Tagged-Weak π-Method

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Contents

- **Introduction**
- **Impurity Effects**
- **Medium Effects**
- **Tagged-Weak π-Method**
- **Example of $^{7}_{\Lambda}$He**
- **$^{7}_{\Lambda}$He with** HπS
- **Summary**

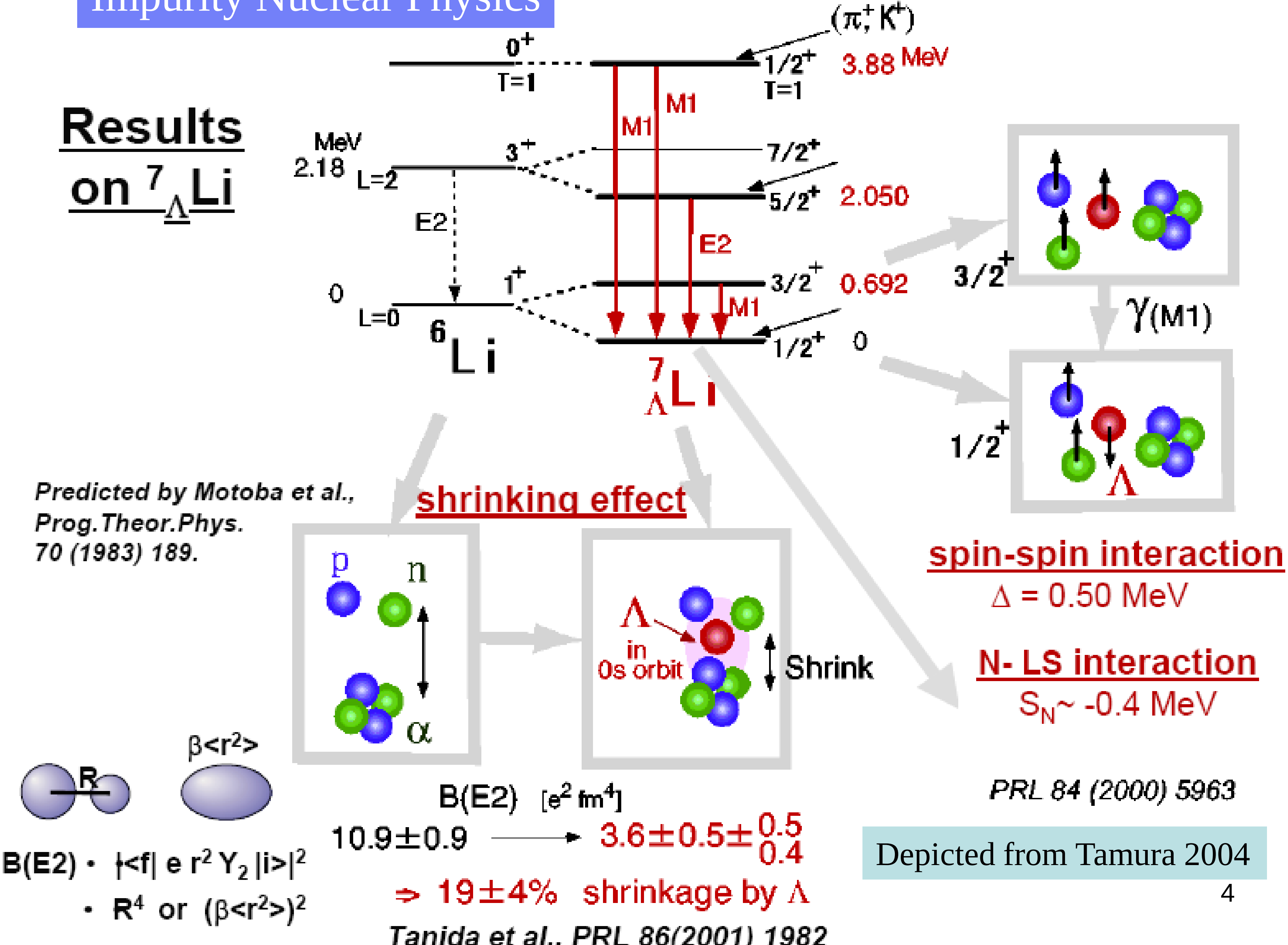
Introduction

Impurity Nuclear Physics: since a Λ-particle does not suffer from Pauli blocking, it can locate at the center of a nucleus; then the Λ attracts surrounding nucleons and makes the nucleus shrink. For the E2 electromagnetic transitions the transition probability B(E2) is very sensitive to size contraction as it is approximately proportional to fourth power of the nuclear size

