Max-Planck-Institut für Plasmaphysik

# A buffer-gas trap for the NEPOMUC high-intensity low-energy positron beam

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APEX collaboration

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## Motivation

Pair plasmas are comprised of positive and negative charges of equal mass. The mass symmetry is predicted to eliminate many of the destabilizing effects that are common to ion-electron plasmas [1], although this has not yet been experimentally verified. Advances in the production and storage of antimatter [2] have recently made investigations of low-energy neutral pair plasmas feasible.

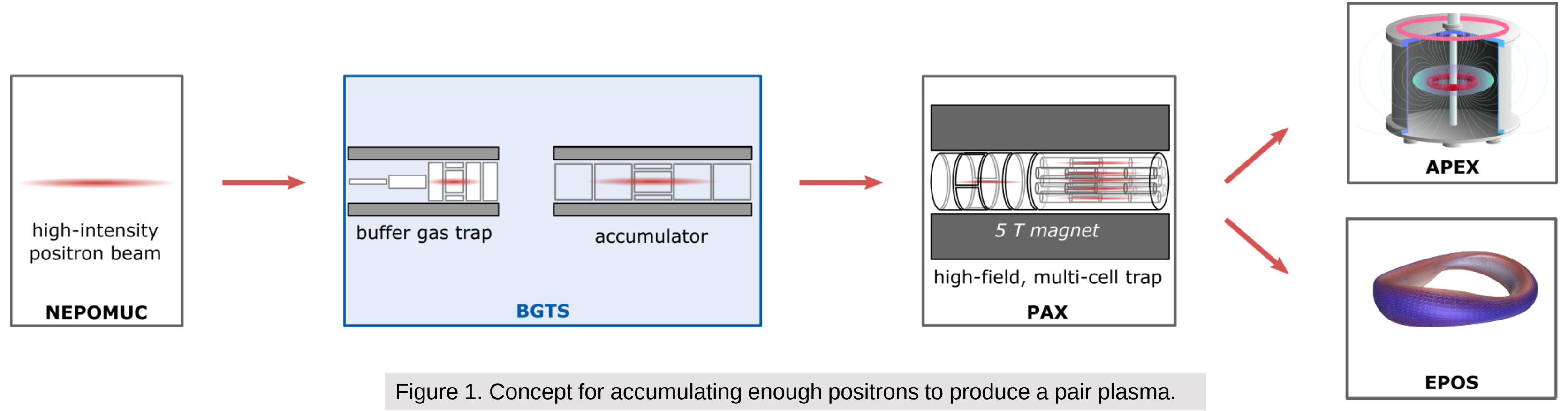

Figure 1. Concept for accumulating enough positrons to produce a pair plasma.

The goal of the APEX collaboration is to produce an electron-positron plasma and to confine it within the magnetic field of a levitated dipole [3]. More than $10^{10}$ positrons are needed to create a short-Debye-length pair plasma with a volume of 10 litres and a temperature of ~1 eV. A short and intense pulse of positrons (~1 mA) will be obtained by coupling a buffer-gas trap (BGT), an accumulator, and a multi-cell trap (PAX) to the NEPOMUC positron beam.

## NEPOMUC positron source

The NEPOMUC is the world's highest intensity source of low-energy positrons [4]. Thermal neutrons generated by the FRM-II research reactor impinge on a cadmium target to produce gamma-radiation, which subsequently instigates pair-production of electrons and positrons in a structure of platinum foils. The foils moderate the positrons, which are extracted as a near mono-energetic 1 keV beam of up to $10^9$ $e+$/s. Brightness-enhancement is achieved by focusing the positrons on to a tungsten re-moderator, from which a 20 eV, 3-mm beam is reflected [5].

