Measurement of the Rate for $\mu^- + He^3 \rightarrow H^3 + \nu$ *

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A measurement of the rate for $\mu^- + He^3 \rightarrow H^3 + \nu$ has been made using a high pressure, He^3 filled, gas scintillation counter as the target for stopping muons.(1) The counter is well suited to the problem since it allows for clean separation of the 1.9 MeV triton recoils and μ decay electrons, which are 300 times more numerous. The tritons, because of their short range, are detected with close to 100% efficiency, whereas the energy lost in the counter by the minimum ionizing electrons is less than 0.8 MeV in all cases. Furthermore, pulses from such electrons are rejected with 90% efficiency by surrounding electron detectors. The measured reaction rate is

$$\lambda_c = \lambda_d \, (t/e),$$

where t is the recoil triton count and e is the decay electron count for muons stopping in He, each corrected for efficiency of detection. λ_d is the μ^- decay rate in He^3 which is taken equal to the free μ decay rate.

The gas counter consists of three separate light-tight compartments in a cylindrical steel pressure vessel, as shown in Fig. 1. Counters 3 and 4 share a common gas system of 100% Xe and are used both in the stopping muon telescope and in detecting μ decay electrons. The He counter, #5, is separated from counters 3 and 4 by a thin-walled (.018 in.) cubical Ag box of 1 liter capacity. Scintillation is viewed by a 5 inch phototube (EMI 9579) through the glass pressure window and light pipe, on top of which there is a 1/16 in. thick CsI (Tl) crystal, as shown. The Ag box has a high Z diffusely reflecting coating, inside and out, of 10 mg/cm^2 of smoked CsI (pure) and the remaining reflecting surfaces of the electron counter have a similar coating of MgO.All the reflecting surfaces have coatings of 100 μg/cm^2 of diphenylstilbene wave length shifter and transmitting surfaces have coatings of 25 μg/cm^2. The three counters were maintained at 21°C and 360 psia during the experiment. By proper time analysis delayed events from muons stopping in high Z material can be rejected, but it is essential to prevent detection of those muons which stop in the glass. To be detected at all, such a muon must pass through the CsI (Tl) crystal (scintillation decay time of 0.55 μsec.). It is then rejected by a pulse shape discrimination circuit (PSD) which sorts out the characteristically long pulse. PSD is also used to count μ decay electrons.

The addition of 10% Xe to the He enhances the scintillation efficiency by about a factor of 4 over pure He. It also reduces the correction for triton recoils which leave the counter by a factor of 2.5. Except for certain auxiliary runs, counter 5 was filled with 40 psi Xe and 320 psi He (1 mole). The evidence from a study of the muon mean lives in this mixture is that there is no detectable stealing of muons from the He mesic atom by the Xe.

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Any such stealing does not affect the final result since the ratio t/e is measured. The slow neutron reaction $n + He^3 \rightarrow H^3 + p + .76$ MeV and the triton recoils yield an energy scale of zero intercept. The widths of the peaks are also consistent with photoelectron statistics when account is taken of a spatial nonuniformity of 4% rms deviation from the mean.

A stopping muon coincidence is

$$\mu \equiv 1\ 2\ 3\ 5\ \overline{4} \quad (\overline{PSD}).$$

The thresholds on the counter 3 and counter 5 pulses prevented detection of beam electrons and enhanced rejection of muons stopping in glass. Candidates for muon associated events are

$$T \equiv 5(\overline{PSD})\ \overline{3}\ \overline{4}\ \overline{2},$$

$$E_{34} \equiv (3 \text{ and/or } 4)\ \overline{2},$$

$$E_{PSD} \equiv (PSD)\ \overline{3}\ \overline{4}\ \overline{2}.$$

The PSD, #3, #4 and #5 pulses in the latter are shaped pulses with frequently checked, stable thresholds. After a 0.7 μsec delay, the μ pulse triggers a timing circuit which sorts the gated candidates into 8 time bins: four of 1 μsec, three of 2 μsec and one of 8 μsec duration. E_{34} and E_{PSD} are counted in separate banks of Sodeco registers. The T pulse gates the RIDL 400 channel pulse height analyzer and the timing system routes the linear triton pulse to one of 8 time subgroups of 50 pulse height channels each. Measurements in He^4 of decay rates for μ^+ and μ^- mesons yielded $\lambda^+ = 0.4530 \pm 0.0010\ (\mu sec)^{-1}$ and $\lambda^- = 0.4538 \pm 0.0016\ (\mu sec)^{-1}$ where the μ^- rate is corrected for captures.[2] The errors quoted are statistical only. The error in decay rate or amplitude due to timing uncertainty is 0.5% but cancels out of any ratio. The agreement for $\lambda^{\pm}$ indicates that, with high confidence, the negative electron count was contaminated by less than 7% glass stops.

