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Surface and bulk investigations at the high intensity positron beam facility NEPOMUC

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ABSTRACT

The NEutron-induced POsitron source MUniCh (NEPOMUC) at the research reactor FRM II delivers a low-energy positron beam (E = 15–1000 eV) of high intensity in the range between 4×10^7 and 5×10^8 moderated positrons per second. At present four experimental facilities are in operation at NEPOMUC: a coincident Doppler-broadening spectrometer (CDBS) for defect spectroscopy and investigations of the chemical vicinity of defects, a positron annihilation-induced Auger-electron spectrometer (PAES) for surface studies and an apparatus for the production of the negatively charged positronium ion Ps^-. Recently, the pulsed low-energy positron system (PLEPS) has been connected to the NEPOMUC beam line, and first positron lifetime spectra were recorded within short measurement times. A positron remoderation unit which is operated with a tungsten single crystal in back reflection geometry has been implemented in order to improve the beam brilliance. An overview of NEPOMUC's status, experimental results and recent developments at the running spectrometers are presented.

1. Introduction

The in-pile positron source NEutron-induced POsitron source MUniCh (NEPOMUC) generates positrons by pair production from absorption of high-energy prompt γ-radiation in platinum after thermal neutron capture in cadmium [1]. In the summer of 2004, NEPOMUC first delivered positrons with an intensity of several 10^8 moderated positrons per second at a beam energy of 1 keV.

NEPOMUC is located at the research reactor *Heinz Maier–Leibnitz* FRM II of the Technical University Munich (TUM). The FRM II is routinely operated with a nominal power of 20 MW for 260 days a year corresponding to five reactor cycles of 52 days each. This research reactor serves as a user-dedicated facility for scientific experiments and industrial applications. Hence, the positron beam facility (open beam-port) and the positron instruments are open to external user experiments as well. Besides time for instrument development, beam adjustment and maintenance of the positron beam facility it is planned to allocate up to 2/3 of the available beam time for external users. For this reason, members of the international scientific community and industry are kindly invited to propose experiments, which can be performed at NEPOMUC. FRM II provides easy access for new users via the Internet at the user-portal https://user.frm2.tum.de, where one can subscribe as an external scientist in order to propose an experiment and request beam-time. Similar to other leading large-scale facilities a peer-review procedure is established where twice a year a committee of external experts evaluates the submitted proposals.

Up to now, great efforts have been made to connect several spectrometers to the NEPOMUC beam line. The first two running experimental facilities were the positron annihilation-induced Auger-electron spectrometer (PAES) and the coincident Doppler-broadening spectrometer (CDBS) which were both developed at the TUM. In addition, an open multipurpose beam-port allows the installation of additional experimental setups for positron investigations with high beam intensity. At this position, an experimental setup for the production of the negatively charged positronium ion Ps^- has been connected to the beam line. It has

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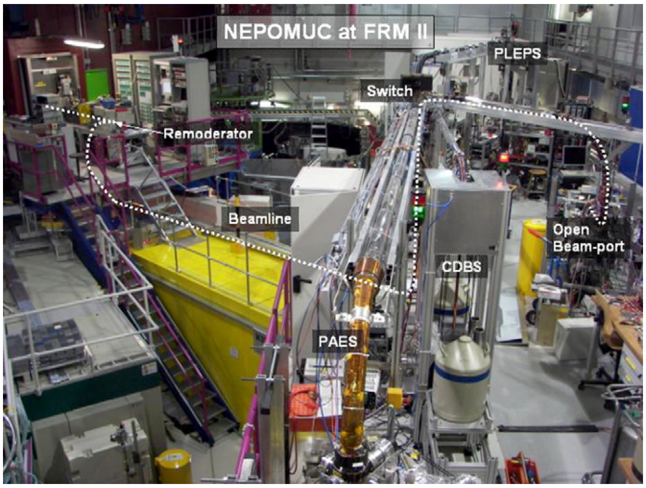

Fig. 1. NEPOMUC at FRM II: the beamtube with the in-pile positron source is located behind the biological shield of the reactor (dark wall on the left). Instruments: PAES—positron annihilation induced Auger electron spectrometer, CDBS—coincident Doppler broadening spectrometer, and PLEPS—pulsed low-energy positron system. The positron beam guidance via the remoderator and the beam switch to the open beam-port is visualized by the dotted line.

been developed and operated at the Max-Planck institute for nuclear physics in Heidelberg [2,3]. These experiments have been performed with the primary positron beam with variable beam energy between 15 eV and 1 keV. A novel remoderation device has been installed at NEPOMUC through the collaboration of UniBW and TUM in order to increase the brilliance of the primary positron beam. The pulsed low-energy positron system (PLEPS), which was previously running with a ^{22}Na-based beam at the UniBW, was transferred to the FRM II. Recently, first positron lifetime spectra was recorded within the last reactor cycle.

