PETRA III OPERATION AND STUDIES IN 2025

J. Keil*, M. Schaumann, R. Wanzenberg
Deutsches Elektronen-Synchrotron DESY, Hamburg, Germany

Abstract

The synchrotron light source PETRA III is one of the core facilities at DESY and offers scientists outstanding opportunities for experiments with hard X-rays of very high brilliance since 2009. The 25 beamlines provide excellent and diverse experimental methods for more than 3500 users per year. The light source is operated mainly in two operation modes with 480 and 40 bunches at a beam energy of 6 GeV. A new beamline (P25) for medical imaging, powder diffraction and innovation is presently in the commissioning phase. First light from the undulator was observed on Sep 25, 2025 at the beamline. Parallel to operation with high availability, a comprehensive study program supports hardware and software developments for the forthcoming PETRA IV upgrade. This paper provides a detailed description of the operation and studies in 2025, reviews the availability and fault statistics and gives an outlook to the next runs.

INTRODUCTION

PETRA III [1] is a 6 GeV third generation synchrotron light source with a low emittance of 1.3 nm rad providing synchrotron radiation mainly in the hard to high-energy X-ray region to experiments. The machine is operated in two modes: a continuous mode with 480 bunches and 120 mA and a timing mode with 40 bunches and 100 mA. In both modes the machine is using top-up with 1 % current variation.

Since the start of user operation in mid-2010, the number of operational beamlines has increased constantly. Initially, only one octant of PETRA was modified to accommodate 14 undulator beamlines (Max von Laue Hall). In a long shutdown 2014 two additional experimental halls in the North (PXN) and East (PXE) were built and the lattice was modified in these sections to allow 10 more beamlines [2].

BEAMLINE ACTIVITIES

In the PETRA extension hall east (PXE) the last beamline P25 has started the commissioning in November 2025. First light from the undulator was seen on screens during the commissioning of the undulator on September 25, 2025. This beamline is designed and funded in a collaboration between PETRA III Photon Science and the DESY Innovation & Technology Transfer (ITT) group. It aims at academic research and industrial applications for applied bio-medical imaging, powder diffraction and innovation.

The optimization of the beam position was done in consent with the beamline P24, who shares the same canted straight section. Finally, on November 26, 2025 the beamline P25 passed the radiation safety check for standard beam operation. One more slot is reserved for beamline P63 in the PETRA extension hall North (PXN) hall. This beamline is still in preparation and anticipated to be commissioned in summer 2026.

* joachim.keil@desy.de

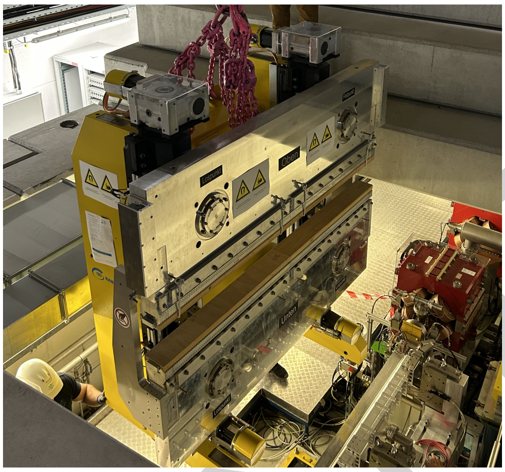

Figure 1: Exchange of radiation damaged undulator PU02, located in the Max von Laue Hall in October 2025.

For a long time, it has been observed that some undulators are affected by radiation damage of the permanent magnets [3, 4]. For the beamline P02 the beam quality had degraded so much, that it was necessary to replace the full undulator. In the October service week the old undulator was removed and the new one craned into its position in less than 3 hours including the opening and closing of the tunnel roof in the Max von Laue Hall (Fig. 1). The beamline observes a gain of a factor two in flux and an improved beam focus, again enabling the desired high-quality experimental conditions.

OPERATIONAL STATISTICS

Availability and MTBF

Regular user operation was scheduled between March 4 and December 12, 2025 with 4656 hours of beam time. Those were delivered with an availability of 98.4 % (see Fig. 2). In total only 63 faults with an average duration of 1.1 hours occurred during the user run, leading to a Mean Time Between Failure (MTBF) of 71 hours. The delivered 4584 hours of user run time were supplemented with 1117 hours of test run time (Fig. 3). About 54 % of the user time was allocated to the 480-bunch mode and 46 % to the 40-bunch mode. For 42 user run days the alternative so-called low beta optics was operational.

The long-term development of the MTBF shown in Fig. 4 illustrates that 2025 was the second-best operational year of PETRA III. Only in 2020 the MTBF and also the avail-

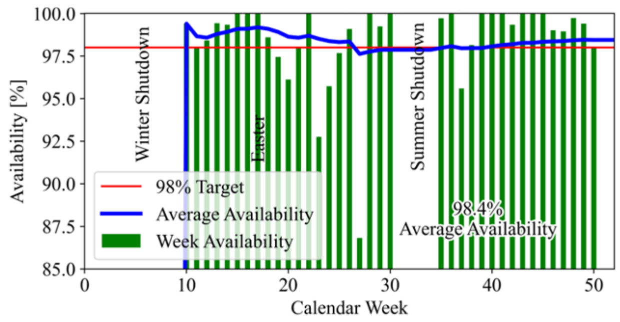

Figure 2: PETRA III weekly availability in 2025.

