An Experiment to Measure the Bound- β-decay of the Free Neutron

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The two-body neutron β-decay into a hydrogen atom and an electron antineutrino

$$n \to H + \bar{\nu} \tag{1}$$

is investigated. The hyperfine-state population of the monoenergetic hydrogen atoms(325.7 eV) yields the neutrino left-handedness or a possible right-handed admixture and possible small scalar and tensor contributions to the weak force [1]- [4]. The constraints on the neutrino helicity and the scalar and tensor coupling constants of weak interaction can be improved considerably.

Using the through-going beam tube of a high-flux beam reactor, a background free hydrogen rate of ca. $3\,\mathrm{s}^{-1}$ can be obtained. In fig. 1 the suggested setup is sketched.

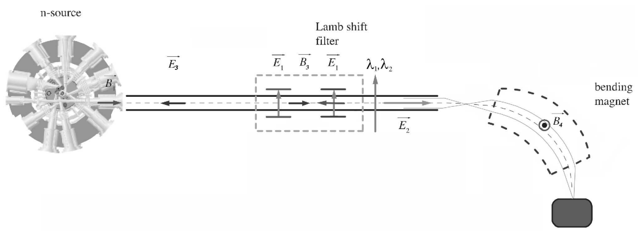

Fig. 1: Sketch of the experimental setup for measuring hydrogen atoms from neutron bound-β- decay at a high flux beam reactor through-going beam tube. The axial spin holding magnetic field $\vec{B_1}$ and an axial electric counter field $\vec{E_3}$ for suppressing the neutron β-decay protons are drawn. The spin filter consists of an axial quantization $\vec{B_3}$ with a Stark mixing transverse electric field $\vec{E_1}$ and an azimuthal magnetic rf field. After the spin filter there are two transverse laser beams with wavelengths λ_1 and λ_2, a longitudinal accelerating and focussing electric field $\vec{E_2}$ and a bending and focussing magnetic field $\vec{B_4}$

A small axial $\vec{B}$ field keeps the initial e^- and p spin directions of the H atom. The neutron β-decay protons can be shielded by a small axial counter $\vec{E}$ field. Other charged and neutral particles and γ rays moving in transverse directions are suppressed by neutron and γ absorbing orifices on both sides of the maximum neutron flux. By means of the MCNP program the neutron and γ flux together with the particle and photon directions have been calculated for the FRMII SR6 beam tube. In order to suppress these particles and photons, the orifices are designed using GEANT4 with the MCNP data as an input. The metastable H(2s) atoms are analyzed downstream by a Lamb shift source type spin filter selecting the four hyperfine states.

The remaining state-selected H atoms (e. g., $2s_{1/2}, F = 1, m_F = 1$) are excited by two CW lasers with $\lambda_1(2s \to 10p)$ =379.68 nm and $\lambda_2(10p \to 27d) = 10.56\mu$m. The Doppler shifted frequency is given by

$$\nu' = \nu \frac{\sqrt{1-\beta^2}}{1+\beta\cos\phi}, \tag{2}$$

where ϕ is the angle between the H atom and the photon. For $\phi = \pi/2$ the second order Doppler shift $\nu' = \nu\sqrt{1-\beta^2}$ results. The relative shift due to the H(2s) velocity $\beta = 0.83 \cdot 10^{-3}$ is $\Delta\nu'/\nu = \beta^2/2 = -3.44 \cdot 10^{-7}$. The relative width due to the velocity spread $d\beta = 0.73 \cdot 10^{-5}$ because of the thermal motion of the decaying neutrons is

$$\frac{d\nu'}{\nu} = -\frac{\beta\, d\beta}{\sqrt{1-\beta^2}} = -6.06 \cdot 10^{-9} \tag{3}$$

yielding an absolute width $d\nu' = -4.785 \cdot 10^6\, s^{-1}$ for $\nu_{2s-10p} = 7.896 \cdot 10^{14}\, s^{-1}$ which corresponds to a single mode laser width. Thus, using the second order Doppler effect H(2s) atoms with a large velocity spread can be excited. However, the angular width, within which the excitation occurs, is very small being $d\phi = (d\nu'/\nu)/\beta = -7.3 \cdot 10^{-6}$. The divergence of the H atoms in our experiment, which must correspond to the divergence of the photons within the laser resonator, is 1000 times larger. Therefore, the resonator mirrors must be curved.

Fig. 2 shows the Monte Carlo calculated level occupations for various laser 2 positions. The 2s occupation is rather constant and high, the 10 p always low. There is a position, where the 27 d occupation is 45 % which is quite efficient.