Medium Effects: by the same reason a Λ-particle can be a probe to investigate possible modifications of baryon properties in nuclear matter. For example, the measurement of B(M1) in a spin-flip M1 transition provides information on the magnetic moment of Λ in a nucleus, which may be changed if a baryon is "swelling" in nuclear matter

B(E2) and B(M1)
can be derived from excited states lifetimes

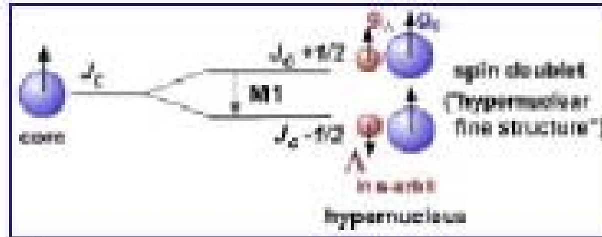
Impurity Nuclear Physics



Depicted from Tamura 2004

Medium effect

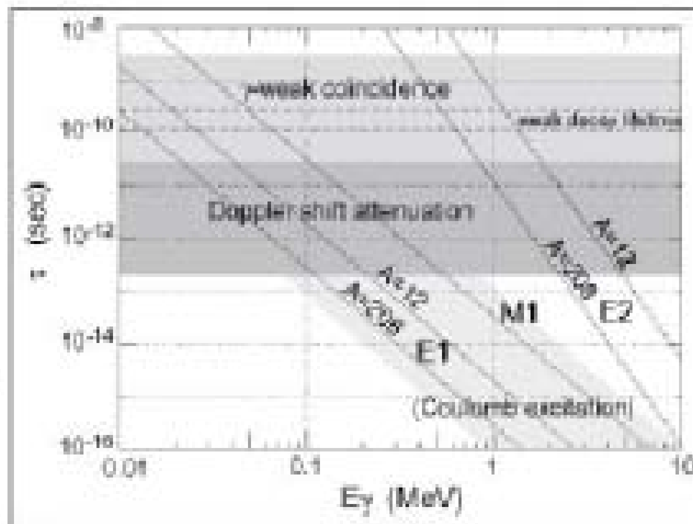
If the mass or the size of a hyperon is modified in a nucleus, its magnetic moment may be changed



$$B(M1) \propto \left|\left\langle \phi_{lo} \middle| \mu^z \middle| \phi_{up} \right\rangle\right|^2 = \left|\left\langle \phi_{lo} \middle| g_N J_N^z + g_\Lambda J_\Lambda^z \middle| \phi_{up} \right\rangle\right|^2$$

