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BESSY III - STATUS AND OVERVIEW

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Abstract

The “Pre-Conceptual Design Report” of the BESSY III facility has been finalized in August 2022 and reviewed by a Project Advisory Committee. In 2023, it is expected that the project will enter the Conceptual Design Report phase. In this paper, we give a status report of the BESSY III facility project and will discuss aspects of the general setup, lattice design, technical specifications, initial developments *starting within the BESSY II+ project*, and a first estimate of power consumption compared to BESSY II.

HZB’S AND BESSY’S NEAR FUTURE

HZB is preparing for its future light source with two main projects [1]: the BESSY II+ project and BESSY III. BESSY II+ is a refurbishment and modernization project of BESSY II to enable state-of-the-art operation for the next decade. The greenfield BESSY III project aims to establish a storage ring-based light source of the 4th generation based on a Multi-Bend-Achromat (MBA) lattice. A first sketch to the facility was recently published in a pre-CDR [2]. This two-step Ansatz is mainly motivated by the following reasons.

In 2023 BESSY II is in operation for 25 years and needs refurbishment, modernization, and a widening of its scientific landscape.

In 2019, the BER II (Berlin Research Reactor) was shut down for user operation on the Lise-Meitner-Campus (LMC) in the southwest of Berlin and will be dismounted in the near future. The in parts 70 years old building substance on the LMC is no longer sustainable, so HZB is focusing its research more and more on its main campus in the eastern part of Berlin, in Germany’s largest science and technology park, Berlin-Adlershof. Also, the HZB stakeholders have indicated the wish to concentrate research in Adlershof on one campus and open the old LMC for other options. This relocation will need the space for additional 400-500 employees in Adlershof.

The advent of the first 4th generation ring-based light sources, MAX IV in 2017 and Sirius & ESRF-EBS in 2020, demonstrating increased spectral brilliance by $10^2 - 10^3$ due to lower emittance, strengthened the wish for a BESSY II successor. Different from other in-tunnel upgrades, first estimates have clearly shown that the BESSY II tunnel and radiation concept is not capable to host a MBA lattice and would need a complete reconstruction, increasing dark time to an unacceptable length. Especially the contracts between Physikalisch Technische Bundesanstalt (PTB) and its industrial users do not allow for long dark times of BESSY. The PTB is Germany’s national metrology institute and it uses BESSY’s radiation since 1982 for metrological applications.

Following these arguments, and taking into account the availability of the envisaged site, the initial operation of a greenfield project is not expected earlier than 2035, so a modernization of BESSY II is mandatory and requested with the BESSY II+ project. It will pave the way towards BESSY III. The time schedule for BESSY II+/III is shown in Fig. 1.

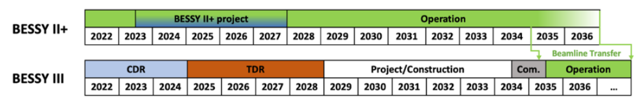

Figure 1: Time schedule for BESSY II+/III project.

BESSY III PARAMETERS

The main objectives and also largest changes compared to BESSY II, as summarized in Table 1, is the increase of energy up to 2.5 GeV and the decrease of emittance down to 100 pmrad, motivated by the science case request for diffraction-limited radiation with adjustable polarisation up to 1 keV photon energy from the 1st undulator harmonics. Although it is planned to increase the beam energy by about 50%, the natural separation between PETRA IV and BESSY III between soft and hard X-rays will remain at about 5 keV photon energy. The requests for the desired photon beam energies of both user communities are visualized in Fig. 2. The sweet spot for BESSY III is at 1 keV, and is accessible at BESSY II only with the 3rd or 5th harmonics of normal APPLE II undulators. It is not satisfying, that the first harmonic reaches only up to 0.5 keV as shown in Fig. 3. Energies above 1 keV at BESSY II are mainly used from bending sources or the two 7 T wavelength shifters, but at much lower brilliance. Only a single beamline provides undulator radiation into the tender X-ray regime by the CPMU17, a cryogenic permanent in-vacuum undulator, recently installed.

Table 1: Main parameters of BESSY II and BESSY III.

Parameter	BESSY II	BESSY III
Energy	1.7 GeV	2.5 GeV
Circumference	240 m	~ 350 m
# of straights	16 with 5.0 m	≥ 16 with 5.6 m
Emittance ε_0	5 nm rad	100 pm rad
$\beta_{x,y}$ in straights	(1.2, 1.2) m	~ (3, 3) m

With the increase of the electron beam energy up to 2.5 GeV, undulators with a standard period length of 40 mm