Table 1. Typical parameters for the NEPOMUC primary and remoderated beams in 5 mT.

| | flux (/s) | $E_{/\!/}$ (eV) | $\Delta E_{/\!/}$ (eV) | $\Delta E_{\perp}$ (eV) | FWHM (mm) |
|---|---|---|---|---|---|
| primary beam | $5\times10^8$ | 1000 | 10 | 4 | 14 |
| W remoderated | $5\times10^7$ | 20 | 3 | 1.3 | 2.6 |
| SiC remoderated† | $3\times10^8$ | 20 | 1 | 0.5 | - |

† predicted values

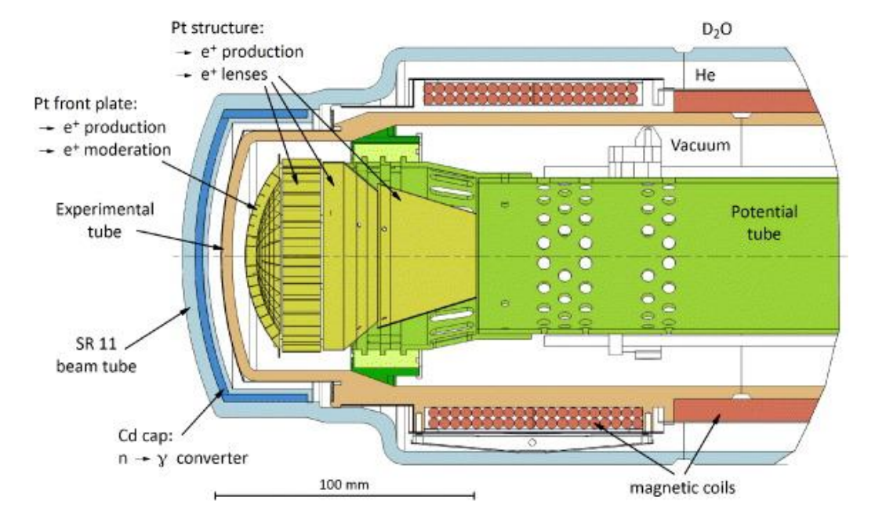

Figure 2. Cross-section of the NEPOMUC in-pile positron source.

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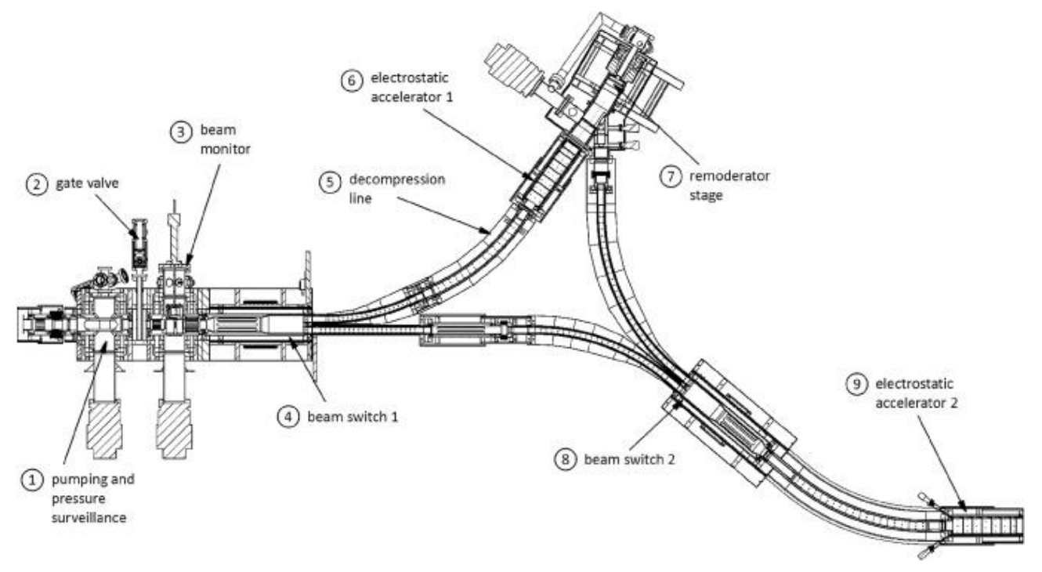

Figure 3. Setup for switching between the high-intensity and brightness-enhanced NEPOMUC beams.