$$\propto (g_N - g_\Lambda)^2$$

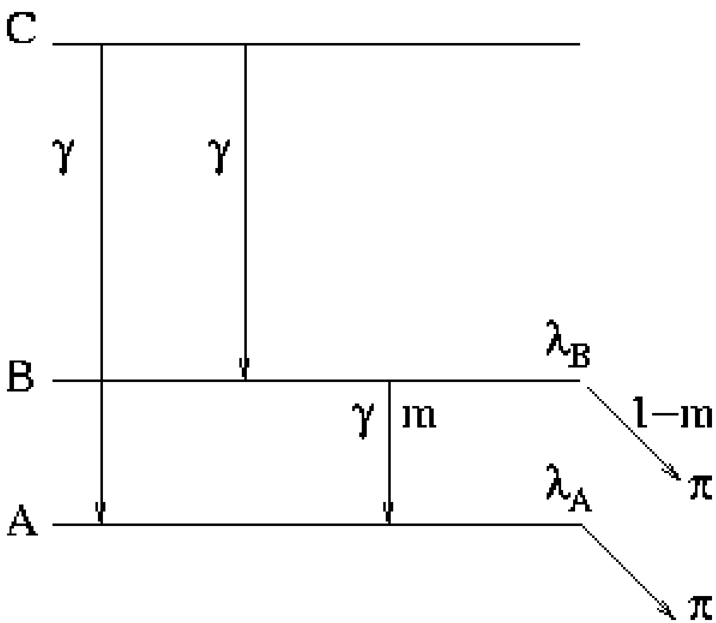
B(M1) can be derived from excited states lifetimes



- Doppler-shift attenuation method
- γ-weak coincidence method

Depicted from Bressani 2005

Tagged-Weak π-Method



$$P^{B\to weak}(t) = (1-m)\lambda_B(\lambda_B^{\pi^-}/\lambda_B)N_B e^{-\lambda_B t}$$

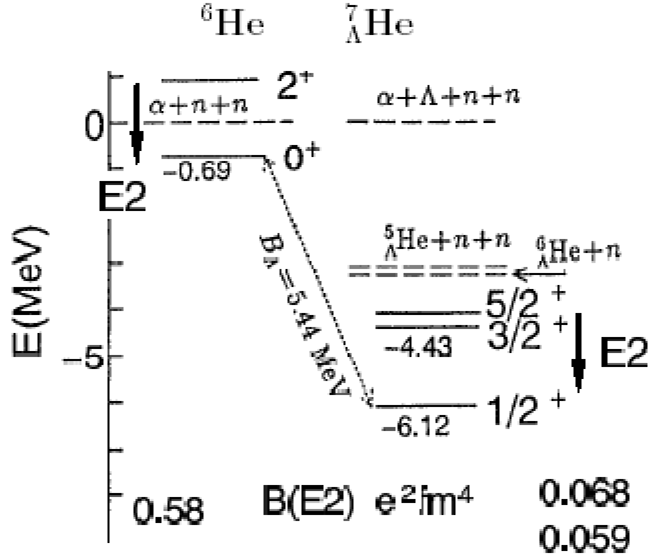
$$P^{A\to weak}(t) = (P^{B\to A}(t) + \lambda_A N_A e^{-\lambda_A t})(\lambda_A^{\pi^-}/\lambda_A)$$

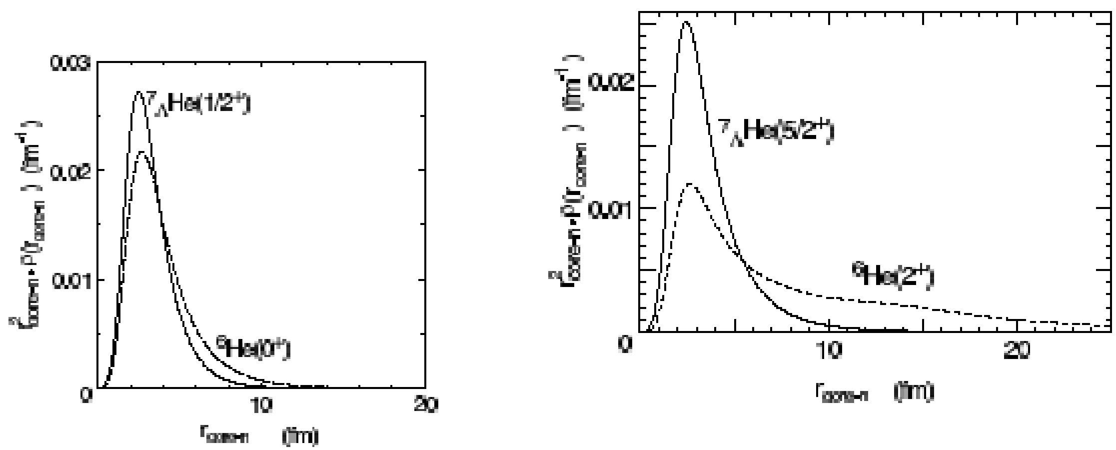
$$P^{B\to A}(t) = \frac{\lambda_A\lambda_B}{\lambda_A-\lambda_B} m N_B (e^{-\lambda_A t} - e^{-\lambda_B t})$$

