

Positron Beam Characteristics at NEPOMUC Upgrade

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Abstract. In 2012, the new neutron induced positron source NEPOMUC *upgrade* was put into operation at FRMII. Major changes have been made to the source which consists of a neutron- γ -converter out of Cd and a Pt foil structure for electron positron pair production and positron moderation. The new design leads to an improvement of both intensity and brightness of the mono-energetic positron beam. In addition, the application of highly enriched ^{113}Cd as neutron- γ -converter extends the lifetime of the positron source to 25 years. A new switching and remoderation device has been installed in order to allow toggling from the high-intensity primary beam to a brightness enhanced remoderated positron beam. At present, an intensity of more than 10^9 moderated positrons per second is achieved at NEPOMUC *upgrade*. The main characteristics are presented which comprise positron yield and beam profile of both the primary and the remoderated positron beam.

1. Introduction

The principle of the reactor based positron source NEPOMUC at FRMII is based on the emission of high-energy prompt γ -rays after thermal neutron capture in ^{113}Cd . The released high-energy γ -radiation can convert into positron-electron pairs in a structure of Pt foils that also leads to the emission of mono-energetic positrons (see e.g. [1]). After 1250 days of reactor operation at the nominal power of 20 MW the lifetime of the beam tube was reached due to the burn-up of ^{113}Cd . Therefore, the inclined beam tube SR11 was replaced by an upgraded version of NEPOMUC using Cd enriched with 80% ^{113}Cd which leads to an extension of the operation time to 25 years. In addition, a new design of the positron beam extraction was developed in order to increase both intensity and brightness of the primary positron beam. The new geometry at NEPOMUC *upgrade* with electric lenses and magnetic field coils including calculations of positron trajectories are presented in detail elsewhere [2, 3].

Due to major construction work in the experimental hall in 2010 and 2011 the positron beam line and several spectrometers had to be reinstalled. Subsequently, the beam line was reconstructed and a new beam switching and remoderation unit (see e.g. [4]) was installed in order to allow quick toggling between the primary high-intensity and the high-brightness remoderated positron beam [2]. In 2012, NEPOMUC *upgrade* started operation successfully.



Technical details like the simulation of temperature field in the tip of the beamtube and the measured temperature increase as function of reactor power are presented in [3]. Until now, the spectrometers PLEPS, CDBS, PAES, and the open beam port have been connected to the positron beam line.

In this work, the new beam monitor at NEPOMUC *upgrade* is elucidated that allows the determination of both intensity and shape of the primary positron beam. The measured beam characteristics of both the primary and the remoderated positron beam generated by a W(100) crystal in back reflection geometry are presented.

2. Experimental: Positron beam monitor and annihilation target

The positron beam parameters like shape and intensity can be determined at the first accessible place outside the reactor shielding. For this purpose, a beam monitor and an Al target, which are mounted on an UHV-manipulator, can be moved onto the axis of the beam line (see Figure 1). The beam monitor consists of a micro-channel plate (MCP) detector with a phosphorus screen and 45° mirror. The image on the mirror is recorded by a CCD-camera through an UHV-window.