A more sensitive test was made for stops in light elements other than He by filling counter 5 with 100% Xe. The residual long time component count was (2 ± 1)% of the electron count in the standard gas mixture. This is consistent with the expected number of stops in the wave length shifter. The final electron count is corrected for this effect.

The efficiency of counter 4 for electron detection, η_4, was measured in a separate run with 200 psi Xe and 160 psi He^4 in counter 5. E_{34} and E_{PSD} efficiencies are obtained by cross calibrating to this result. With this amount of stopping material in counter 5 electron path lengths down to 1 cm yielded pulse heights almost entirely free from tube noise and low level random counts. The E_{34} coincidence was changed to $E_4 \equiv 4\ 5\ \overline{2}$ and the same three simultaneous time analyses were performed as during the main runs. The efficiency of counter 4 is $E_4 / (E_4 + T + E_{PSD})$ for zero threshold in counter 5. η_4 was measured for two thresholds corresponding to minimum path lengths in counter 5 of 1.8 and 3.6 cm. About 90% of the decay electrons meet the lower threshold requirement and 60% the higher one, yet the two measurements agree within statistics. The efficiency of counter 4 is 0.613 ± 0.018, the average for the two runs. The error of 3% represents mainly the uncertainty in extrapolation to zero threshold in counter 5. The overall efficiency for electron detection is 0.90 ± 0.03. This differs from the 100% geometrical efficiency because of the non-zero thresholds in counters 3 and 4.

Two runs were made during which 4500 triton recoils were observed in run I, and 2500 in run II. Figs. 2 and 3 show the pulse height spectra for these runs for the first 8 μsec of analyzed time, with and without random background subtracted. The stopped muon rate was 3.5 sec^{-1} and consequently 30 tritons/hr. were observed. In the first run a residual impurity caused a reduced scintillation efficiency so that the resolution of the triton peak was 27% (full width at half maximum). The gas was repurified for run II and the triton resolution for it was 15%. There is a time dependent background under the triton peak which is likely due to muon capture to unbound H^3. In run II this background is seen cleanly both below and above the peak. Under the peak the background can be interpolated to within 2% of the peak area assuming a smoothly varying function. The remaining tritons fit a gaussian curve. A similar procedure can be applied to run I by fitting the spectrum to a gaussian plus slowly varying background. Although the valley is narrower the counts in it are still almost entirely due to the background seen in run II. Alternatively the ratio of background/peak from run II can be applied to run I. The latter approach, which we have adopted, yields the smaller error. A further correction to the triton count must be made for those recoils which leave the counter. At present an estimate has been made of this effect based on a plausible stopped muon distribution. If the stop distribution were uniform throughout the counter this correction would be 5%. Since the stops are less dense near the surface, for the present the correction is taken as (3 ± 2)%. The overall error in the triton count is 4%.

The reaction rate measured in this experiment is

$$1440 \pm 90 \ sec^{-1}.$$

Further analysis of the electron detection efficiency, triton surface correction, and triton background subtraction is expected to yield a smaller error. This result is in good agreement with other experiments:

$1520 \pm 50 \ sec^{-1}$	Auerbach, et al.[3]
$1410 \pm 140 \ sec^{-1}$	Falomkin, et al.[4]

Our result is also in agreement with the theoretical prediction[5] of 1530 sec^{-1}, based on the Universal Fermi Interaction with conserved vector current and $g_P/g_A = +8$. Experiments on muon capture in hydrogen [6] and oxygen [7], on the neutron asymmetry in muon capture [8], and on the radiative muon capture [9], suggest a larger value of the pseudoscalar coupling. If $g_P/g_A = 16$, the predicted rate reduces to 1400 sec^{-1}. However, the present uncertainty in the theory is 10%, so that the He^3 capture experiments agree with either value.

