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# First positron experiments at NEPOMUC

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## Abstract

The in-pile positron source NEutron induced POsitron source MUniCh (NEPOMUC) of the new Munich research reactor FRM-II is now operated at the nominal reactor power of 20 MW. Recently, intensity and positron beam profile measurements were performed at 30 eV and 1 keV, respectively. For this purpose, NaI-scintillators detect the 511 keV $\gamma$-radiation of positrons that annihilate at a removable target in the beam line. The beam profile is determined with a micro-channel plate detector and a CCD-camera. In the present arrangement of NEPOMUC's instrumentation the positron beam is connected to a coincident Doppler broadening (CDB) facility and to a positron induced Auger electron spectroscopy (PAES) analysis chamber. First experiments were carried out in order to show the performance of these new spectrometers. An overview of the positron beam facility is given and first experimental results of PAES are presented.

*Keywords:* NEPOMUC; Positron beam; High intensity; PAES; CDB

## 1. Introduction

Intense positron beams of low energy are of major interest in solid state and surface physics, in material science as well as in atomic physics. For most experiments, such as positron lifetime or Doppler broadening measurements, a high intensity of mono-energetic positrons is desirable in order to reduce the time of measurement or improve statistics. Moreover, there are a variety of examples of experiments, where sophisticated techniques may be applied, if strong positron beams are available: in coincident Doppler broadening measurements both annihilation quanta are detected in coincidence, in order to reduce the background efficiently and to enhance the energy resolution [1]. Multiple remoderation for brightness enhancement and hence improved lateral resolution will become feasible [2], e.g. for positron lifetime measurements. Positron annihilation induced Auger electron spectroscopy will tap its full potential, when intense positron beams are available [3]. A further example is the production of exotic leptonic bound states, such as the negatively charged positronium ion $Ps^-$ [4].

Conventional laboratory beam facilities based on a $\beta^+$ active isotope and a positron moderator are limited in intensity due to self-absorption of positrons in the

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source material. The yield of moderated positrons usually ranges between $10^4$ and $10^6$ positrons per second. Therefore, great efforts have been made to generate positrons by pair production using bright γ-sources. For this reason bremsstrahlung in a target at electron linear accelerators [5,6] or γ-radiation from nuclear fission [7,8] is used to produce positron–electron pairs by absorption of high-energy γ-radiation. Another approach is to benefit from the high-energy prompt γ-rays after thermal neutron capture [9].

## 2. NEPOMUC: the positron beam facility and its instrumentation

### 2.1. Positron production

At NEPOMUC positrons are generated by pair production from absorption of high-energy prompt γ-rays after thermal neutron capture in cadmium [10]. For this purpose, a cadmium cap is placed inside the tip of the inclined beam tube SR11 in the heavy water moderator tank. A structure of platinum foils is mounted inside the cadmium cap in order to convert high-energy γ-radiation into positron–electron pairs. This platinum structure is composed of three zigzag shaped ring sections with a diameter of 65 mm and a honeycomb-like structure which is mounted on a front plate. Due to the negative positron work function, moderation in annealed platinum leads to emission of monoenergetic positrons [11,12]. Positive high voltage is applied at the platinum foils in order to vary the kinetic energy of the positrons between a few eV and 1 keV. After extraction by electrical lenses the positron beam is magnetically guided in a solenoid field of typically 6 mT. The moderated positron beam passes three bents in the biological shield in order to eliminate background of fast neutrons as well as γ-radiation from the reactor core and the cadmium cap which acts as bright γ-source in the tip of the beam tube.

Details of the positron source design as well as results of heat input, neutron and γ-flux obtained by Monte Carlo calculations are presented elsewhere (e.g. in Ref. [13]). Besides theoretical considerations experimental experience was gained with a first positron source set-up. For this purpose, a prototype of the in-pile positron source was installed on a movable support at an external neutron guide of the high flux reactor at the ILL in Grenoble. Thus, different source geometries could be compared experimentally in order to optimize the source design [14].

### 2.2. Positron beam facility

Subsequent to a first vacuum pumping unit the beam line leads from the biological shield of the reactor pool to the experimental platform which is located in the north-east corner of the experimental hall of FRM-II. An overview of NEPOMUC and the positron instruments connected to the positron beam facility is given in Fig. 1.

The vacuum system of the positron beam line consists of stainless steel vacuum tubes, computer controlled valves and vacuum gauges as well as several pumping units. Magnetic field coils are mounted directly on the stainless steel tubes for the beam guidance. Transversal field components should be compensated in order to adjust the positron beam and to minimize transport loss. Therefore, straight sections of the beam line are μ-metal shielded, and correction coils are mounted at the curved parts of the beam line where the inhomogeneous guide field at the curvature would lead to a drift motion.

### 2.3. Positron experiments

At present, the positron beam is connected via a magnetic beam switch to a coincident Doppler broadening spectrometer (CDB) and an analysis chamber for positron induced Auger electron spectroscopy (PAES). The PAES facility and recent results are discussed in detail in a separate section (see below). Planned instruments and future projects are depicted by dashed lines in Fig. 1.

#### 2.3.1. CDB coincident Doppler broadening

The Doppler broadening measurement of the annihilation radiation is widely used for defect studies. More detailed information about the annihilation sites in the sample is obtained by analysis of the high electron momenta of core electrons that reveals chemical information of the annihilation site [1]. For this reason, the CDB technique is used in which both annihilation photons are detected in coincidence by