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OVERVIEW OF THE ARES BUNCH COMPRESSOR AT SINBAD*

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Abstract

Bunch compressors are essential for the generation of short bunches with applications in e.g. colliders, free electron lasers, and advanced accelerator concepts. The up-and-coming ARES accelerator located at SINBAD, DESY will support the formation of ~100 MeV, pC, sub-fs electron bunches for LWFA research and development. We give an overview on the ARES bunch compressor, providing start-to-end simulations of the machine and an update on its technical design.

INTRODUCTION

The accelerator research experiment at SINBAD (ARES) is a conventional S-band electron linac dedicated to producing ultra-short 100 MeV bunches for accelerator research at DESY [1, 2]. The ARES accelerator sections consists of a coaxial-coupled 1.5 cell RF gun which is now being commissioned [3, 4]. Two travelling wave linac structures are currently installed and are planned for commissioning in summer 2019. Subsequently an experimental area for dielectriclaser acceleration experiments will be temporarily located at the position of a 3rd travelling wave structure [5–8]. A movable magnetic chicane is being designed and is the focus of this paper. The bunch compressor will support the formation of ~fs, pC-scale bunches to explore the limitations of ultra-short high brightness electron bunches and for external injection into a laser-driven plasma accelerator stage, as in the context of ATHENA ("Accelerator Technology HElmholtz iNfrAstructure"), see [9, 10].

The ARES bunch compressor (BC) is discussed in [11]. The design, as depicted in Fig. 1, consists of 4 magnets (B1, B2, B3, B4) with a maximum on-axis magnetic field of 0.5 T. Magnets B2 and B3 are on a movable platform with a maximum travel range of 20 cm; see Table 1 for details. Moreover there are four elements between B2 and B3: a beam position monitor (BPM), a movable-slit collimator, a general mask collimator and finally a screen station.

We use a European XFEL (Eu-XFEL) BPM in the bunch compressor. The BPM provides an online, non-invasive energy-change measurement via $\delta = \Delta x/R_{16}$. The resolution of this BPM is approximately 3 μm for a bunch charge of 20 pC at the Eu-XFEL. We anticipate similar performances although our beam will be asymmetric in this region, as we will explain in the following sections.

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Table 1: Specifications of the Bunch Compressor

Parameter	Symbol	Value	Unit
max. travel range	Δx	20	cm
travel step size	δx	10	μm
max. B-field	B_0	0.5	T
good field full width	-	10	cm
good field full height	-	4	cm
eff. magnet length	-	22	cm
current in main coil	-	342	A
mom. comp. at 100 MeV	R_{56}	0-8.8	cm
pipe diameter	-	40.5	mm
dist. betw. B1,B2 and B3,B4	-	60	cm
dist. betw. B2,B3	-	3	m

Two collimators are being developed. The first collimator system consists of two movable blades to cut the beam in the dispersive plane i.e. the 'slotted-foil' approach, shown in Fig 2 [12]. In this configuration the bunch length (FWHM) after the chicane can be given by

$$\Delta\tau = \frac{2.35}{|\eta h| c}\sqrt{\eta^2\sigma_{\delta_0}^2 + (1 + hR_{56})^2(\Delta b^2/3 + \epsilon\beta)}, \quad (1)$$

where η is the dispersion, h the energy chirp, σ_{δ_0} is the initial rms uncorrelated energy spread, b is the slit width, ϵ is the geometric emittance, and β the betatron function.

The blades will be mounted off-plane to avoid any possible collisions in the vacuum system. In addition, we are exploring the addition of a scintillating material on the blades to image the beam from the frontside; here we anticipate we could take a negative of the beam image as an online beam measurement diagnostic, see Fig. 2 (top). The second

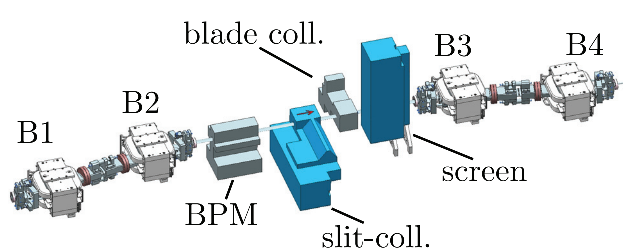

Figure 1: Overview of the ARES bunch compressor under design. The two center magnets (B2, B3) surround a BPM, two collimator systems, and a screen station. The maximum distance of travel corresponds to Δx=20 cm.

