Muon capture on deuteron and ^{3}He

L.E. Marcucci [1 2] M. Piarulli [3] M. Viviani [2] L. Girlanda [4 5] A. Kievsky [2] S. Rosati and R. Schiavilla [3 6]

[1]Dipartimento di Fisica, Università di Pisa, Italy

[2]Istituto Nazionale di Fisica Nucleare sez. di Pisa

[3]Department of Physics, Old Dominion University, Norfolk, VA 23529, USA

[4]Dipartimento di Matematica e Fisica "E. De Giorgi", Università del Salento, Italy

[5]Istituto Nazionale di Fisica Nucleare sez. di Lecce, Italy

[6]Jefferson Lab, Newport News, VA 23606, USA

Muon capture reactions on light nuclei provide an ideal testing ground for models of the nuclear interaction and electroweak currents, which in turn are crucial for understanding many astrophysically relevant reactions. In this spirit we have studied in Ref. [1] the reactions

$$\mu^- + d \to n + n + \nu_\mu, \quad (1)$$

$$\mu^- + {}^3\mathrm{He} \to {}^3\mathrm{H} + \nu_\mu. \quad (2)$$

In the first reaction, the stopped muons are captured from two hyperfine states $f = 1/2$ or $f = 3/2$, but we focus on the doublet capture rate Γ^D which has been found to be ~ 40 times larger than the quadruplet. As for the muon capture on ^{3}He, it can also occur through the two- (nd) and three-body (nnp) breakup channels of ^{3}H, which however have branching rations respectively of 20% and 10%. Bound and continuum nuclear wave functions were generated with the Hyperspherical Harmonics method [2]. It consists of expanding the nuclear wave function in a basis of hyperspherical harmonics functions, and determining the coefficients of the expansion using the Rayleigh-Ritz and Kohn variational principle. We used as input the AV18 and chiral N3LO two-nucleon potentials, supplemented respectively by the Urbana IX and chiral N2LO three-nucleon potentials for the $A = 3$ systems. For the nuclear weak charge and current operators, two models were used: the first, developed within a meson-exchange framework and including contributions from Δ excitations (so-called "Standard Nuclear Physics Approach" -SNPA), and the second, within heavy baryon chiral perturbation theory (HBCHPT) at N3LO [3,4]. The one-body components are the same for both models, while the two-body components differ. In both models we calibrated the axial component by fitting tha Gamow-Teller matrix element in tritium beta-decay. The SNPA model is thus completely determined. In the HBCHPT model, this is done by adjusting the low-energy constant d_R of a two-nucleon contact term. Two further contact terms, named g_{4S} and g_{4V}, contribute to the electromagnetic current (whose isovector component is related to the corresponding weak current through isospin transformation) and are fixed to reproduce the triton and ^{3}He magnetic moments. This fitting procedure is performed for different values of the cutoff Λ of the effective theory. The variation with Λ can be taken as estimate of the theoretical uncertainty.

For the muon capture on deuteron we have included all channels with total angular momentum of the final nn state, $J \leq 2$ and relative orbital angular momentum $L \leq 3$, i.e., in a spectroscopic notation, $^1S_0$, $^3P_0$, $^3P_1$, $^3P_2$, $^1D_2$ and $^3F_2$. Partial waves of higher order contribute less than 0.5% to the rate. The results for the total doublet capture rate are presented in the Table 1, while

SNPA (AV18)	Γ^D
g_A=1.2654(42)	390.4(7)
g_A=1.2695(29) 390.9(7)	
HBCHPT (AV18)	Γ^D
$\Lambda = 500$ MeV	392.7(8)
$\Lambda = 600$ MeV	392.6(8)
$\Lambda = 800$ MeV	392.4(7)
HBCHPT (N3LO)	Γ^D
$\Lambda = 600$ MeV	393.6(7)

Table 1
Total rate for muon capture on deuteron, in the doublet initial hyperfine state, in s^{-1}. Two values for the axial-vector coupling constant g_A have been used, but in each case the GT matrix element for tritium beta decay has been refitted. The numbers among parentheses indicate the theoretical uncertainty arising from the adopted fitting procedures.

individual partial wave contributions to the differential capture rate $d\Gamma^D/dp$ as function of the nn relative momentum p, calculated with the SNPA (AV18) model, are shown in Fig. 1.

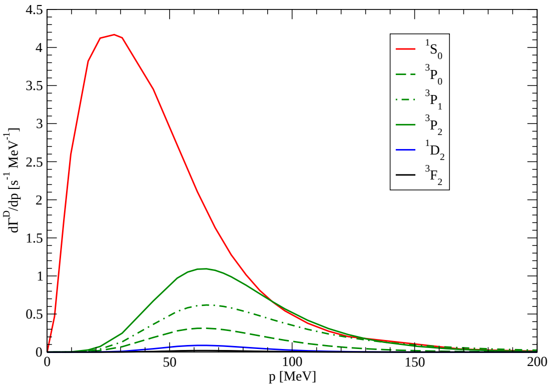

Figure 1. Differential capture rate $d\Gamma^D/dp$ as a function of the nn relative momentum p in MeV. The calculation is performed with the SNPA (AV18) model.

The model depedence due to interactions, currents and the cutoff Λ is at the 1% level. In conclusion, we ascribe to reaction (1) a total doublet capture rate in the range

$$\Gamma^D = (389.7 - 394.3)\mathrm{s}^{-1}. \tag{3}$$

While present measurements are not very precise, with errors of order 10%, there are prospects for a factor 10 better precision at the PSI by the MuSun Collaboration[5]. The experimental situation for reaction (2) is much clearer [6], with a total capture rate of

$$\Gamma_0 = 1496(4)\mathrm{s}^{-1}. \tag{4}$$

Our result for this rate are collected in Table 2

The model dependence is, again, very weak, at the 1% level, and excellent agreement with the experimental result is found. In both examined cases, the weak model dependence is a consequence of the procedure adopted to constrain the weak current.

SNPA (AV18/UIX)	Γ_0
g_A=1.2654(42)	1486(8)
g_A=1.2695(29)	1486(5)
HBCHPT (AV18/UIX)	Γ_0
$\Lambda = 500$ MeV	1487(8)
$\Lambda = 600$ MeV	1488(9)
$\Lambda = 800$ MeV	1488(8)
HBCHPT (N3LO/N2LO)	Γ_0
$\Lambda = 600$ MeV	1480(9)
EXP.	1496(4)

Table 2
Total rate for muon capture on ^{3}He, in s^{-1}. The numbers in parentheses indicate the theoretical uncertainties due to the adopted fitting procedure. The triton and ^{3}He wave functions are obtained from the AV18/UIX and N3LO/N2LO Hamiltonians.

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