PENELOPE - A Precise Experiment to measure the NEutron Lifetime Operating with Proton Extraction

I. Altarev, J. Bröcker, F.J. Hartmann, A.R. Müller, S. Paul, R. Picker, D. Tortorella, and O. Zimmer

The neutron lifetime has always been an active area in fundamental research. Various measuring methods have been developed and utilized: Beam methods for thermal and cold neutrons and storage methods for ultra-cold neutrons. The relative accuracy ranges from 95 s some 30 years ago to 0.8 s for the latest measurements. The value adopted by the Particle Data Group [1], $\tau_n = 885.7 \pm 0.8$ s, is mainly determined by a measurement with ultra-cold neutrons (UCN) stored in a bottle with fomblin coated walls [2]. A new experiment, using the same method but cooled fomblin, determined the lifetime to $\tau_n = 878.5 \pm 0.8$ s, a deviation of more than $6\,\sigma$ [3]. Therefore it is mandatory to scrutinize the results again by conducting a new measurement and, if possible, by using a different method.

The main source of systematic errors in the storage measurements described above are neutron losses during collisions with the trap walls. In order to avoid such losses one may use a magnetic field to contain "low-field seeking" UCN, i.e. those neutrons that are repelled from regions of high flux density. This method is complementary to most of those used up to now and should allow a reduction of errors.

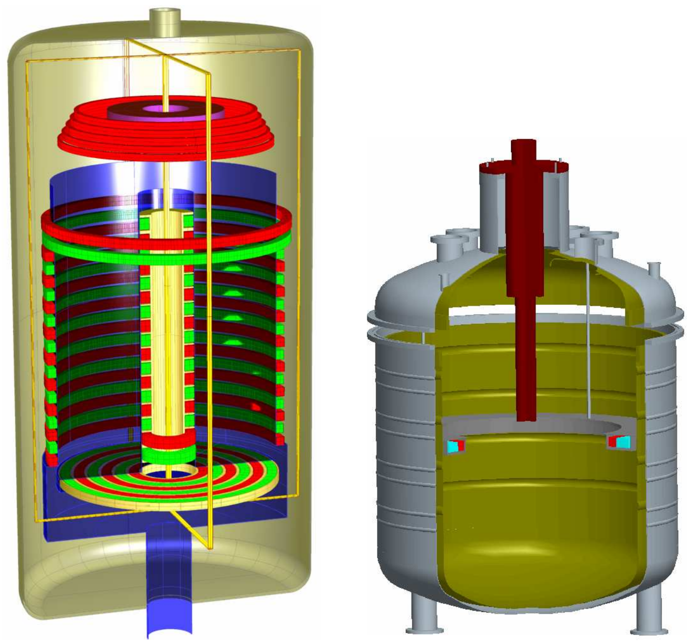

Fig. 1:
(left) Schematic view of the magnetic storage device for UCN. The superconducting coils are shown in light and dark grey. Five coils at the top serve to focus the accelerated decay protons on the detector. Further explanations may be found in the text.
(right) Schematic view of the test cryostat, with current leads at the top and one solenoid inside.

The left part of Fig. 1 shows a schematic view of the planned trap with superconducting magnets. A double cylinder with 12 cm inner and about 50 cm outer radius and with a height of around 1.2 m is composed of sandwiches of superconducting ring coils (cross-section about $3 \cdot 4$ cm^2, current densities between 230 and 370 A/mm^2) with the storage volume in between. The direction of the current is reversed from coil to coil. In a similar way, concentric rings form the bottom of the trap. The axis of the arrangement is vertical and the top may stay open, as gravity keeps the UCN inside the trap. Four racetrack coils on the axis serve to avoid zero-field regions with their enhanced danger of neutron spin flip. Monte Carlo spin-flip simulations are on the way to confirm this.

The coil setup has been designed to store neutrons with kinetic energies of up to 120 neV; at a volume of about 700 dm^3 and a UCN density of well above 10^3/cm^3 at FRM II, we expect to store more than 10^7 UCN in one filling. This large number of trapped UCN, together with the possibility to vary the magnetic flux density by changing the current in the superconducting coils, allows to scrutinize possible systematic effects. In this way we expect to decrease the total error for τ_n to about 0.1 s.

In addition, the system will be constructed to allow the collection of decay protons. An electromagnetic extraction field inside the storage volume and magnetic field lines pointing towards the detector above the trap should enable us to collect about 70% of them. After acceleration to more than 30 keV the protons hit a large-area CsI(pure) scintillator, which has good detection efficiency at the low temperatures necessary to operate the superconductors. The detector is currently developed and tested at the institute [4]. Applying this detection method also demonstrates an advantage of magnetic storage, as decay-proton detection with a material trap has not been achieved yet.

As a constraint, it was necessary to optimize the coil setup to reduce the maximum flux density in the coils to below 6 T. When this was achieved, a study was conducted to confirm the technical feasibility of the experiment. Here the critical point was the relatively fast ramping of the storage coil current: To fill in the neutrons through a slit in the lower edge, the magnetic field has to be zero and then will be increased to its storage value in around 100 s. This causes AC losses in the conductor and may lead to a quench. The study reasoned that such a short ramping time is possible, but nevertheless recommended to build a test setup with one of the coils from the later experiment. A schematic view of the test cryostat to be realized at MLL, Garching is shown in Fig. 1 on the right. With it, cooling, pumping, ramping of the solenoid, magnetic field measurements, high voltage and so on may be tested.

This work is supported by BMBF under contract 06MT191I.

References

[1] S. Eidelman *et al.*, (Particle Data Group), Phys. Lett. **B592** (2004) 1
[2] S.S. Arzumanov *et al.*, Nucl.Instr.Methods **A440** (2000) 511
[3] A. Serebrov *et al.*, Phys.Lett. **B605** (2005) 72
[4] H. Angerer *et al.*, this report, p.89.