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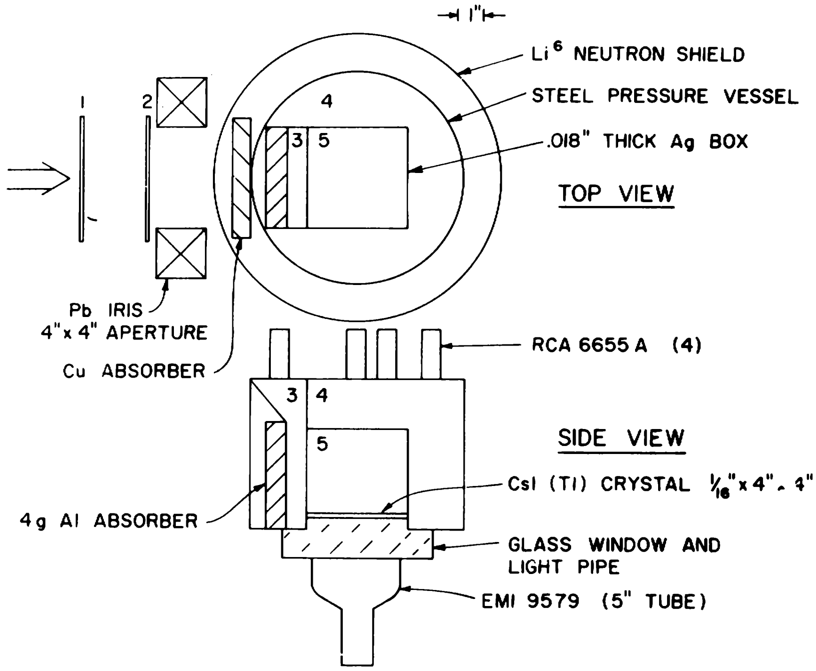
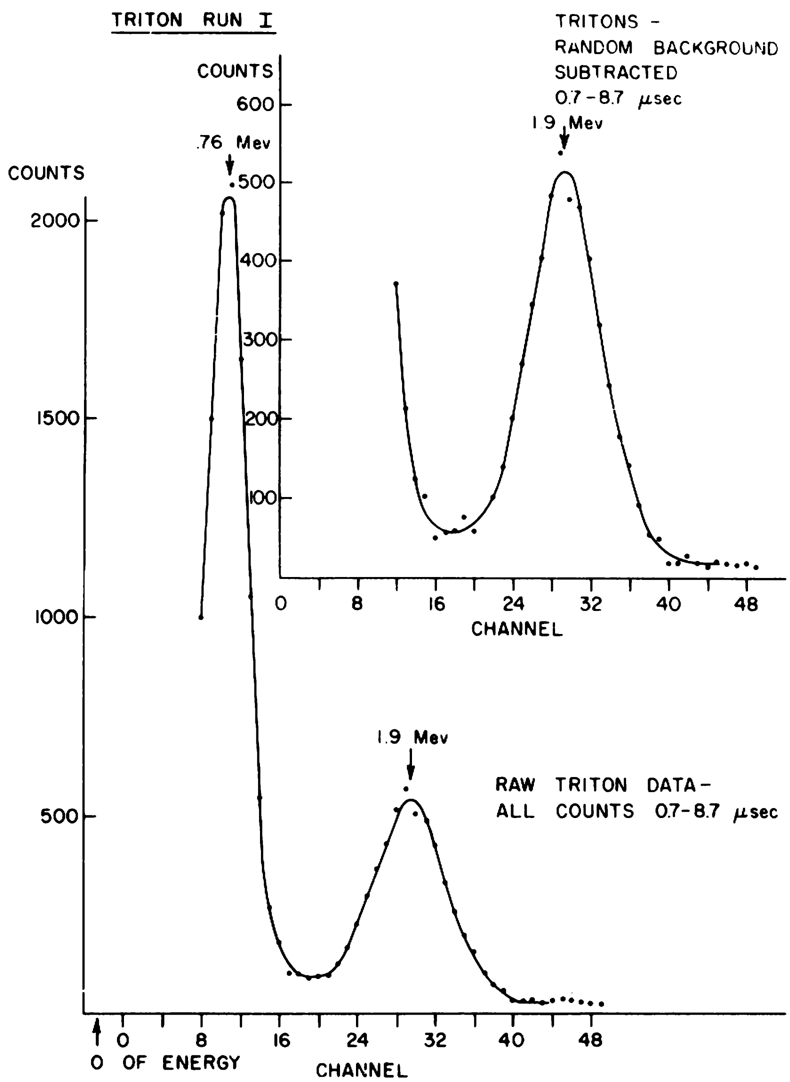
