dielectric Laser Acceleration (DLA) and medical imaging. We present the design study of the dogleg at the SINBAD linac, which is capable of delivering ultra-short bunches to the second beamline. The longitudinal dispersion of the dogleg can be finely tuned so that it can either transport the ultra-short bunch produced upstream by velocity bunching, or compress the incoming long bunch. The achievable beam parameters are investigated by start-to-end simulations.

INTRODUCTION

The SINBAD (Short INnovative Bunches and Accelerators at DESY) facility is a long-term dedicated accelerator R&D facility currently under construction at DESY [1]. It is foreseen to host various experiments in the field of production of ultra-short electron bunches and novel high-gradient acceleration techniques, e.g. Laser-Wake-Field Acceleration (LWFA), Dielectric Laser Acceleration (DLA) and THz based acceleration (the AXISIS experiment) [2].

The SINBAD-ARES linac [3] will provide a unique opportunity to compare different compression schemes (velocity bunching, magnetic compression and hybrid compression) for generating low charge electron bunches (0.5 pC ~ 20 pC) with bunch durations ranging from several fs to sub-fs. It will consist of a compact photo-injector providing ultra-short electron bunches to one of the two connected beamlines, as shown in Fig. 1. The ~5-MeV electron bunches generated by the 1-1/2 cell S-band photocathode RF-gun are accelerated by two S-band travelling-wave RF-structures to around 100 MeV. A third S-band TWS is foreseen in the future to boost electron bunches to 200 MeV. The pulse duration of the Yb-doped photocathode laser can be tuned between 190 fs and 10 ps. Downstream of the photo-injector, the main beamline includes a magnetic chicane bunch compressor with a slit located in the middle of it. This setup provides a cost-effective way to generate sub-fs electron bunches with bunch charges up to ~5 pC and bunch arrival-time jitters less than 10 fs [4]. In order to deliver ultra-short bunches to the second beamline, a dogleg section with variable R_{56} is also being planned.

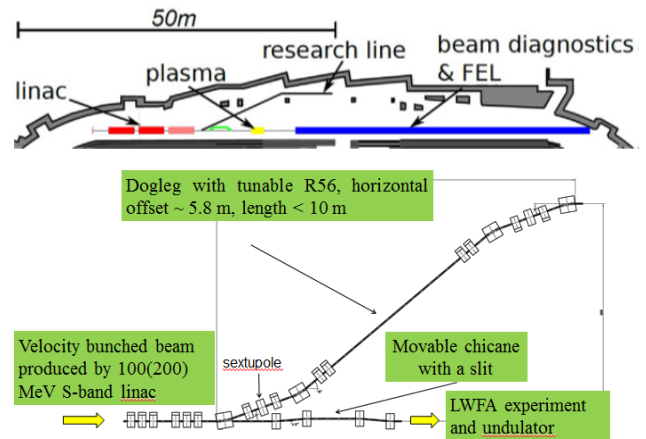


Figure 1: Layout of the SINBAD-ARES linac in the upper straight section of the SINBAD tunnel (up) and sketch of the magnetic lattice (down).

OVERVIEW OF THE DOGLEG DESIGN

The dogleg is supposed to deliver ultra-short electron bunches with energies up to 200 MeV to the second beamline. Due to the space constraint, the horizontal displacement between the first and second beamlines is required to be about 5.8 m, and the length of the dogleg should be less than 10 m. In the current design, it consists of four 0.42-m-long rectangular dipole magnets with bending angles of (+, +, -, -) 20°. There are eight quadrupole and 2 sextupole magnets in between these dipole magnets. The arrangement of the quadrupole magnets and drifts is symmetric about the midpoint of the dogleg. The locations of the two sextupole magnets are also symmetric about the midpoint of the dogleg, while the signs of their currents are opposite. The R_{56} of the dogleg can be changed by adjusting the strengths of the four quadrupole magnets at both ends simultaneously, while the strengths of the other quadrupole magnets need to be tweaked accordingly in order to completely suppress the dispersion at the dogleg exit. The sextupole magnets are able to suppress the second-order longitudinal dispersion term T_{566} and cancel the longitudinal phase-space curvature of the incoming bunch, which is of vital importance for generating ultra-short bunches.

The start-to-end (S2E) simulation of the beam dynamics from the photocathode to the dogleg exit were performed with ASTRA [5] and ELEGANT [6]. The electron bunch was first transported to the end of the linac by using ASTRA with a 2D cylindrical-symmetric space-charge algorithm, and the rest was simulated by using ELEGANT with a 1D Coherent Synchrotron Radiation (CSR) model afterwards. The beam energy is 100 MeV.