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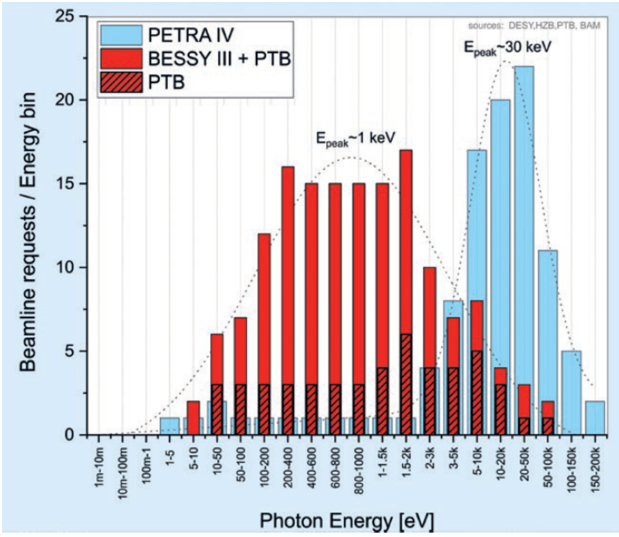

Figure 2: Spectral range requested by the user communities of PETRA IV and BESSY III.

will cover this range. It seems that beamline scientists and the user community will prefer the in-vacuum-Apple type undulator (IVUE) because the gap can be closed down to ~5 mm instead of ~12 mm for the out-of-vacuum type, enabling a wider photon energy range starting from 100 eV or even below [3]. By the reduction of the emittance by

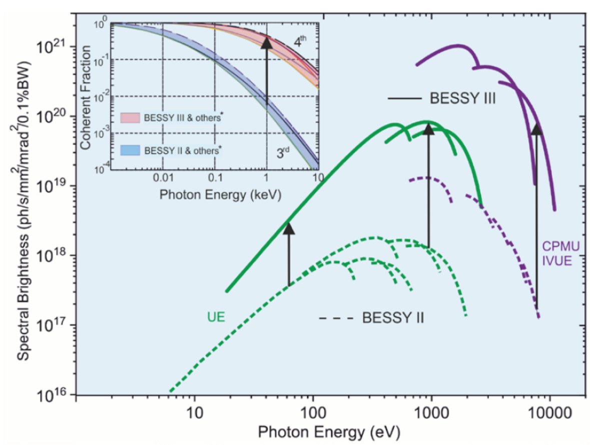

Figure 3: Spectral brilliance and coherent flux of BESSY III compared to BESSY II.

a factor of 50, the spectral brilliance will gain by 2 orders of magnitude in the soft-X-ray regime and by 3 orders of magnitude in the tender-X-ray range.

In addition to the improved radiation parameters, the user community strongly requests multi-modal experimental capabilities, starting with an outstanding and tailored sample environment, easily accessible and state-of-the-art synchrotron instrumentation combined with correlative off-line lab methods, complex onsite material synthesis, and accelerated data processing in one integrated research facility. This transition process - from a unique and highly productive analytical tool towards an integrated research facility with unique operando and in-situ capabilities for material discoveries and innovation has already started at BESSY II with projects like EMIL, BELChem, CatLab or Care-O-Sene and with HZB CoreLabs, e.g., for quantum materials and correlative microscopy and spectroscopy. This transition will be continued in the BESSY II+ project with a strong focus on operando capabilities for the energy transition.

Not only HZB's scientific infrastructure but also those of its Partners as the Max-Planck-Institutes, PTB/BAM, Leibniz institutes (MBI, FBH, IKZ) and the Berlin universities and high-tech companies, make Berlin-Adlershof the one and only place to be for BESSY III. There is still one free site left in Germany's biggest Science and Technology Park, which will limit BESSY III's circumference to 350 m. With the envisaged emittance of 100 pmrad, see Fig. 4, BESSY III will rank between current and future upgrades worldwide, staying competitive for the next decades and further scientific challenges to come.

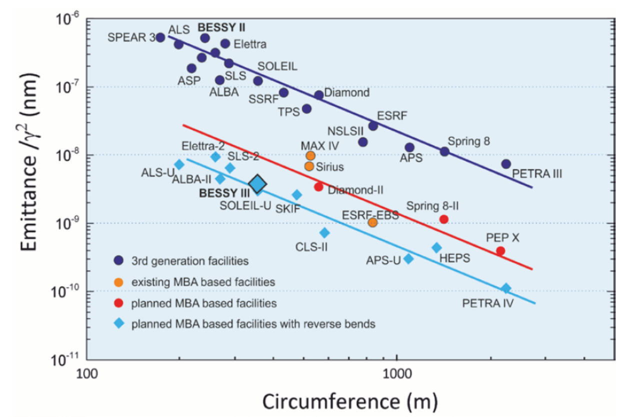

Figure 4: The BESSY facilities on the emittance-circumference landscape.

The magnetic lattice development is ongoing and will be summarised in [4] and the references within. A special feature compared to other MBA storage rings is the request from PTB for radiation sources for metrology applications. This is best realized with homogeneous bends, a boundary conditions posing the biggest impact on our storage ring design.