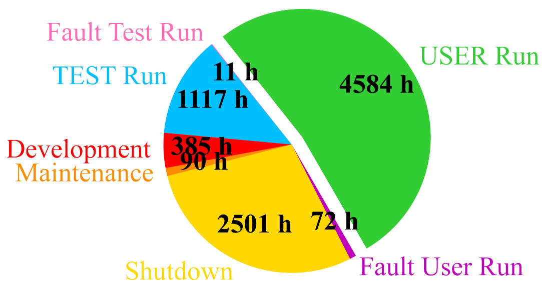

Figure 3: Time distribution of machine states in 2025.

ability had been better. This is a great success, especially considering the aging infrastructure.

Major Faults in 2025

The most serious faults were caused by the cooling water system. First, a series of broken water hoses caused three water leaks within 4 weeks. In all cases equivalent hoses at different sextupoles in the copper-water circuit showed point-like holes, while the inner surface was covered with copper rust and cracked defects. Because of the recurring fault pattern, all hoses of this type and location were exchanged in the summer shutdown. A series of samples from other locations were collected, no issues were found.

Second, a broken water filter distributed small raisin particles over the full copper-water circuit around the accelerator ring. These particles plugged the 529 dirt traps in front of the magnet coils and power supplies that are connected to the same water circuit. A cleaning of all dirt traps was necessary before operation could be resumed. As a consequence, dirt traps have been installed directly on the in- and outlet of all filters of this type in the PETRA complex.

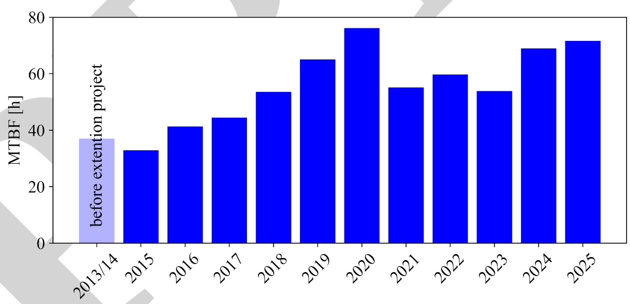

Figure 4: Long-time development of the MTBF.

MODELLING OF DAMPING WIGGLER ABSORBER INCIDENTS

Failure of the Final Absorbers

In PETRA III 20 damping wigglers (DWs) [5] are installed in the straight sections North and West to reduce the emittance to 1.3 nm rad. Each DW emits a power of 26 kW at a beam current of 120 mA. Besides 11 water-cooled copper absorbers to shield the vacuum chambers from synchrotron radiation (SR), each straight has a final absorber which accepts the on-axis radiation of 78 kW [6]. In the North some of the on-axis SR is used by the wiggler-beamline P61.

In May 2024 the final absorber A12 in West developed a vacuum leak after a manual beam dump with full current. One month later, the final absorber in North also failed with a similar damage. Inspection of the failed absorbers revealed that an uncooled stainless steel flange was leaky, but also that copper had melted at the top side of the inner absorber surface due to overheating. As a possible reason discrepancies of the inner dimensions between the manufactured absorbers and the drawings were found. Additionally, the SR fans seemed to be not at their design positions, which is analysed in the following chapter. A vertical orbit interlock is active for beam currents above 35 mA, limiting orbit excursions to 1.5 mm with respect to the golden orbit in the wiggler sections.

Modelling of Beam Trajectory

For better understanding of the failures, the beam trajectory in the wiggler sections was modelled with the Accelerator Toolbox (AT) [7]. The model uses the misalignments of the quadrupole magnets and damping wigglers in that section, which were measured in January 2024 (straight West) and later in January 2025 (straight North). The kicks of the fast and slow corrector magnets, as well as the measured field integrals of the wigglers were also taken into account.

For the trajectory model, the initial conditions of the beam upstream of the first DW were varied, and the differences from the measured beam positions were minimized with a least-squares fit. In addition, misalignments of two quadrupoles that were not measured during the survey were fitted, too. In the West, the trajectory model (blue line) can predict the measured orbit (blue circles) with an accuracy of 300 µm, as shown in Fig. 5. The beam essentially passes through the centers of the quadrupoles (red stars) after orbit correction.

From the beam trajectory the direction of the SR fans of the DWs can be computed (Fig. 6). In the straight West the SR fans of wiggler 9 and 10 were pointing upwards and hit the upper side of the final absorber A12 at the leak position at 92 m. In addition, the SR fans of wiggler 3 and 4 were pointing downwards and were hitting absorber A7 at 53 m.