By measuring both of $P^{B\to weak}(t)$ and $P^{A\to weak}(t)$ and fitting them together to the equations above, λ_A , λ_B and m can be determined, assuming $\lambda_W^A = \lambda_W^B$

$$\lambda_A = \lambda_W^A,\quad \lambda_B = \lambda_W^B + \lambda_\gamma^{B\to A} \text{ and } m = \frac{\lambda_\gamma^{B\to A}}{\lambda_\gamma^{B\to A} + \lambda_W^B}$$

Example of $^{7}{}_{\Lambda}He$



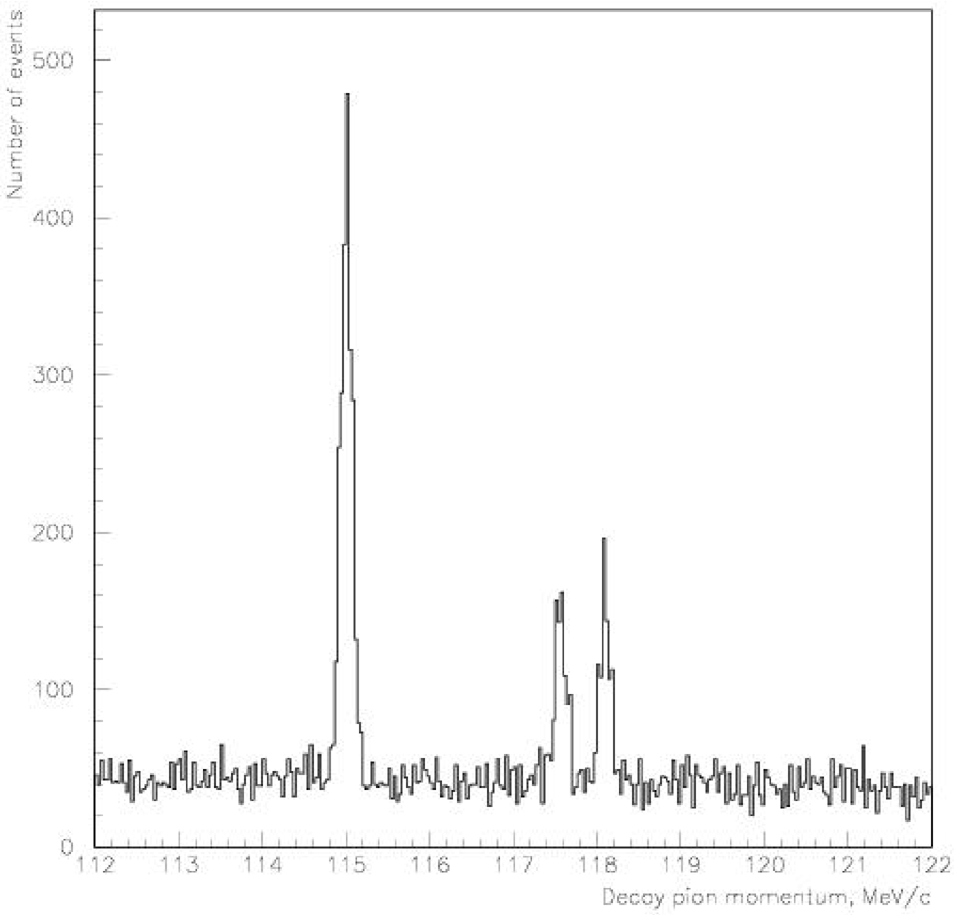


Expected level scheme of $^{7}{}_{\Lambda}He$, *B(E2), and density distribution of valence neutrons, Hiyama et al., 1996*.

