ISBN: 978-3-95450-215-8 ISSN: 2226-0366 doi:10.18429/JACoW-LINAC2022-THPOJ001

# THE ARES LINAC AT DESY

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*Abstract*

The generation and acceleration of ultra-short, high quality electron beams has attracted more and more interest in accelerator science. Electron bunches with these properties are necessary to operate and test novel diagnostics and advanced high gradient accelerating schemes. Furthermore, several medical and industrial applications require high-brightness electron beams. The dedicated R&D linac ARES at DESY (Deutsches Elektronen-Synchrotron) is now fully operational and able to produce these electron beams at the nominal energy of 155 MeV and deliver them to users. This paper gives an overview of the ARES linac and summarizes the beam parameter measurements. The possibilities for user operation will be described in detail.

## THE SINBAD FACILITY

SINBAD (Short INnovative Bunches and Accelerators at DESY) is an accelerator R&D platform in the former DORIS accelerator tunnel at DESY, Hamburg. Its goals are to demonstrate the generation and acceleration of ultra-short electron bunches and to test advanced acceleration techniques such as laser driven plasma wake-field acceleration (LWFA), dielectric laser acceleration (DLA) and THz-driven acceleration, in multiple independent experiments [1–3]. ARES (Accelerator Research Experiment at SINBAD) at SINBAD represents one of these experiments. The construction of the linear RF accelerator with a target energy of 100–155 MeV was finished in 2021 followed by an extensive commissioning phase. The facility provides ultra-short, high brightness electron bunches with an excellent stability and reproducibility.

## THE ARES LINAC

The ARES linac starts with a normal conducting RF photoinjector generating single electron bunches with a repetition rate of up to 50 Hz [4]. The bunch is afterwards accelerated by an S-band linac section, consisting of two travelling wave structures (TWS) accelerating the beam to its nominal momentum of 155 MeV/c. A first in-vacuum experimental area is installed downstream of the linac section. A movable magnetic bunch compressor (as part of the german Helmholtz-ATHENA project, [5]) will allow the generation of ultra-short bunches in the fs to the sub-fs regime based on the combined techniques of velocity bunching and magnetic bunch compression [6]. The high brightness beam will then serve as a test bench for novel diagnostic devices such as the PolariX TDS, an advanced modular X-band transverse deflecting structure (TDS) system. It has the new feature of providing variable polarization of the deflecting force [7–10]. Further downstream and connected to the spectrometer section, two additional experimental stations were installed, allowing experimentalists to perform tests also in an in-air setup. A picture of the ARES linac is shown in Fig.1.

### *Beam Parameters*

The actual commissioning and design beam parameters are listed in Tab.1. With additional high sensitive beam diagnostics it was possible to characterize the bunches down to 2.5 fC. The nominal bunch length of a few fs down to the sub-fs can only be measured with the PolariX TDS being fully operational, which is foreseen for mid 2023. Still without magnetic compression a bunch duration of 30 fs rms was reconstructed at the entrance of the second TWS using tomographic methods. This corresponds to the resolution limit of these methods on ARES. [11].
ARES has already demonstrated an outstanding stability with a relative momentum stability of 6E-5 over 16 hours at 155 MeV and a mean FWHM energy spread of 0.06 MeV.

Table 1: ARES design beam parameters and actual commissioning parameters.

| **Parameter** | **Actual** | **Design** |
|---|---|---|
| Momentum | 45 - 155 MeV/c | 45 - 155 MeV/c |
| Charge per pulse | 0.003 - 200 pC | 1 - 100 pC |
| Rep. rate | 1 - 50 Hz | 1 - 50 Hz |
| Bunch length | 30 fs | sub-fs |

### *Experimental Areas*

ARES offers three experimenal stations for DESY-internal and external user experiments and R&D purposes. The first experimental area is in the machine vacuum system and therefore only compatible with UHV, particle free setups. The experimental chamber is equipped with a hexapod. A screen and a nano-wirescanner are located on the hexapod. A quadrupole triplet as well as corrector magnets allow for an excellent beam control. A side view inside the chamber is depicted in Fig. 2 [12].
The second experimental area is located in the dispersive arm of the spectrometer section at the end of the linac. It consists of a vacuum chamber, separated from the machine vacuum by a 50 $\mu$m thick titanium foil. This experimental area is dedicated to detector tests with detectors in low-pressure or nitrogen atmosphere. A picture of the chamber is shown in

