PENeLOPE - Preparations for a Precise Neutron Lifetime Measurement

R. Picker, I. Altarev, P. Amos, E. Gutsmiedl, F.J. Hartmann, A.R. Müller, S. Paul, and R. Stoepler

The measurement of the neutron lifetime τ_n opens the way to determine the coupling constants of weak interaction and hence the element V_{ud} of the CKM matrix precisely. It also plays a vital role in Big Bang nucleosynthesis. Latest experimental results [1] deviate from the current PDG value by 6 σ.

The most precise measurements of τ_n were performed by storing ultra-cold neutrons (UCN) in material bottles. However, there are significant losses during wall collisions whose nature is not yet fully asserted. Therefore systematical errors cannot be decreased much below their present values. Magnetic storage has been proven to be a viable alternative [2].

In our experimental setup PENeLOPE the volume between two nested cylinders with 50 cm and 12 cm radius will be used to store UCN. Superconducting coils at the walls and at the bottom of the trap produce a magnetic field of around 2 Tesla. The top at a height of 110 cm may stay open as gravity prevents UCN from leaving there. It is foreseen to measure the surviving neutrons as well as the decay protons. In the volume of over 700 l more than 10^5 neutrons may be stored.

Therefore it is possible to collect large statistics in short time. In one filling of PENeLOPE a statistical accuracy of $\Delta\tau = 1$ s can already be reached and our goal of 0.1 s is attained in less than four days. The crucial point for a precise neutron lifetime measurement, however, is to avoid or understand all systematic effects. The main effects are spin-flip with subsequent neutron loss [3] and the storage of marginally-trapped neutrons: UCN with a slightly larger energy than the trap depth might have trajectories to stay in the trap on time scales comparable to the decay lifetime.

PENeLOPE will have a trap depth of around 110 neV, so it is necessary to remove neutrons with higher energies. This shall be managed after filling the trap while the magnetic field is still very low. During this time an absorber installed at the walls shall eat all marginal UCN. When the coil current is ramped up, the neutrons will not reach the absorber any more, so magnetic storage is not influenced.

To test this scheme a cryogenic storage vessel, called AbEx, similar to the PENeLOPE storage bottle, was built at the MLL to simulate the ring-shaped absorber for PENeLOPE (Fig. 1). An electro-polished stainless steel helium bath cryostat with an inner diameter of 400 mm and a height of 1000 mm is surrounded by a flow-through liquid nitrogen shield made of copper. The absorbers (titanium and polyethylene in our case) are mounted on a support frame made of copper and have a height of 100 mm at a radius of 190 mm. Storage of neutrons is assured by closing the filling hole at the bottom center with a bath-tub-plug like neutron valve. Energy selection of UCN is performed via a rotatable 'U' made of electro-polished UCN guides, so only neutrons above a certain energy can reach the detector. The storage walls and the absorbers can be cooled down to either liquid-nitrogen or liquid-helium temperature, so one can measure at three different temperature values.

During a beam time of 20 days at the UCN turbine in the Institute Laue-Langevin, Grenoble in December 2006, the setup could be successfully mounted and tested. After some vacuum problems it worked according to design, the only issue was an increased heat input through the UCN guide, which limited the measuring time at liquid helium temperature. During the beam time 382 hours or 15.9 days worth of data could be taken which resulted in approx. $4.1\cdot10^7$ counted UCN. The storage time of the bottle without absorber could be determined energy dependent at all three temperature points. Due to the increased heat input, PE as absorber material could only be measured down to 80 K, but with Ti we could reach temperatures down to 5 K by mounting it directly onto the storage walls.

The ring shape of the absorber was proven to be effective: the storage time of UCN with a kinetic energy high enough to reach the absorber at its current height was always lower than 10 s. This results in a reduction of marginally trapped neutrons to a level of $< 10^{-4}$ after 100 s of cleaning time, which is sufficient for the aspired accuracy of PENeLOPE. A clear temperature dependence of the storage time in the stainless steel bottle was also seen: it changed from 151 ± 5 s at room temperature to 277 ± 6 s at 6 K. Detailed data analysis is still ongoing.

Preparatory work for a setup to test two superconducting coils resembling those of PENeLOPE was also continued. The first energization of the magnet will take place in 2007 as problems with its helium vessel delayed the project.
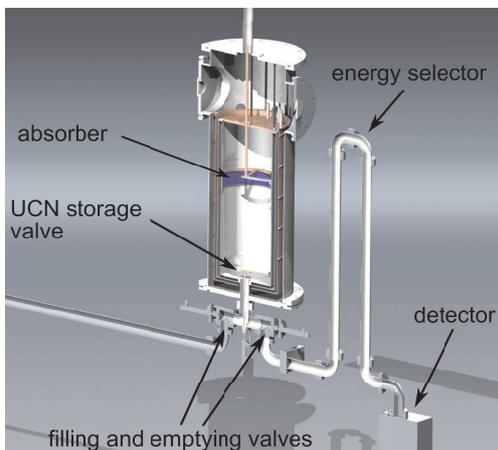
Fig. 1: Cut-away view of the AbEx cryostat

References

[1] A. Serebrov *et al.*, Phys. Lett. **B605** (2005) 72
[2] V. Ezhov *et al.*, J. Res. Natl. Inst. Stand. Technol. **110** (2005) 345
[3] I. Altarev *et al.*, Annual report 2005, p. 89