$^{7}_{\Lambda}$He

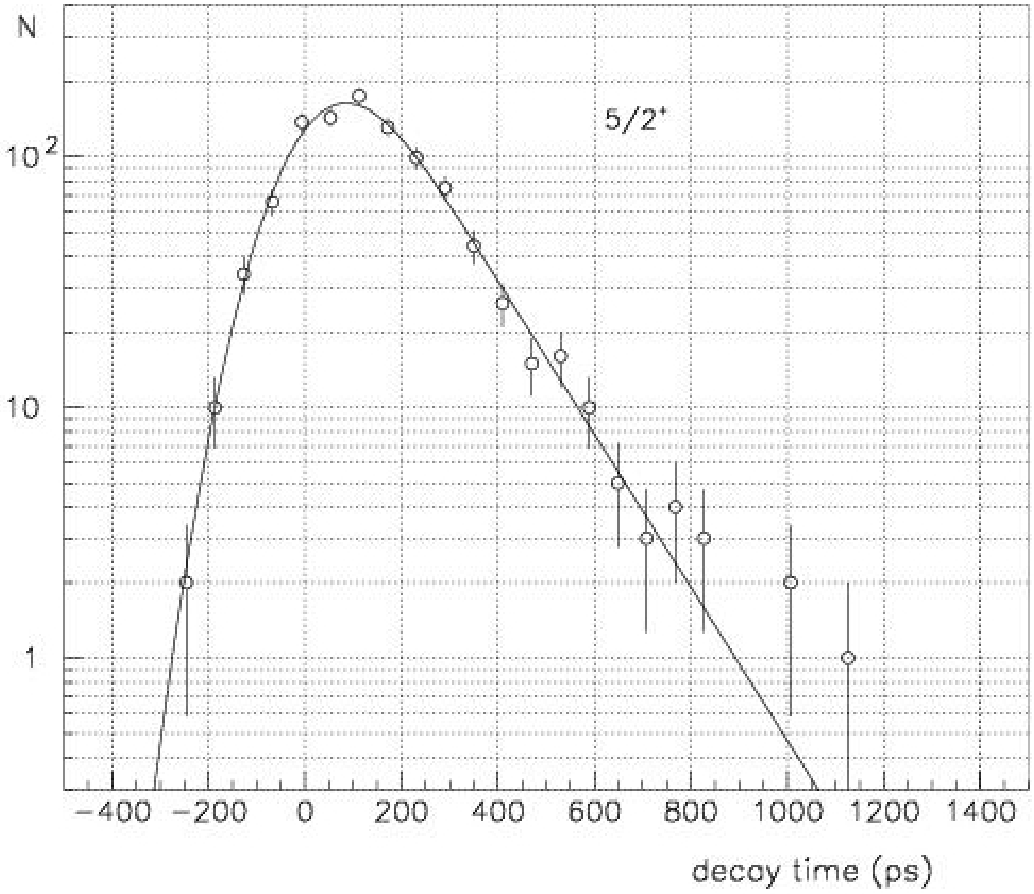
- The first excited state of ^{6}He 2+ is observed as an unbound
- When we add a Λ to ^{6}He, the neutron skin in the ground state is expected to shrink. The ^{6}He (2+) state, which has widely spread two valence neutrons, becomes bound by a Λ , and the core E2 transitions (5/2+, 3/2+ → 1/2+) are observed with rates (1/466 ps) and (1/1133 ps) and are competing against weak decay
- We propose to employ the "tagged-weak **π** -method" at H**π**S to measure B(E2)'s for 5/2+ → 1/2+ and 3/2+ → 1/2+ transitions of $^{7}_{\Lambda}$He
- Experimental determination of the level energies and the B(E2) will provide valuable information on the structure of ^{6}He and the effect of a Λ on the valence neutrons in it
- The weak decays from the 5/2+, 3/2+, and 1/2+ states can explain the observed large spread of binding energy values of $^{7}_{\Lambda}$He , measured in emulsion, which was interpreted by Pniewski and Danysz as a weak decay from a long-lived hypernuclear isomeric states