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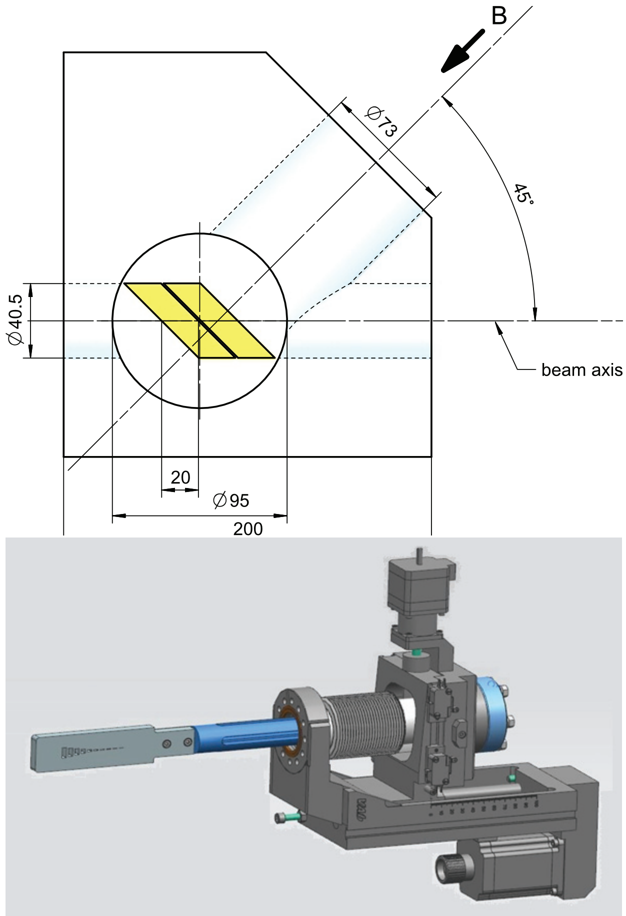

Figure 2: The movable-slit collimator concept is illustrated (top); here the beam comes from right-to-left, two scintillating blades mounted on Cu are used to produce a negative image of the electron beam, as captured by a viewport at 45 deg. A single blade collimator with various slit sizes is shown (bottom) and will include other mask designs for advanced concepts.

collimator consists of a single-blade design adapted from an existing model in the low-energy section of ARES. This collimator system will help reduce electromagnetic showers downstream of the variable-slit collimator and support longitudinal bunch shaping for advanced concepts, as shown in Fig. 2 (bottom).

Finally, a screen station is located as the final element in the movable platform. The screen will be used without the collimators present. In addition it will be useful for commissioning where the trim coils in the magnets can be tuned to minimize dispersion after the BC. Here the location of the BPM (entrance) and screen (end) will allow us to measure and correct for unwanted angles in the beam trajectory.

MECHANICAL VACUUM DESIGN

The ARES bunch compressor will have a maximum travel range of 20 cm (Fig. 3 (a,b)), allowing for a wide range of R_{56} to support a broad range of possible applications. The design of the mechanical vacuum system decouples the translational and rotational movements of the BC with a track and hinge respectively; Fig. 3 (c). A prototype is under construction and is anticipated for completion in late Spring 2019. Subsequently, a full version will be constructed for planned commissioning of the bunch compressor in the first half of 2020.

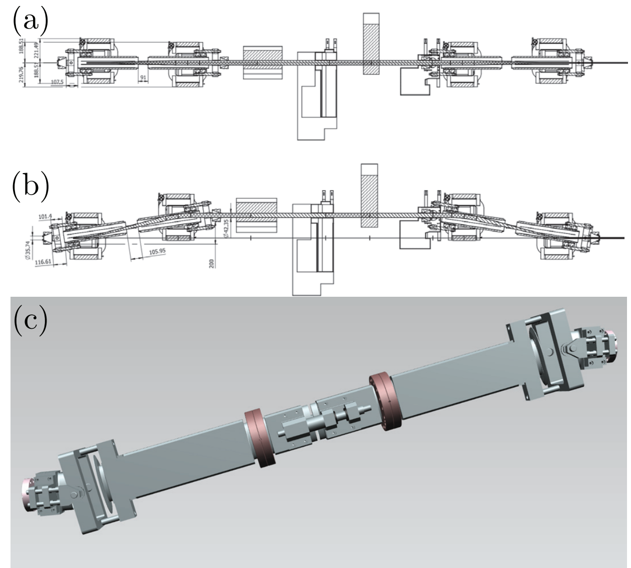

Figure 3: The mechanical vacuum design is illustrated. In (a) the platform has zero offset, while in (b) there is a 200 mm offset. Finally (c) illustrates a 3D rendering, showing the translational and rotation decoupling.

START-TO-END SIMULATIONS

The ARES linac is simulated with a combination of ASTRA [13], ELEGANT [14], and IMPACT-T [15]. ASTRA is used to simulate the photoinjector up to the end of the second travelling wave structure. Subsequently ELEGANT is used to match the beam through the bunch compressor, this consists of optimizing the 6 matching quadrupoles for certain applications. Finally, with the ELEGANT results, we use IMPACT-T to simulate from the output of the travelling wave structures, though the matching section and finaly through the bunch compressor. We employ 3D space charge calculations and 1D CSR in the latter simulation. Finally, the slit collimator is also performed in IMPACT-T. Radiation levels along the beamline are analyzed with G4BEAMLINE [16] to prepare with e.g. sufficient shielding of electronic components.