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## Buffer-gas positron trap

Low-energy positrons will be magnetically guided from the NEPOMUC source into a buffer-gas trap (BGT) [6]—a type of Penning trap, which uses a combination of electric and magnetic fields to confine the charged particles.

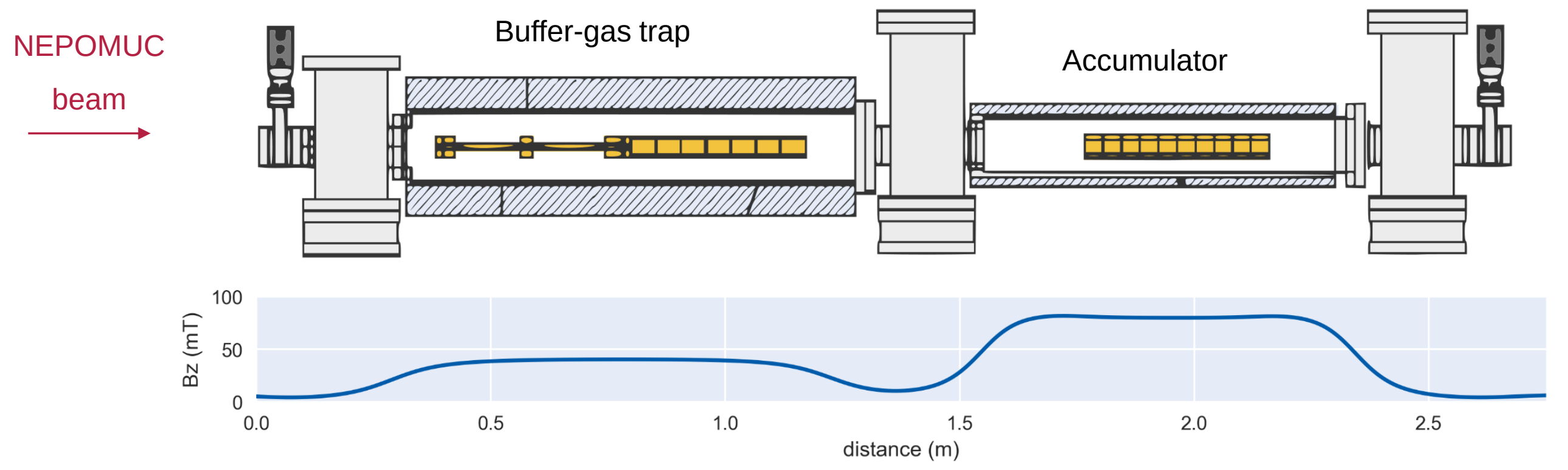

Figure 4. Schematic of the buffer-gas trap & accumulator system and on-axis magnetic field.

A collision within the trap between an N2 molecule and an incoming positron can dissipate sufficient energy for the positron to become confined by the electrostatic potentials applied to the electrodes. Differential pumping and the asymmetric electrode structure create a pressure gradient that optimizes the competing processes of capture by inelastic scattering and annihilation.

