Letter of Intent
for precise measurement of the lifetime of Hydrogen Hyperisotopes $^{3}_{\Lambda}$H and $^{4}_{\Lambda}$H

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We are planning to propose an experiment to precisely measure the lifetimes of $^{3}_{\Lambda}$H and $^{4}_{\Lambda}$H using the ^{3,4}He$(\pi^-, K^0)^{3,4}_{\Lambda}$H reaction at the K1.1 beamline by employing the SKS spectrometer and scintillation counters around the target.

The Hydrogen Hyperisotopes $^{3}_{\Lambda}$H and $^{4}_{\Lambda}$H were actively studied in the early days of Hypernuclear Physics with visualizing techniques (emulsions, He filled Bubble Chambers). The selected samples had the common drawback of a limited statistics and the deduced observables, in particular the lifetime τ, were determined with huge errors (statistical and systematic). The large spread of values did not allow to draw reliable conclusions on the lifetimes. In particular, it was not possible to verify the theoretical predictions that, expecially for $^{3}_{\Lambda}$H, the lifetime, $\tau(^{3}_{\Lambda}\mathrm{H})$, would be very close to the value of the free Λ (τ_Λ=263.2 ps) due to the very low binding energy of the Λ (B$_\Lambda$=0.13±0.05 MeV).

The interest in the experimental value of $\tau(^{3}_{\Lambda}\mathrm{H})$ was very recently growing following the observation of the production of $^{3}_{\Lambda}$H and, even more important, of its antipartner $\overline{^{3}_{\Lambda}\mathrm{H}}$ in ultrarelativistic Au-Au collisions by the STAR Collaboration at RHIC. The value reported for $\tau(^{3}_{\Lambda}\mathrm{H})$, even though still affected by a 30% error, was considerably lower than τ_Λ. It was confirmed soon afterwards by the HypHI Collaboration at GSI by analyzing the events recorded in the collisions of ^{6}Li ions on a ^{12}C target and by the ALICE Collaboration in ultrarelatistic Pb-Pb collisions at LHC. Unfortunately also these last two measurements were affected by errors exceeding 20%. All the relevant references for the preceding and subsequent items can be found in the very recent review paper on Hypernuclear Weak Decays [1]. A combined analysis of all the above data following a Bayesian approach yielded a value of 216^{+19}_{-16} ps [2], significantly lower than τ_Λ. The precise confirmation of a $\tau(^{3}_{\Lambda}\mathrm{H})$ value considerably shorter than τ_Λ, in strong contrast with the available theoretical calculations [1], could have a significant impact on the description of the three-body Λnp system and possibly on the comprehension of the underlying mechanism of the low energy ΛN interaction.

A similar situation exists for $^{4}_{\Lambda}$H, for which a value of $\tau(^{4}_{\Lambda}\mathrm{H})=192^{+20}_{-18}$ ps was reported in a Bayesian approach analysis [2] of old data with visualizing techniques, from a counter experiment performed in the ‘90 at the KEK PS and a very recent one by the HypHI Collaboration. Concerning the theoretical evaluations, we remark that a reduction of $\sim$ 14% of $\tau(^{4}_{\Lambda}\mathrm{H})$ with respect to $\tau(^{4}_{\Lambda}\mathrm{He})$ is predicted by [3], compared to an experimental value of about 23% (we recall that

$\tau({}^{4}_{\Lambda}\mathrm{He} = 250 \pm 18$ ps), fully consistent with τ_Λ). However, we remark that nearly all values calculated by [3] for light and medium A hypernucler systems overestimate the experimental ones, possibly due to the omission of the 2N-induced non-mesonic weak decay. The reduced $\tau({}^{4}_{\Lambda}\mathrm{H})$ value compared to the $\tau({}^{4}_{\Lambda}\mathrm{He})$ one can be naively understood as due to the circumstance that the two-body π^- decay of ${}^{4}_{\Lambda}\mathrm{H}$ ($\sim$ 49% of the total mesonic width [4]) is absent in the case of ${}^{4}_{\Lambda}\mathrm{He}$: for ${}^{4}_{\Lambda}\mathrm{He}$ only the two-body π^0 decay is present, with a smaller branching ratio ($\sim$ 1/2 due to the ΔI=1/2 rule).