ISOCHRONOUS BEAMLINE

The dogleg can be used to transfer the velocity-bunched beam from the first beamline to the second one with little impact on the longitudinal phase-space. The beam optics and the evolution of the longitudinal dispersion for the isochronous setup are shown in Fig. 2. It should be noted that the R_{56} of the drift space (~ -0.026 mm/m for the 100 MeV beam) is not included in the plot. Simulation shows that the longitudinal phase-space of the 10-pC, 183-fs bunch, remains almost unaltered after passing through the dogleg, as shown in Fig. 3. However, the transverse projected emittance largely increases from $0.14 \mu\text{m}$ to $0.39 \mu\text{m}$. Although the whole dogleg is nearly isochronous, the R_{56} value fluctuates along the beamline. Therefore, the bunch will experience compression or decompression if the chirp of the bunch is non-zero. In this case, the bunch is compressed to about 50 fs after the third dipole magnets, as shown in Fig. 4, which greatly enhances the CSR effect. It is worth noting that the emittance growth is sensitive to the phase advance between the third and fourth dipole magnet, which is found to be minimized when the phase advance is about 180° .

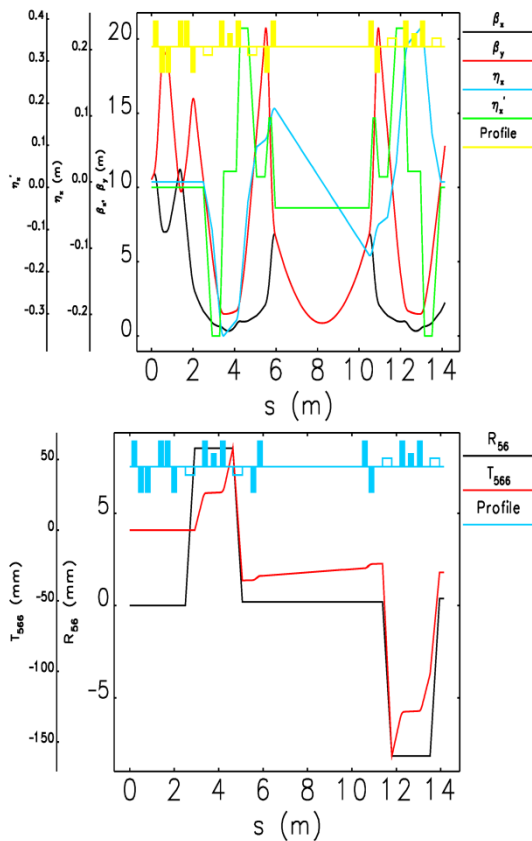


Figure 2: Design optics (up) and evolution of the longitudinal dispersion (down) along the dogleg beamline.

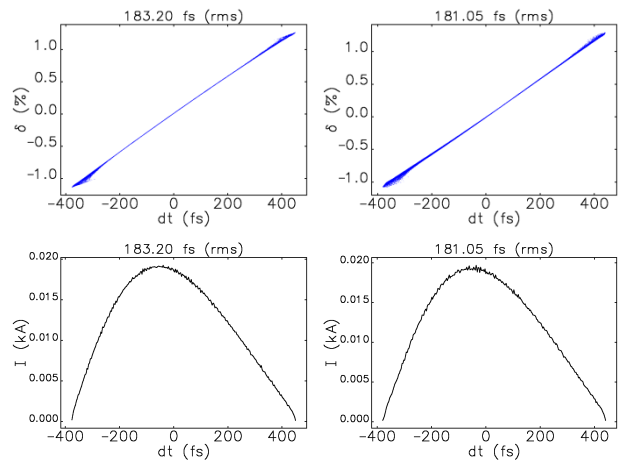


Figure 3: Longitudinal phase-spaces (up) and current profiles (down) of a 10-pC bunch before (left) and after (right) the dogleg.

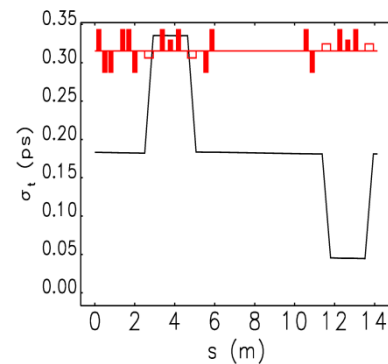


Figure 4: Evolution of the bunch length along the dogleg. The bunch charge is 10 pC and the overall R_{56} is about 0.

In another example, we start with a nearly fully compressed 0.5-pC bunch, as shown in Fig. 5. Since the bunch is largely decompressed and then re-compressed at each pair of dipoles, as shown in Fig. 6, the CSR effect is considerably mitigated. The bunch becomes even shorter after the dogleg, and the horizontal projected emittance only increases from $0.06 \mu\text{m}$ to $0.08 \mu\text{m}$.