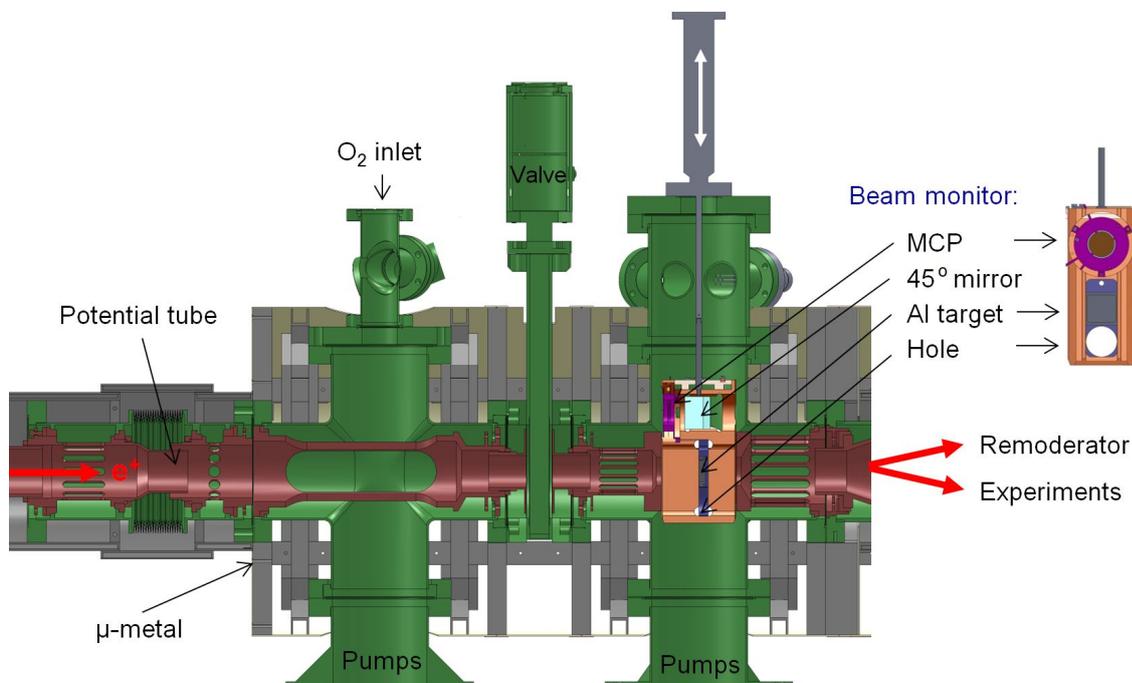


Figure 1. Characterization of the primary positron beam: Movable beam monitor (MCP detector with phosphorus screen and 45° mirror) and Al target for intensity measurements.

By moving the Al target into the beam the non-reflected positrons annihilate in the target leading to the emission of 511 keV annihilation radiation. Hence, the detection of annihilation quanta enables the determination of the positron beam intensity. For this, the γ -spectrum is recorded with a NaI(Tl)-scintillator (3" \times 3") placed perpendicular to the beam axis at a distance of 1.05 m. The Al target is slightly tilted with respect to the field of view of the detector in order to minimize selfabsorption of annihilation quanta in the target. The detector is collimated by 10 cm thick Pb bricks with a holesize of 25 mm. A Pb plate of 10 mm and an additional Cu plate of 10 mm (for absorption of characteristic x-rays from Pb) were put between the target and the detector in order to reduce the dead-time of the detector.

Without beam, a ^{22}Na -calibration source encapsulated in Al can be mounted at the target position in order to record an annihilation spectrum with known intensity with the same

experimental constraints. Hence, systematic errors such as γ -attenuation in the stainless steel wall of the beamline or Compton scattering in the lead shielding could be minimized.

3. Measurements and results

The parameters of the primary positron beam at NEPOMUC *upgrade* were first measured at a kinetic energy of 540 eV in a longitudinal magnetic guide field of 5 mT. The shape of the beam was recorded with the MCP-detector and a CCD-camera. The resulting diameter of the primary beam amounts to $d_{\text{FWHM}}^+ = 9.3 \text{ mm}$ (see figure 2).

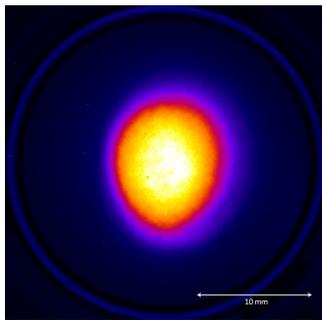


Figure 2. Beam shape at $E_{\text{kin}}=540 \text{ eV}$ in a longitudinal magnetic field of $B_{\parallel}=5 \text{ mT}$ with a diameter of $d_{\text{FWHM}}^+ = 9.3(1.0) \text{ mm}$.