VIA BESSY II+ TOWARDS BESSY III

The strategic focus points of the BESSY II+ project are "operando capabilities, modernization, and sustainability". Overall it is a 100 M€ project, where nearly 25% will be covered by HZB, other 25% by strategic partners or third-party projects and 50% are requested from the funding bodies. About 50% of the BESSY II+ project scope will be invested in new beamline & endstations (25%), sample environment (12.5%), and digitalization (12.5%) to strengthen the operando capabilities of BESSY II and HZB. 35% will be used for the modernization of the accelerator complex

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(30%) and beamline instruments (5%), and 15% is foreseen to improve the sustainability of BESSY II.

Up to eight new beamlines & endstations are planned. For example, two of them are, the *Operando Photovoltaic Endstation PRESTO* [5], which will provide multimodal in-situ and operando capabilities for the BESSY II user community in photovoltaic and beyond, or the new *Enhanced Liquid Interface Spectroscopy and Analysis beamline ELISA* [6] for core-level and vibrational spectroscopy of solid-liquid and liquid-vapor interfaces, i.e., functional interfaces of, e.g., batteries and (photo-)electrochemical devices. These new instruments will set new operando capabilities for the energy transition and start to set the foundation for future BESSY III science.

The modernization scope for the accelerator complex will not only cover general preservation and modernization measures, e.g., the replacement of the uninterruptible power supply, the timing and synchronization systems, or old magnet power supplies but also includes technology development towards BESSY III.

A project already advanced is the development of an active normal conducting 1.5 GHz higher harmonic cavity (HHC) with HOM damper within a European collaboration between ALBA, DESY, and HZB. The prototype, designed and purchased by ALBA and RF tested at HZB, is installed in the BESSY II storage ring [7]. Since autumn 2022 it is tested with beam and conditioned for user operation. Based on this experience, a new HHC system will be developed for BESSY II also including the option for a 1.75 GHz cavity system to generate a beating in the bunch focusing, allowing for simultaneously storing of short and long bunches. This development will lay the foundation for the respective RF systems for the next-generation light source BESSY III.

Another important work package is the development of a BESSY II & BESSY III digital twin as a natural interface for the efficient implementation of digitalization measures [8,9]. This framework and methods are mandatory for the startup, commissioning, and efficient operation of BESSY III and are utilized already for the design process, e.g., in order to check for lattice robustness and develop simulated commissioning.

The work package *Permanent Magnets for Energy Efficiency* within the BESSY II+ is mainly motivated by BESSY III. In order to improve sustainability and to reduce the power consumption of BESSY III, it is discussed to replace the well-established classical iron yoke electromagnet technology with permanent magnets wherever possible, i.e., at dipoles and quadrupoles. Therefore conceptional designs, prototyping, and testing under real operating conditions are necessary. Within BESSY II+, it is foreseen to replace a very power-hungry bending electromagnet in the transferline between booster and storage ring with a permanent magnet solution to gain experience and know-how [10]. Since the PTB has special requirements on the bending radiation source for metrology purposes, it is also discussed to replace two main bends of one double-bend-achromat section with permanent magnets.

Further, conceptional developments which are not covered by the BESSY II+ project, mainly driven by beam dynamics, such as highly coupled or round beam operation, two-orbit operation with TRIBs, limitations due to collective effects, negative alpha operation, or the investigation of different injection concepts will not only be investigated in simulations but wherever possible, BESSY II and the MLS will be used as a testbed to pave the path for stable and best user operation of BESSY III.

POWER CONSUMPTION AND SUSTAINABILITY

One ambitious goal of the BESSY III project is to keep the power consumption reasonably small. This is challenging due to the fact that we switch from DBA to 6MBA. The other big electrical power consumption driver is the RF system. The stored current of 300 mA should stay the same, but the increase of beam energy by 47% and the 80% higher energy loss per turn will increase the RF power consumption.

On average, the whole BESSY II facility with office building needs 4 MW for user operation, 3.5 MW in the cold winter months, and 4.5 MW in the hot summer months. The storage ring itself needs ~ 900 kW, whereas 400 kW go for the RF system and 450 kW for the magnets.

Due to the increased number of magnets, the electric power consumption needed for magnets is estimated to be 730 kW if using the conventional iron yoke-based magnet technology. If the bending magnets will be replaced by permanent magnets and quadrupoles will be realized as variable permanent hybrid magnets with only additional small coils to allow for a gradient variation of 10% of the design value, the electric power consumption can be reduced by a factor of 3.5 down to 200 kW.

The power consumption of the BESSY III RF system is approximately expected to be twice larger than for BESSY II. The BESSY II RF system runs at 1.4 MV to compensate an energy loss per turn of ~300 keV (170 keV from bends and 130 keV from IDs and others), resulting in a power consumption of 400 kW. At BESSY III the energy loss per turn in a first estimation is expected to be ~700 keV, 300 keV from bends and 400 keV from IDs. So the energy loss ratio between IDs and bends is increased. We expect the BESSY III RF system to be in the range of 700 kW to 900 kW depending on the momentum acceptance of the lattice, the number of wavelength shifters installed, and the stored current.

So overall, i.e., magnets + RF system, we expect for the storage ring operation of BESSY III a power consumption of < 1.2 MW, an increase of only 33 % compared to BESSY II due to the permanent magnet development.

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