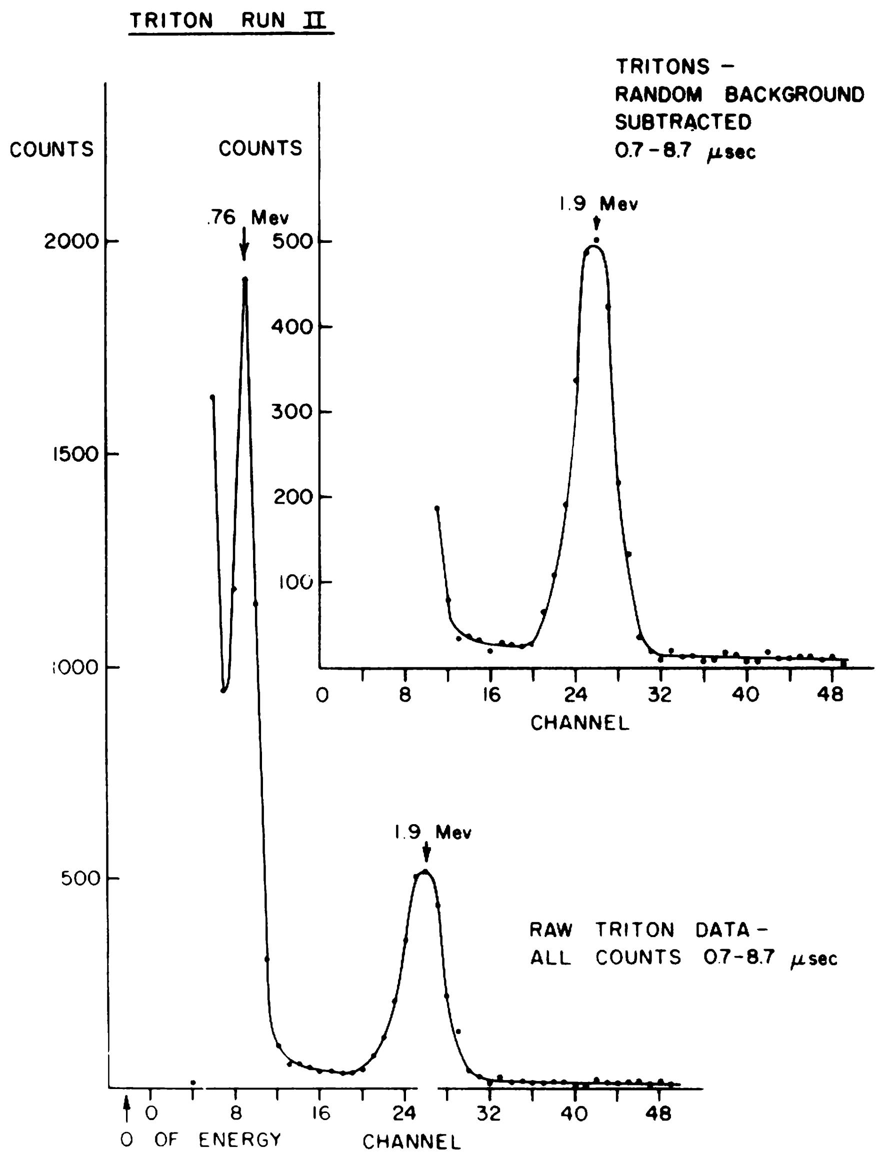


1. Experimental Apparatus



2. Recoil Triton Spectra, Run I



3. Recoil Triton Spectra, Run II