Several working points have been investigated by J. Zhu [11]. Here we dicuss a low (<pC) working point used to generate 0.36 fs long bunches for external injection into a laser-driven plasma accelerator. The short bunch lengths and small beam sizes are anticipated to improve energy spreads and emittance growths in the plasma. A set of beam parameters is shown in Table 2. The Twiss parameters

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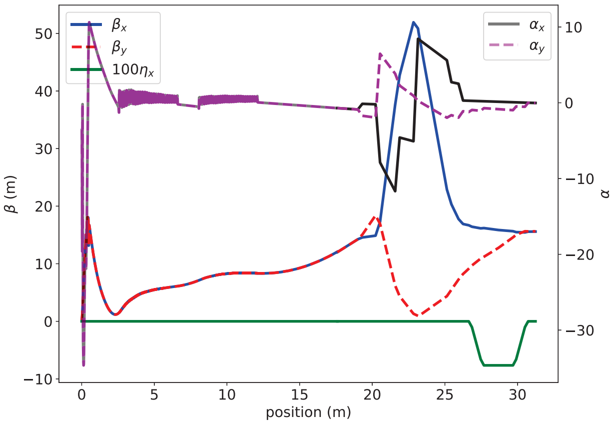

Figure 4: The Twiss parameter evolution is illustrated along the length of the linac. The bunch compressor terminates at z=~31 m, the plasma is anticipated to be located at ~34 m.

along the linac are illustrated in Fig. 4. The longitudinal and transverse phase spaces at the BC exit are shown in Fig. 5; there are strong space charge effects which dilute the beam over the following ~3 m propagation distance to the plasma entrance. The optimization of the beamline is underway to minimize the beam size and bunch length at the plasma entrance, see [9].

CONCLUSION

We have given an overview on the ARES bunch compressor which is undergoing design at SINBAD, DESY. The BC will provide versatile control over final bunch properties for a broad set of applications including LWFA in the context of ATHENA. The bunch compressor is planned for commissioning in 2020.

Table 2: Final Bunch Parameters for Sub-fs Compression

Parameter	Symbol	Value	Unit
energy	$< E >$	100	MeV
charge	Q	~0.8	pC
norm emit	$\gamma\epsilon$	100	nm
peak current	I_p	2.8	kA
bunch length	σ_z	110	nm
rel. rms energy spread	σ_δ	~0.002	-

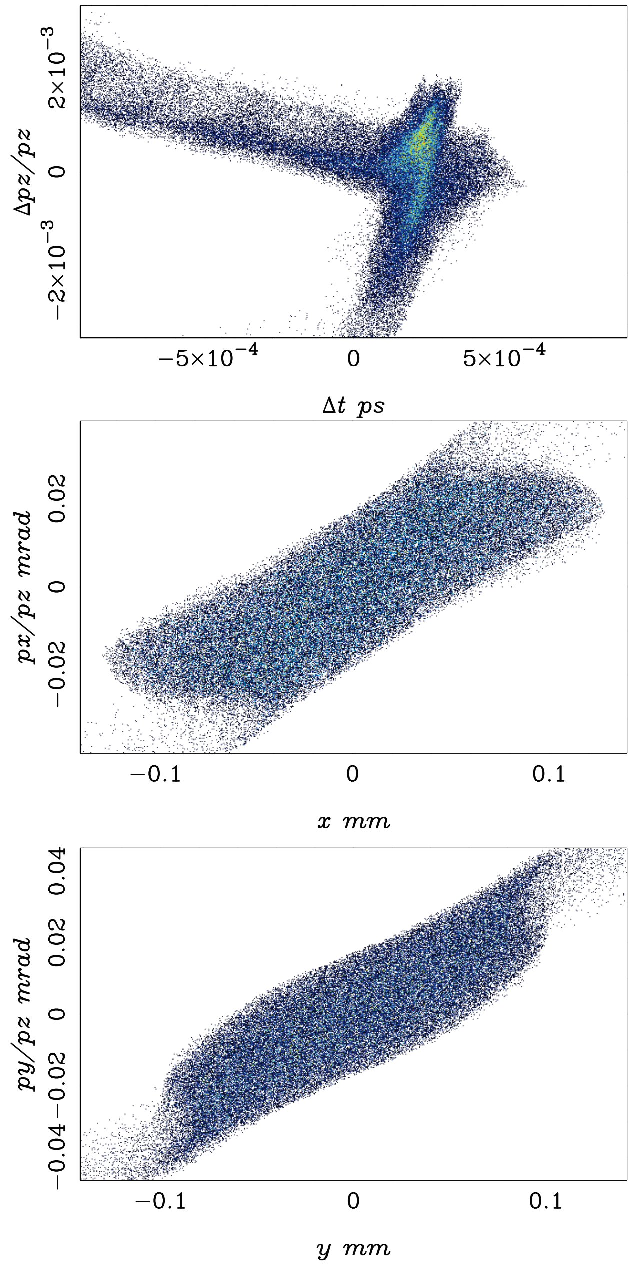

Figure 5: Final snapshots of the longitudinal and transverse phase spaces at the exit of the bunch compressor for beam parameters in Table 2.

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