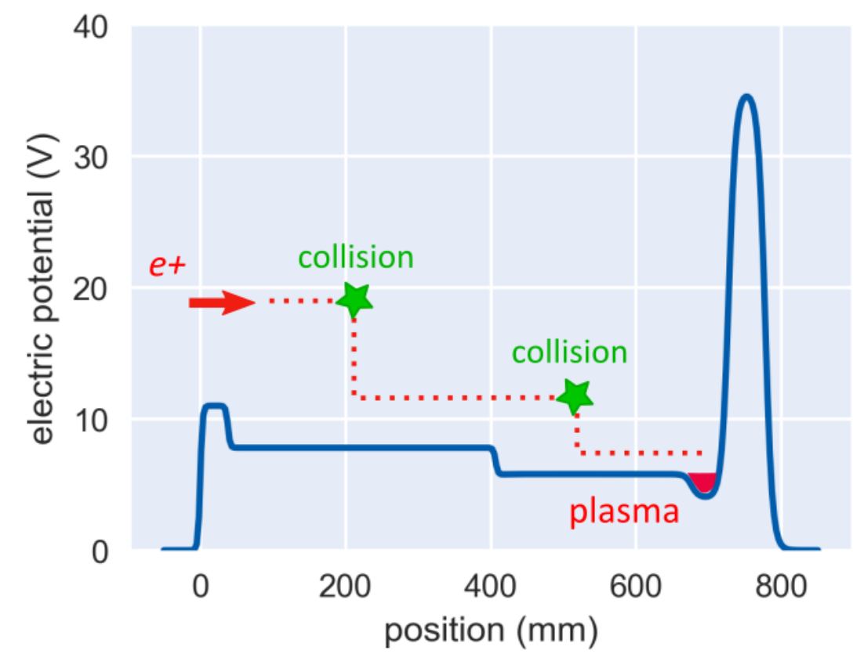

Figure 5. The asymmetric electric potential of a buffer-gas positron trap.

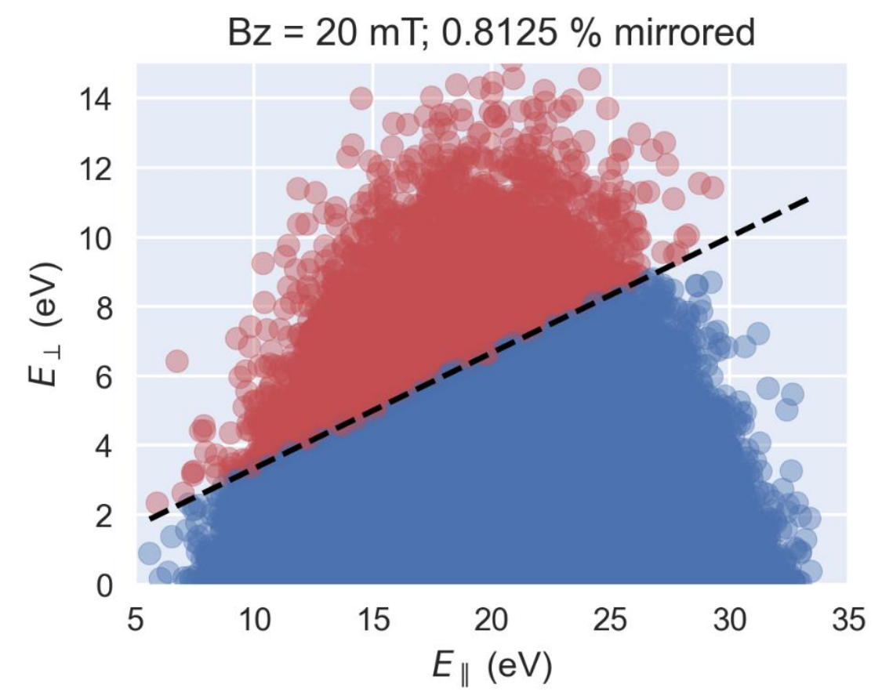

Figure 6. Monte-Carlo simulation of magnetic mirroring of the 20 eV DC positron beam.

The BGT will operate at ~1 Hz, with an expected trapping efficiency of 5 - 10%. Ejected pulses will be stacked in the accumulator. A non-neutral plasma containing hundreds of millions of positrons will be accrued every 60 s. Future upgrades that increase the remoderation efficiency and/or minimize the energy spread of the DC beam (e.g., Ne or SiC) will significantly improve the trapping rate.