For the determination of the beam intensity, i.e. positron yield Y_{mod}^+ the annihilation radiation at the Al target was detected and compared with a ^{22}Na calibration source.

$$Y_{\text{mod}}^+ = \left(\frac{I_{pp}^{\text{beam}}}{I_{pp}^{\text{cal}}} \cdot A \cdot 0.9 \right) \cdot (1 - r)^{-1} \cdot (1 + F_{3\gamma}) \cdot (1 + F_{\text{Pileup}}) \quad (1)$$

The number of 2γ annihilation events is calculated from the background-subtracted areas of the photopeaks for the beam I_{pp}^{beam} and for the calibration source I_{pp}^{cal} . The positron yield of the ^{22}Na source is given by the branching ratio for positron emission of 0.9 times its activity $A = 2.22 \cdot 10^5 \text{ Bq}$. The second term in equation 1 accounts for the fraction of back-scattered positrons which amounts to $r \approx 12\%$ for 540 eV positrons impinging on Al [5].

Ortho-positronium (o-Ps) emitted from the surface leads to a considerable contribution of 3γ annihilation events that is observed by a strongly asymmetric annihilation photopeak and higher event rate at γ -energies below 511 keV. Detailed analysis of the spectrum leads to the result that about $F_{3\gamma}=0.466(7)$ of the intensity of the 511 keV photopeak corresponds to γ 's of the 3γ -decay of o-Ps. Despite the application of Pb and Cu absorbers in front of the detector pile-up events are still observed. The last term in equation 1 takes into account that annihilation events are recorded as pile-ups with a fraction of $F_{\text{Pileup}}=0.076(3)$ of the 511 keV photopeak.

Later the primary beam energy was set to $E_{\text{kin}}=1 \text{ keV}$ in order to increase the remoderation efficiency at the W(100) remoderator. Shape and yield of the primary beam are not expected to change significantly by increasing its kinetic energy. The measured values of the positron yield Y_{mod}^+ and the beam diameters d^+ for both the primary and the remoderated positron beam are summarized in Table 1.

4. Summary and outlook

After the successful replacement of the beamtube, NEPOMUC *upgrade* enables the continuation of a large variety of studies using the high-intensity positron beam as well as the development of new experiments. These experiments range from high-sensitive and elemental selective

	Positron beam	
	primary	remoderated
E_{kin} [eV]	540 (1000)	20
B_{\parallel} [mT]	5.0	4.0
Y_{mod}^+ [s^{-1}]	$1.14(7) \cdot 10^9$	$3.0(3) \cdot 10^7$
d_{FWHM}^+ [mm]	9.3(1.0)	1.85(35)
d_{FWTM}^+ [mm]	15.4(1.3)	4.8(7)

Table 1. Measured beam parameters at NEPOMUC *upgrade* for the primary moderated and the remoderated positron beam at the kinetic energy E_{kin} in the longitudinal magnetic guide field B_{\parallel} . Y_{mod}^+ is the yield of (re)moderated positrons and d^+ the beam diameter at full width of half (tenth) maximum (index FWHM and FWTM respectively; errors in parentheses). Recently, the primary beam energy was set to $E_{\text{kin}}=1$ keV.

investigations in surface physics over defect spectroscopy in thin films and solids to fundamental studies in atomic and plasma physics. At NEPOMUC *upgrade* the intensity of the mono-energetic positron beam was determined to $1.14(7) \cdot 10^9$ moderated positrons per second. Presently, the remoderated positron beam is used for most positron beam applications. In the upcoming beamtime it is planned to further improve the brightness and the intensity of the beam by implementing a automatic down-hill simplex procedure for adjusting the high number of magnetic field coils and electrostatic lenses.

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