The most reliable technique for measuring the Hypernuclei's lifetime is the one based on the measurement of the time delay spectra, as shown by the series of measurement at the KEK-PS, (see e.g. [5]). A precision of 5% was achieved, with time spectra containing several hundreds of events. It cannot be applied for the measurement of the lifetimes of the Hydrogen Hyperisotopes since they cannot be produced from ^{3,4}He targets in reactions employing only charged meson beams and ejectiles, a target of ^{3}H is very hard to manipulate and ^{4}H does not exists. On the contrary, ${}^{3,4}_{\Lambda}\mathrm{H}$ can be produced on ^{3,4}He targets by the associated production reaction:

$$\pi^- + {}^{3,4}\mathrm{He} \rightarrow {}^{3,4}_{\Lambda}\mathrm{H} + K^0 \tag{1}$$

in the forward direction. The incident π^- momentum should be 1.05–1.10 GeV/c. K^0 should be spectroscopized through the $K^0 \rightarrow K^0_s \rightarrow \pi^+\pi^-$ decay. By taking advantage of the K1.1 beam at J-PARC coupled with the SKS spectrometer, the missing mass (MM) of the produced ${}^{3,4}_{\Lambda}\mathrm{H}$ would be determined by the measurement of (π^+, π^-) pairs in strongly asymmetric decays. The momentum of the π^+ in the forward direction (around 700 MeV/c) would be measured by the SKS spectrometer, the π^- one, at emission angles roughly normal to that of the π^+ and ranging from 60 to 120 MeV/c, would be determined by means of a fine grained range scintillator hodoscope surrounding the target. By assuming an energy resolution of 2 MeV FWHM on both pions, which seems into reach with the existing technologies, we expect a MM resolution better than 3 MeV FWHM.

On the basis of some realistic experimental assumptions on all the physical and experimental quantities entering into the calculations, and the quite pessimistic hypothesis of a beam intensity of 10^7 π^-/s, we obtain some 10^2 ${}^{4}_{\Lambda}\mathrm{H}$ and ${}^{3}_{\Lambda}\mathrm{H}$ produced in about 10 days of beam time each.

The time delayed spectra will be measured by a fast timing scintillator barrel enclosing the target. We expect an error lower than 10% for $\tau({}^{3}_{\Lambda}\mathrm{H})$ and lower than 5% for $\tau({}^{4}_{\Lambda}\mathrm{H})$.

In the case of ${}^{4}_{\Lambda}\mathrm{H}$, a possible strategy could be to identify by means of the range array the π^- from the two-body decay (133 MeV/c) since it would be separated from the most probable value of the distribution of π^- from decays of Λ produced in quasi-free reactions. If this strategy could not be applied to ${}^{3}_{\Lambda}\mathrm{H}$, the detection of the π^- from the three-body decay could be considered, even if it would require a bigger effort since its spectrum (20-100 MeV/c) partially overlaps the spectrum of π^- from Λ free decays. It will be necessary to select the π^- from the ${}^{3}_{\Lambda}\mathrm{H}$ decay with suitable windows on the pattern of signals from the range detector. This selection is strongly needed also taking into account the fact that, whereas for the ${}^{4}_{\Lambda}\mathrm{H}$ case the selection on the MM will strongly decrease the background due to Λ free decays thanks to the Λ binding energy of (2.08±0.06) MeV, this is not true for ${}^{3}_{\Lambda}\mathrm{H}$.

The experiment would be naturally developed in two stages. In the first run $\tau({}^{4}_{\Lambda}\mathrm{H})$ will be measured to a precision better than 5%. To achieve this result the main features of the (π^-, K^0) reaction with the proposed apparatus will be studied. No particular problems are expected for the isolation of the two-body π^- decay of ${}^{4}_{\Lambda}\mathrm{H}$ from which the lifetime will be determined. Since at the same time also events corresponding to the three-body decay will be collected, they will be used too for determining the lifetime. It will be a very useful test for the next run, in which $\tau({}^{3}_{\Lambda}\mathrm{H})$ will be measured to a precision better than 10%, hopefully 5% if a larger beam intensity will be achieved.

This would be the starting point for a series of hypernuclear weak decay experiments which we plan at K1.1 beam line with SKS in the present Hadron Hall and then, hopefully, in the extended Hadron Hall.

The experiment will be prepared and carried out in collaboration with the KEK SKS group, the Tohoku University group and others international collaborators.

References

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