${}^{7}_{\Lambda}$He with HπS



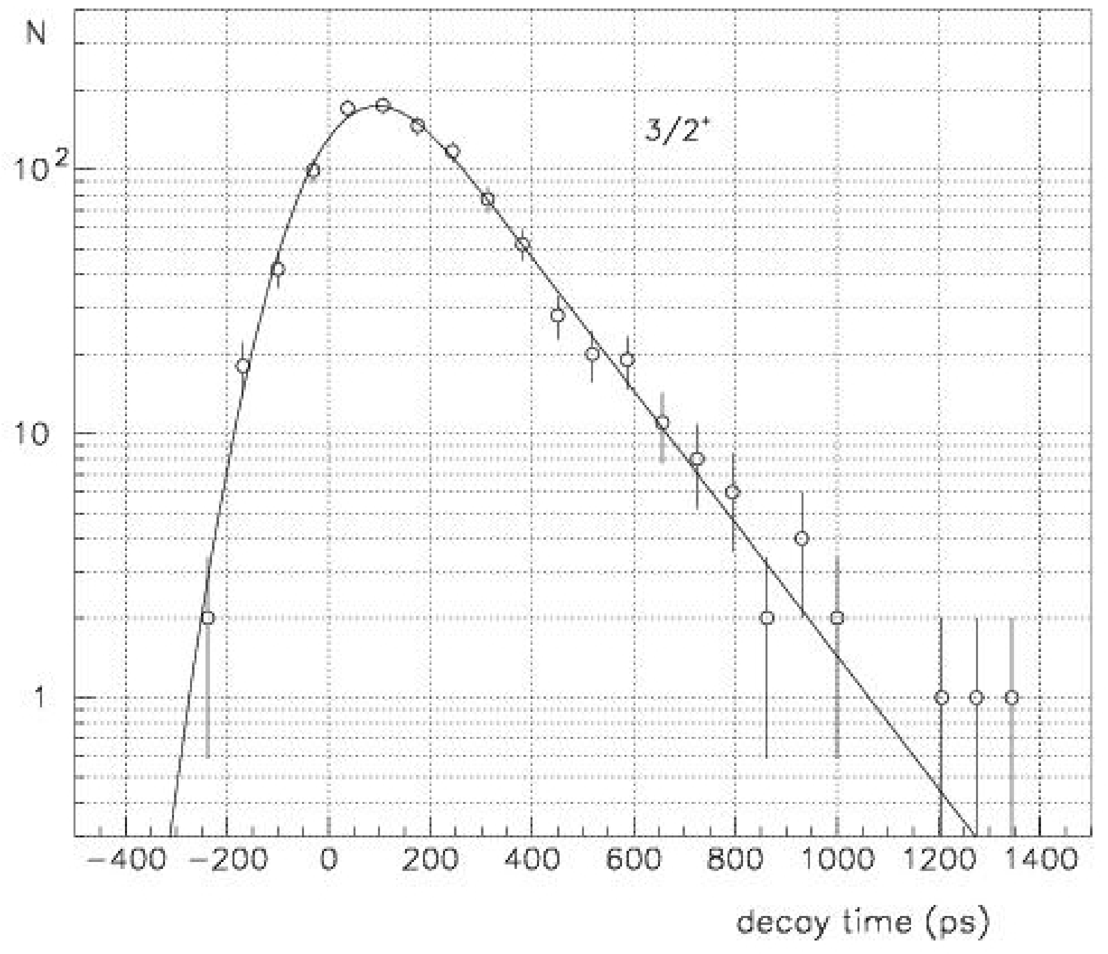
Simulated spectrum of the decayed pions from ${}^{7}_{\Lambda}$He→ ^{7}Li+π^- decay (96.8% - quasi-free, 2% - 115.06, 117.63 and 118.15 MeV/c monochromatic lines each with 0.66% probability). The monochromatic lines corresponds binding energies (states): 5.44 (1/2+), 3.75 (3/2+), and 3.4 (5/2+) MeV, respectively.