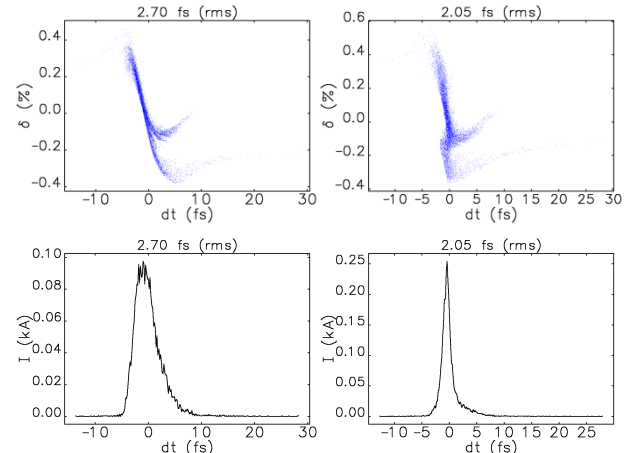


Figure 5: Longitudinal phase-spaces (up) and current profiles (down) of a 0.5-pC bunch before (left) and after (right) the dogleg.

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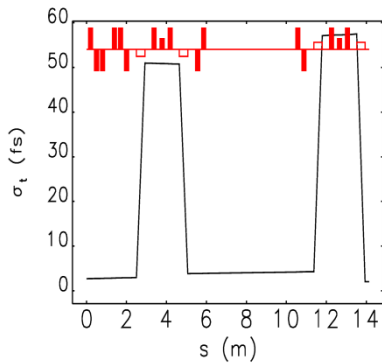


Figure 6: Evolution of the bunch length along the dogleg. The bunch charge is 0.5 pC and the overall R_{56} is about 0.

HYBRID COMPRESSION

The dogleg can also be used to further compress the velocity-bunched beam. The evolution of the longitudinal dispersion for a setup with an overall R_{56} of -10 mm is shown in Fig. 7. The initial and final longitudinal phase-spaces are shown in Fig. 3 and Fig. 8 respectively. The bunch is finally compressed to 4.1 fs with a nearly symmetric current profile and a peak current exceeding 1.4 kA. It is surprising to find that the final horizontal projected emittance is about $3.9 \mu\text{m}$, which is the same as in the previous case when the bunch is not compressed by the dogleg. This can be explained by the bunch length evolution along the dogleg, as shown in Fig. 9. Since the bunch is largely over-compressed in the third dipole magnet, the bunch length is still very long at the entrance of the fourth dipole magnets which mitigates the CSR effect.

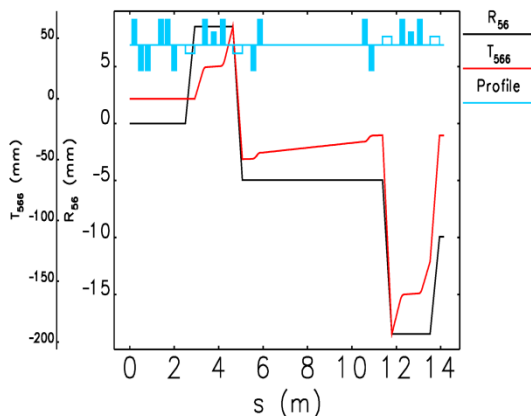


Figure 7: Evolution of the longitudinal dispersion along the dogleg beamline.

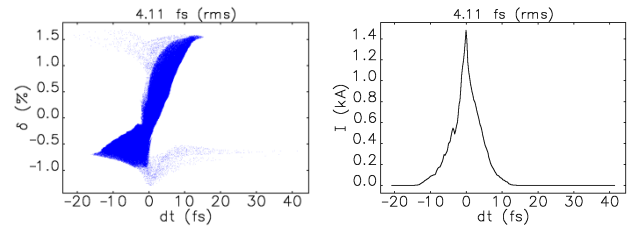


Figure 8: Longitudinal phase-spaces (up) and current profiles (down) of a 10-pC bunch before (left) and after (right) the dogleg.

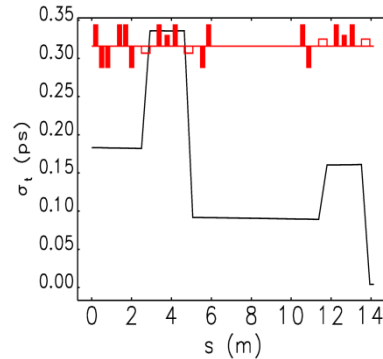


Figure 9: Evolution of the bunch length along the dogleg. The bunch charge is 10 pC and the overall R_{56} is about -10 mm.

CONCLUSION

In this paper, we have presented the design of the dogleg section at the SINBAD-ARES linac. Beam dynamics simulations show that the dogleg can be used either as an isochronous transfer line or a magnetic bunch compressor. In the former case, a 0.5-pC, 2.7-fs bunch is transferred to the second beamline with an emittance growth of about 33%, while the bunch length becomes even shorter. In the latter case, a 10-pC bunch is compressed to 4.1 fs (rms) with a nearly symmetric current profile.

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