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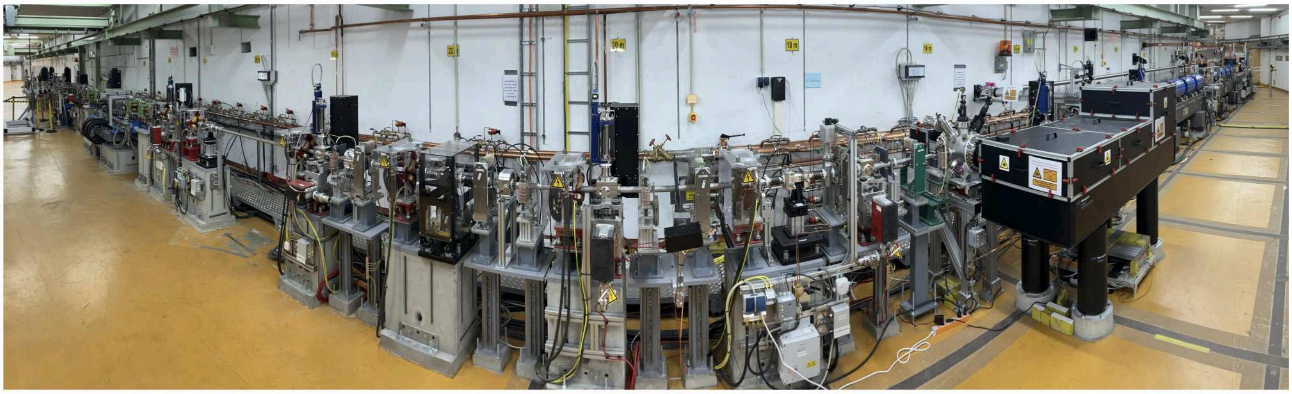

Figure 1: Fisheye-view of the ARES linac. The RF-gun is on the right, followed by two travelling wave structures, the first experimental area, including the optical table for the 2 micron laser is visible in the middle. Further downstream to the left bunch compressor and TDS are installed.

Fig. 3.

In the straight section an in-air experimental station was installed. Also this area is separated by a 50 $\mu$m thick titanium foil from the machine vacuum. There are variable options of the station being equipped with wirescanners, screens and an ICT. The experimental setup can be placed on a set of three linear stages. The station with ICT and wire-scanners is shown in Fig. 4.

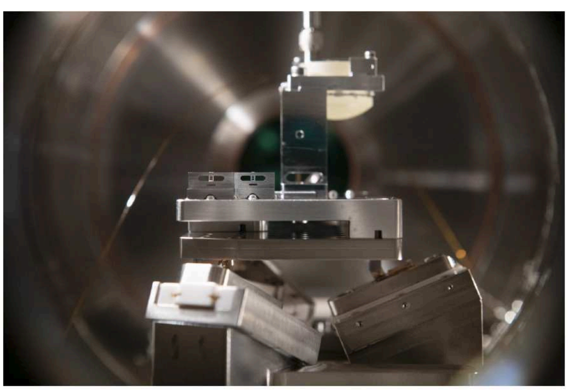

Figure 2: Side view inside the first experimental chamber in UHV. The setup consists of a hexapod, equipped with 2 DLA structures (front left) and a screen with lens holder in the background. The nano-wirescanner is located behind the lens holder.

Figure 3: Second experimental area chamber in the dispersive arm of the spectrometer section at the end of the linac. This station is mainly used for detector development with variable pressure inside the chamber.

## EXPERIMENTS AT ARES

The ARES Linac is dedicated to accelerator R&D DESY internally but also available for external users. Its advantages are easy accessibility, flexibility in beam parameters and excellent beam control and diagnostics. A selection of the projects is listed below:

- Beam diagnostic tests
  - 4D and 5D beam tomography developments [13]
  - Novel stripe detectors development for low-charge applications [14, 15]
  - High resolution screens and optics development
  - High precision beam position monitors [16]
  - Nano-wirescanners and beam loss monitor tests
  - Non-invasive beam diagnostics with dielectric structures
- Hardware tests and prototyping for the big DESY user machines
  - Injection kickers for PETRA IV
  - Movable magnetic bunch compressor
  - 3D printed vacuum chambers
  - RF waveguide windows test stand