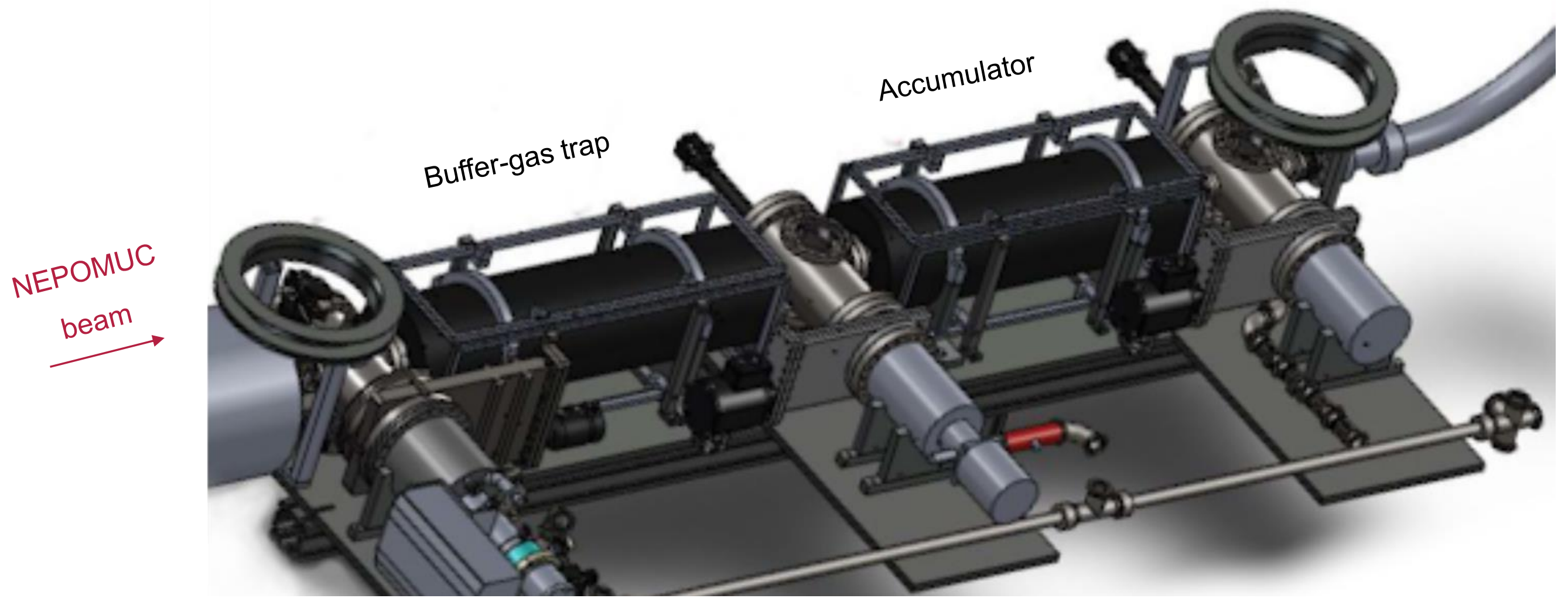

Figure 7. CAD model of the BGT and accumulator.

Work is ongoing at IPP to modify an existing BGT to meet the constraints of operating at FRM-II. Trap-optimization techniques are being developed and tested using electrons. Simulations indicate that magnetic mirroring of the 20 eV DC beam can be reduced to negligible levels and that the particle transport will be adiabatic, i.e., the remoderated NEPOMUC beam will not be adversely affected by the trap.

*Figure 8. The NEPOMUC at FRM-II, in Garching.*

*Photo credit (printed with permission): Bernhard Ludewig*

## Summary

The installation of a buffer-gas trap at the NEPOMUC will significantly extend the scope of experimental opportunities at this unique facility. The trap-based positron beam will be a crucial component of the APEX low-energy pair-plasma experiment. In addition, an intense, pulsed positron source would allow, for example, almost background-free measurements of positron-annihilation-induced Auger-electron spectra, or could be used to generate an extremely dense source of positronium atoms.

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