The frequency integrated power density of the SR fans on a plane perpendicular to the beam axis at the location of the final absorber A12 was calculated based on the trajectory data, see Fig. 7. The contours of the inner absorber surfaces are shown as lines with the affected segment in red. The last

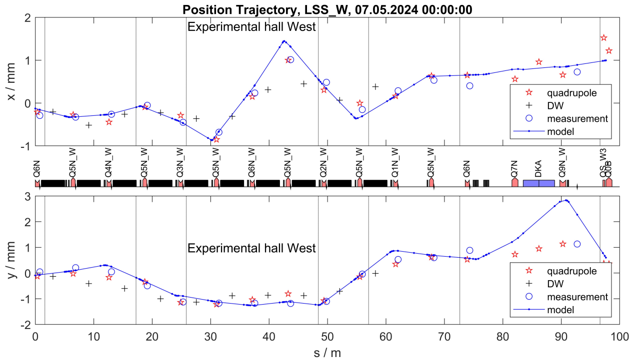

Figure 5: Model of the electron trajectory in the straight section West at the time of the failure of the absorber.

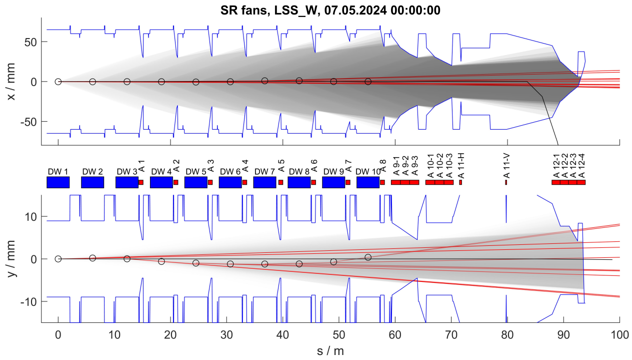

Figure 6: SR fans (red lines) of the wigglers in the straight section West in the horizontal (top) and vertical plane (bottom) with wigglers (blue boxes) and absorber (red boxes). Blue lines are the apertures of chambers and absorbers.

two damping wigglers produce at the location of the final absorber a second spot with a vertical offset, with a large power density near the location where the leak occurred.

It is likely that the reason for the vertical movement of 1.5 mm in the area of the DWs is a long-term drift over the last 10 years of a former experimental hall which is located at 26 m–48 m in Fig. 5. A slow rise of the temperature of the lower side of absorber A7 is also observed and is in agreement with the simulation. It also has a seasonal variation which can be related to temperature effects.

In the straight section North the differences between the model of the trajectory and the measured beam positions were larger. However, a systematic horizontal and vertical movement of elements of up to 1 mm have also been observed in comparison with previous measured survey data.

ORBIT BUMP STUDIES

Local orbit bumps in the wiggler section can be used to change the vertical angle of the SR fans. This helps to reduce large temperature differences between the top and bottom side at the critical absorbers. After a study of the impact on absorber temperatures, a vertical bump was permanently added to the golden orbit of the straight West near wigglers 3 and 4. This bump was able to reduce the temperature at the lower side of absorber A7 substantially.

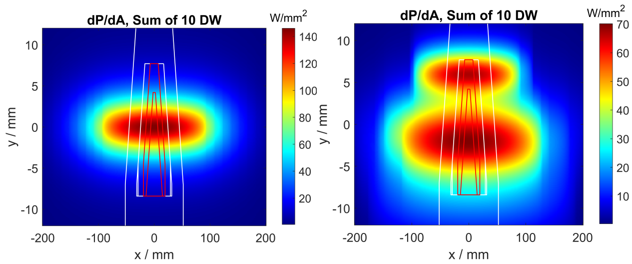

Figure 7: SR power distribution at the final absorber in West without (left) and with quadrupole misalignments (right).

A study together with the wiggler-beamline P61 in the North showed that only the light from the last five (out of ten) damping wigglers reaches the beamline. Aligning all wiggler source points on a straight line with vertical orbit bumps turned out to be impossible. The reason is that the arrangement of the corrector magnets does not allow for steering the SR fans of each wiggler individually. Therefore, it is planned in the next PETRA III shutdown in 2026 to realign both damping wiggler sections.

LPA INJECTION TESTS

Extensive studies at the PETRA III injector complex had been undertaken in 2025 to prepare for a direct injection of electrons at 300 MeV from the laser-plasma accelerator (LPA) LUX [8] into the booster synchrotron DESY II. The results of these studies are currently being prepared for future publication.

For PETRA IV's upgrade [9] a direct injection of a 6 GeV beam from a laser-plasma accelerator is being considered [10]. As the LPA delivers only a small charge compared to the charge provided by a LINAC with a booster synchrotron, studies on the diagnostics resolution, especially for the BPM electronics with low charge injection are ongoing at PETRA III.

OUTLOOK ON FUTURE ACTIVITIES

From September 2026 the PETRA III complex will enter into an approximately six month-long shutdown period. The shutdown length is defined by the interlock renovation of LINAC II, DESY II and the PETRA III RF. Furthermore, the accumulator ring PIA will undergo a significant refurbishment. As a consequence of the absorber faults from 2024 and due to the inability to have all DW source points on a straight line for the wiggler-beamline P61 in the North, it is planned to realign both straight sections North and West during this shutdown. Moreover, in preparation for the PETRA IV construction activities, the magnet cables currently running through the so-called PR-Weg (the old transfer line between PETRA II and HERA) will be re-routed.

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