ISBN: 978-3-95450-215-8 ISSN: 2226-0366 doi:10.18429/JACoW-LINAC2022-THPOJO01

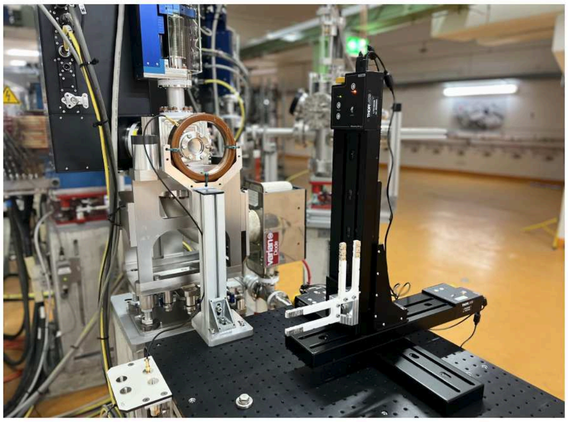

Figure 4: In-air experimental station equipped with ICT (copper ring) and a wirescanner setup on the linear stages. The electrons from the linac are extracted via a 50 $\mu$m thick titanium foil.

  - High stability infrastructures (precision water cooling and RF stations)
  - High resolution cathode charge maps
- Beam Controls
  - Master oscillator developments and fs synchronization
  - Machine learning towards autonomous accelerators [17, 18]
  - Neural nets for emittance data analysis [19]
  - fs bunches and their diagnostics with the PolariX TDS [20]

### *Dielectric Laser Acceleration*

As part of the Accelerator-on-a-chip (ACHIP) collaboration experiments concerning dielectric laser acceleration are performed in the UHV experimental chamber. This is to be achieved by generating accelerating fields of around GV/m in a 1 mm long, laser-illuminated dielectric grating structure. As the structures used at ARES have a period of 2 $\mu$m, the accelerating buckets are only about 1 fs long. A stable transmission through the 1 $\mu$m aperture was shown in 2022. The temporal overlap between electron bunches and laser pulses was not yet achieved. In a future upgrade of the experimental area a new pre-modulation technique will be employed in the longitudinal phase space. With this technique being applied to the injected bunches, it is predicted that stable shot-to-shot operation can be achieved [21–23].

### *External Users*

The ARES linac was part of the ARIES transnational access program. This program was successfully finished in April 2022 with more than 240 hours of beam time delivered to external users.
The first user group from PSI studied reverse tomography methods with wirescanners. This next-generation polygonal nano-wire scanner (PNWS) consists of 1 $\mu$m thick gold wires and was installed in the UHV experimental chamber. The goal of this project was to use the wire scanner to characterize other diagnostics devices and performed a 4D mapping of the electron beam shape, looking at its evolution [24].
The second user group came from EPFL, Lausanne, and the main goal of this project was to experimentally study the color centers created in nitrogen-rich HPHT diamond using ultra-high energy electron irradiation (155 MeV) with high doses. This experiment was placed in the in-air experimental station and stable irradiation was performed over 4.5 days on a 200 $\mu$m spot.

### *Medical Applications*

Medical applications will play a major role in the future ARES scientific portfolio. A collaboration with the Hamburg-Eppendorf University Hospital (UKE) was recently founded to perform studies on cancer irradiation techniques with electron beams. First experiments with cell cultures and diagnostic tests are expected for the end of 2022.
A new method of an electron CT at 155 MeV was successfully tested with a mouse phantom and the optimization (irradiation time, dose to mouse phantom) is currently ongoing.
It is also envisaged to study very-high-energy-electron (VHEE) treatment of tumors, also in-vivo, in collaboration with the medical experts.

## CONCLUSION

The ARES construction was finished in 2021. The facility is now in operation serving as test bed for ultra-short electron pulses and high brightness beams and their diagnostics. ARES is also used for accelerator R&D for internal and external partners. As part of the scientific program the ARES team also is investigating dielectric laser acceleration and beam manipulations with dielectric structures in the frame of the ACHIP program. Medical applications of electron beams such as VHEE treatment and electron CT will be studied in collaboration with the medical experts.

## ACKNOWLEDGEMENTS

The authors would like to thank the DESY technical groups for their support during the design, construction, commissioning and operational phases. The authors acknowledge support from DESY (Hamburg, Germany), a member of the Helmholtz Association HGF. The Helmholtz Association funds the ATHENA project. ACHIP related activities are partially funded by the Gordon and Betty Moore foundation (GBMF4744). Access via the ARIES-TNA program was sponsored via the European Unions Horizon 2020 Research and Innovation program under grant agreement number 730871.

ISBN: 978-3-95450-215-8 ISSN: 2226-0366 doi:10.18429/JACoW-LINAC2022-THPOJ001



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