$^{7}_{\Lambda}$He with HπS



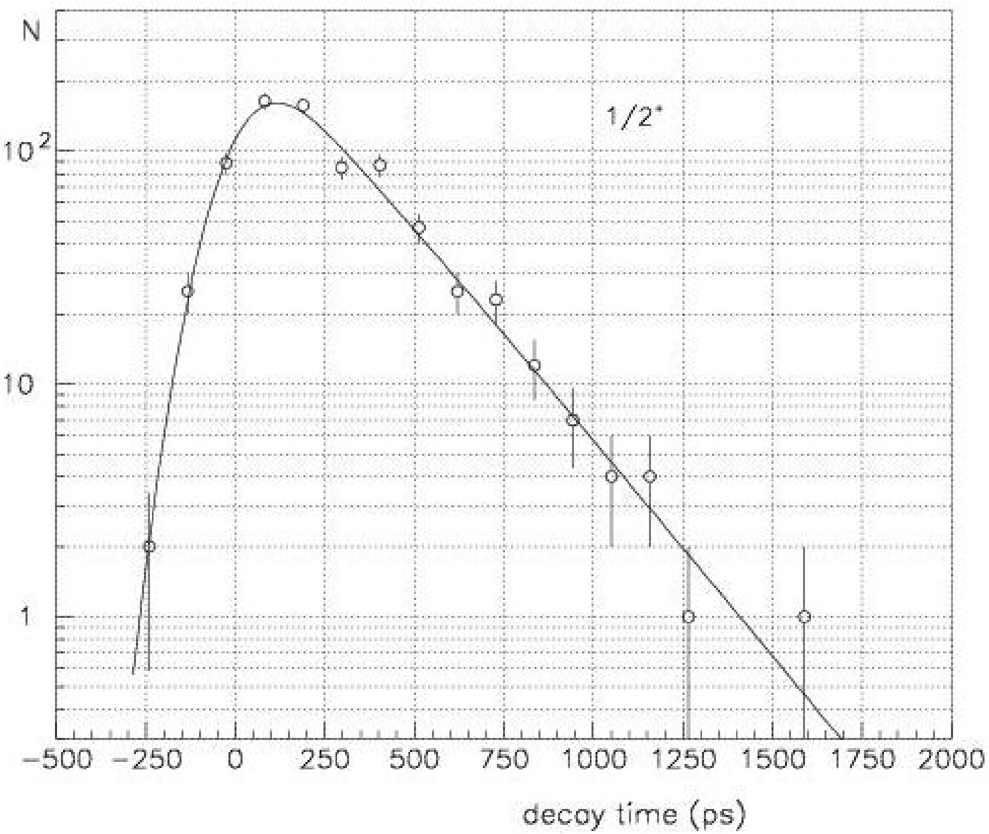
Simulated and fitted time spectrum of $^{7}_{\Lambda}$He→ ^{7}Li+π^- - weak-decay pions from the 5/2+ state. The input lifetime is 140 ps, the time resolution is 100 ps and the total number of events is 1000. The extracted lifetime is 139.6 +- 5.9 ps.