The current status of NEPOMUC with the connected instruments is shown in Figs. 1 and 2. In Fig. 1 the positron beam guidance to the open beam-port is illustrated as a dotted line for

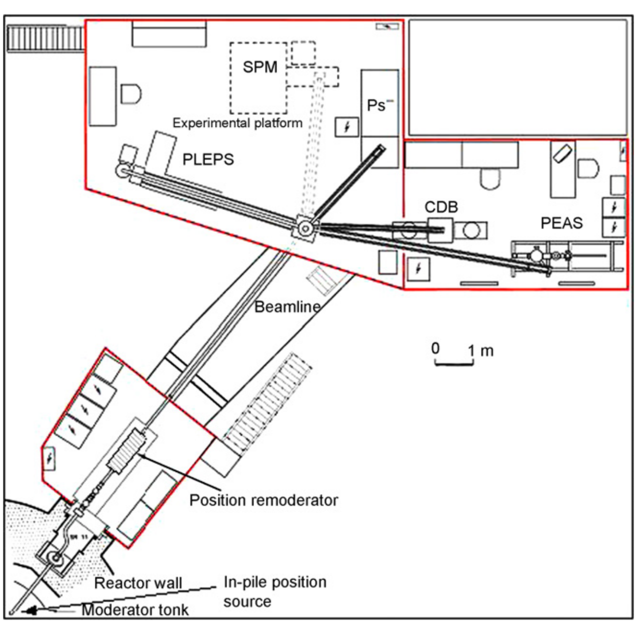

Fig. 2. North-east corner of the experimental hall: the positron beam is magnetically guided to the experimental platform, where the instruments are connected via a magnetic beam switch. The apparatus for Ps^--production and the position designed for the yet to be installed scanning positron microscope (SPM) is depicted as well. For other instruments see Fig. 1.

visibility reasons. The whole positron beam facility and instruments located in the north-east corner of the experimental hall are shown in the topview (Fig. 2).

Within this publication the performance and the improvement of the positron beam is presented. An overview of the current status of the spectrometers and the experiments is given. Future developments of the positron instrumentation are outlined as well.

2. Performance of the positron beam

2.1. The primary positron beam

The positron source of NEPOMUC is mounted as an in-pile component close to the reactor core inside the moderator tank of the reactor. A cadmium cap inside the tip of the beam tube absorbs thermal neutrons and hence acts as a bright γ-source. A structure of platinum foils is used for the conversion of the high-energy γ-radiation into positron–electron pairs and for positron moderation. The platinum structure is floated on positive potential in order to adjust the kinetic energy of the moderated positrons in the range between 15 eV and 1 keV. At higher extraction potentials, the source is unstable due to the limiting properties of the insulating materials in the high radiation field. Electrical lenses are used to extract the positron beam which is then magnetically guided in a solenoid field of typical magnitude 6 mT. Details of the principle and the design of the in-pile source can be found in Ref. [1].

After degradation of the platinum moderator of the source, the emission of moderated positrons can be improved by exposing the platinum surface to a small amount of oxygen during reactor operation. Due to the radiolysis in the high γ-radiation field, nascent oxygen removes possible carbon contamination of the platinum surface and leads to a higher moderation effciency [4].

The vacuum in the beam line is realized by using turbomolecular and iongetter pumps that lead to a basic pressure of typically 5×10^{-8} mbar. At several experiments such as CDBS and PAES, a purely electrostatic beam guidance is required. For this purpose, magnetic field terminators of mu-metal are mounted at the entrances of those devices in order to release the low-energy positron beam non-adiabatically from the magnetic guiding field. Another one is used at the remoderator section.

The positron beam parameters such as intensity, beam diameter, and energy distribution have been experimentally determined. At a beam energy of 1 keV a maximum intensity of up to 5×10^8 moderated positrons per second was achieved. The maximum positron intensity for a low-energy positron beam of 15 eV amounted to 4×10^7 moderated positrons per second. The diameter of the 1 keV-beam was found to be about 7 mm (FWHM) in a longitudinal magnetic guiding field of 6 mT [5]. At a kinetic energy of 15 eV the maximum diameter of the elliptically shaped beam is less than 20 mm [4]. The energy distribution, i.e., the longitudinal component of the positrons kinetic energy, was measured with a deceleration device inside the magnetic guiding field at 1 keV and at 15 eV and amounts to $\Delta E_{FW\ HM} = 60$ eV and $\Delta E_{FW\ HM} = 5$ eV, respectively.

Recently, a novel remoderation device was implemented at NEPOMUC in order to enhance the beam brilliance [6].

2.2. Positron remoderation

A positron beam with small phase space volume comparable to that of a tungsten moderated lab-beam with a small beam diameter is required for the pulsing devices used for example in the PLEPS-apparatus or the scanning positron microscope SPM. For this reason, a positron remoderation device has been installed in