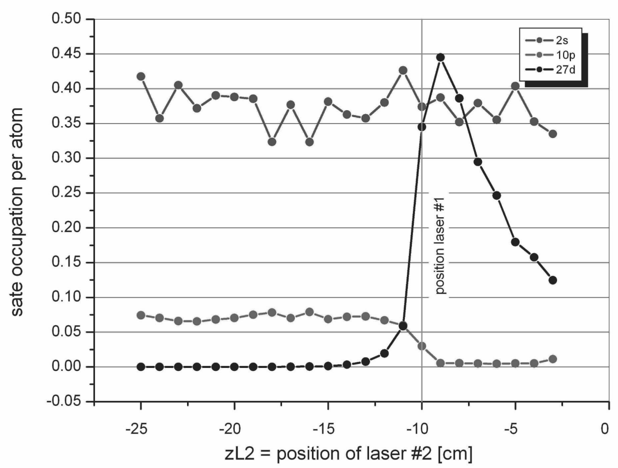

Fig. 2: 2s, 10p and 27d level occupation vs. laser 2 position relative to laser 1 for thermal decaying neutrons and $7.3 \cdot 10^{-3}$ H atom divergence. The power within the resonators is 20 kW and 100 W for laser 1 and 2, respectively

The H(2s) atoms are subsequently field ionized by the axial $\vec{E_2}$ field. The resulting protons are accelerated by $\vec{E_2}$

and are by 90^o bent and focussed by a magnet spectrometer(being designed using the beam optics matrix program GICO and the magnet code OPERA) onto a CsI(Tl) or silicon drift detector. The β-decay electrons are deflected by the transverse $\vec{B_4}$ field of the magnet spectrometer away from the detector.

In a preceding experiment the yield of neutron bound-β-decay H(2s) atoms will be measured at a high flux beam reactor through- going beam line by a transverse $\vec{B}$ field ($\approx$ 10 Gauss, 1 m long, fig. 3) deflecting the charged particles from the beam tube axis followed by an axial $\vec{E}$ field, where the H(2s) are quenched resulting in the emission of Lyman α photons which will be detected perpendicularly to the axis by a photon detector(LAAPD or solar blind PM).

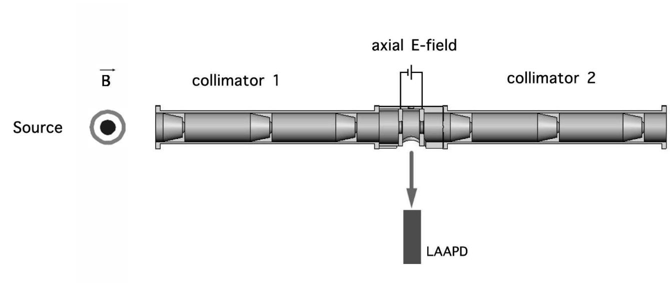

Fig. 3: Neutron bound- β- decay H(2S) yield measurement. The setup contains a transverse magnetic $\vec{B}$ field, two collimators with diaphragms, an axial electric $\vec{E}$ field and a photon detector

Alternatively, the neutron bound- β- decay H(2S) could be charge exchanged to H^- within an Ar cell(fig. 4). A possible thermal H^- background is suppressed by the small $\vec{E_4}$ counter field being advantageous compaired to the Lyman α detection method. The remaining neutron bound- β- decay H^- ions are accelerated by $\vec{E_2}$ and are by 90^o bent and focussed by a magnet spectrometer onto a detector.

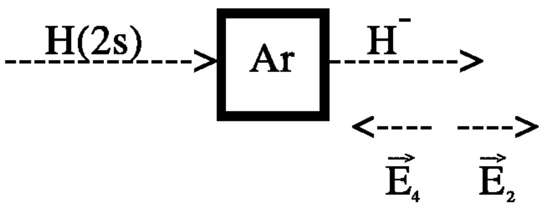

Fig. 4: Neutron bound- β- decay H(2S) yield measured by charge exchanging into H^- using an Ar cell. Thermal H^- are suppressed by a small $\vec{E_4}$counter field. The remaining H^- are accelerated by $\vec{E_2}$ followed by a magnet spectrometer and a detector as in fig. 1

In order to study the Lyman α photon detection, an intense H(2s) source is being set up at the MLL source laboratory, where the produced H^- are stripped within a N_2 cell to protons which are supsequently converted into H(2s) within a Cs cell. After the Cs cell the H(2s) pass the apparatus shown in fig. 3. The N_2 cell, essentially consisting of a 7 mm inner diameter 200 mm long tube, filled with 1.6 mbar N_2, where the throughgoing H^- are charge exchanged into protons with 40 % efficiency, is shown in fig. 5.

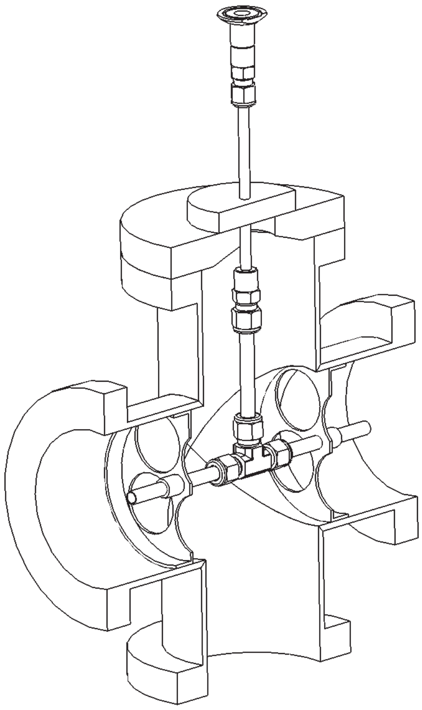

Fig. 5: Perspective section of the N_2 cell for H^- stripping into protons

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