$^{7}_{\Lambda}$He with HπS



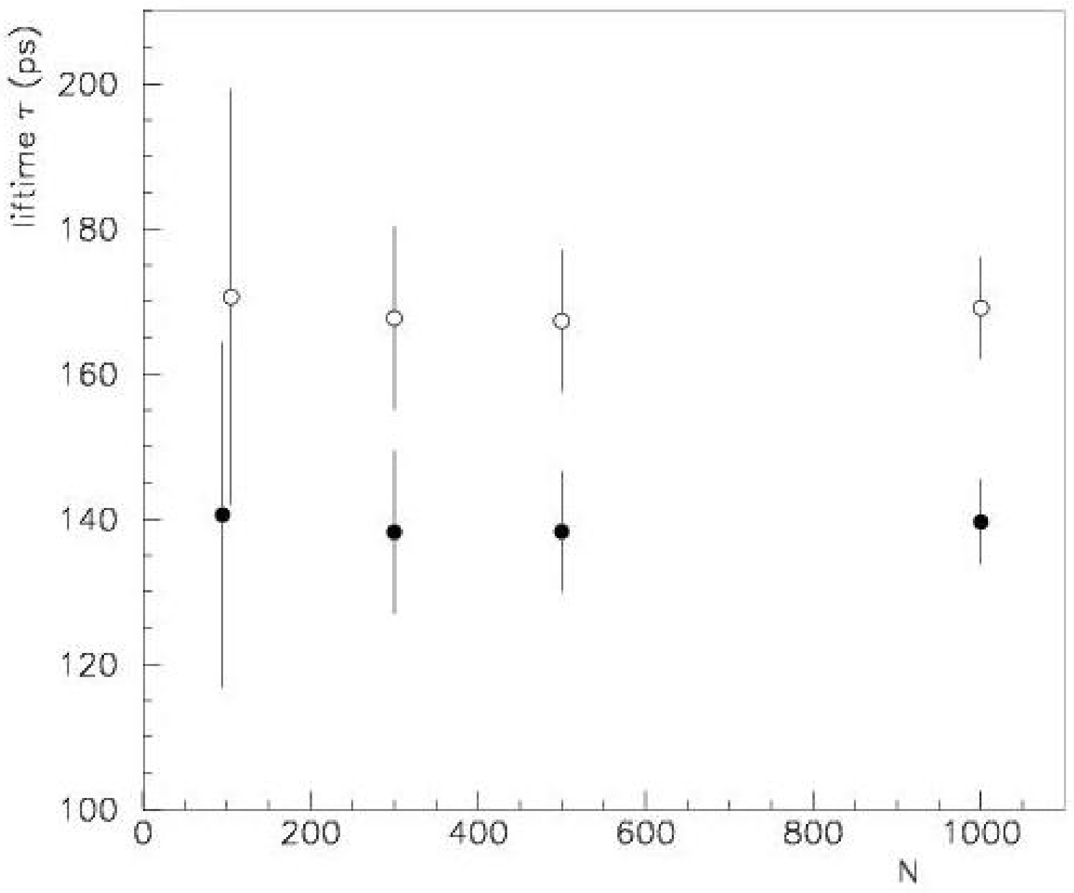
Simulated and fitted time spectrum of $^{7}_{\Lambda}$He→ ^{7}Li+π^{-} - weak-decay pions from the 3/2+ state. The input lifetime is 170 ps, the time resolution is 100 ps and the total number of events is 1000. The extracted lifetime is 169.1 +- 7.0 ps.

$^{7}{}_{\Lambda}$He with HπS



Simulated and fitted time spectrum of $^{7}{}_{\Lambda}$He→ ^{7}Li+π^{-} - weak-decay pions from the 1/2+ state by using the growth-decay function. The input lifetime is 200 ps, the time resolution is 100 ps and the number of events of the 5/2+, 3/2+ and 1/2+ states are 350, 425 and 725, respectively. The extracted lifetime is 204.5 +- 24.1 ps.

$^{7}{}_{\Lambda}$He with HπS



Sensitivity of lifetime measurement for 5/2+ and 3/2+ states. Lifetime error against number of events N.

Summary

- Tagged-Weak π-Method at HπS is a proper tool to measure B(E2), B(M1) for hypernuclear states with electromagnetic transition rates laying in the range (1/100ps)-(1/1000 ps)
- HπS with TOF based on RF phototubes will allow to investigate hypernulear states with electromagnetic transition rates up to (1/20 ps)