EXPERIMENT FOR DIRECT MEASUREMENT OF FINAL STICKING ω_s IN MUON CATALYZED dt-FUSION

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Deuterium-tritium fusion, induced by muons, has recently got great attention, because yields exceeding 100 fusions per muon were experimentally observed. The already measured dt-cycle rates have proved to be large, however the maximum fusion output seems mainly to be limited by muon-alpha sticking (probability ω_s):

$$t\mu + d \longrightarrow d\mu t \begin{cases} \xrightarrow[1-\omega_s]{} \alpha + \mu + n \\ \xrightarrow[\omega_s]{} \alpha\mu + n \,. \end{cases}$$

One should distinguish initial sticking ω_s^0, immediately after the fusion reaction, and final sticking ω_s which is smaller, because the $\mu\alpha$ system has initially a 3.5 MeV recoil energy and can shake off the muon during slowing down. According to recent theoretical calculations $\omega_s = 0.57\%$ and $\omega_s^0 = 0.87\%$ /1/. Unfortunately, there have been no direct measurements of ω_s up to now. Indirectly, the value of ω_s was determined from the muon losses in the muon catalyzed dt-cycles or from observation of the X-rays from the $\alpha\mu$ excited atoms. The obtained results vary from $\omega_s = 1\%$ to $\omega_s = 0.3\%$.

A first direct measurement of the muon sticking probability, ω_{dd}, in the d—μ—d fusion has been performed earlier at LNPI: $\omega_{dd} = (12.2 \pm 0.3)\%$ /2/. The method is based on measurement of charge produced by the fusion products in an ionization chamber (IC) filled with deuterium at 90 atm. The separation of the «sticking» events is achieved via the different charge recombination factors for doubly charged $(^3He)^{++}$ versus that of singly charged $(^3He\mu)^+$ particles.

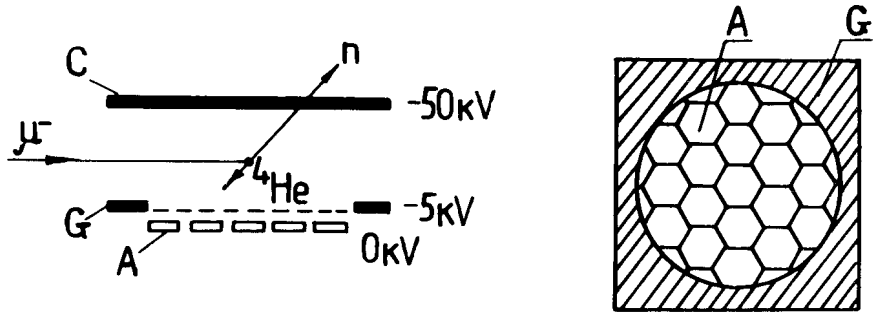

Fig. 1. Geometry of ionization chamber. A — anode, C — cathode, G — grid

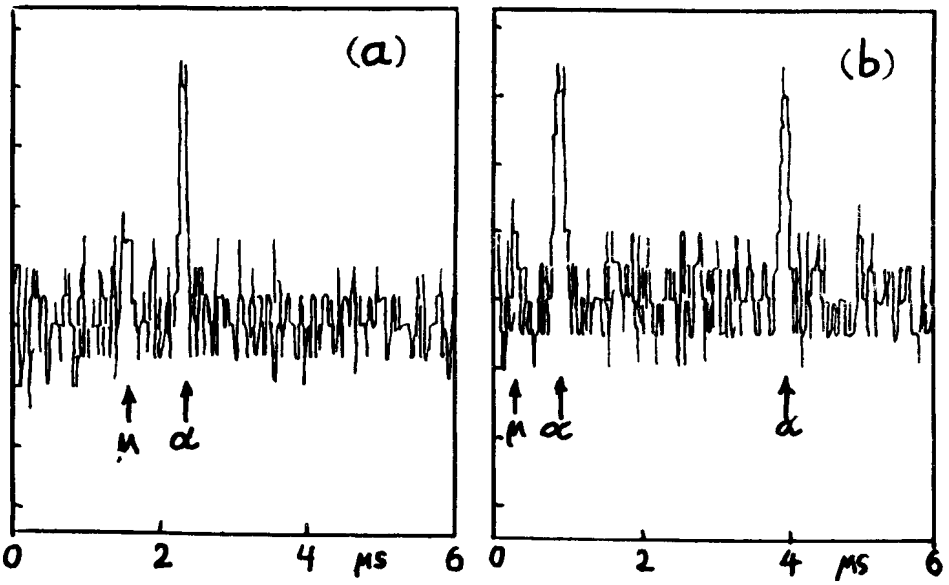

Fig. 2. Two FLASH ADC spectra of typical single dt-fusion (*a*) and double fusion event (*b*)

The application of the IC method to study dt-fusion is complicated by tritium beta-radioactivity that causes ionization current in the chamber. To overcome this problem, a modified IC was constructed with 19 separate anodes and with gas pressure increased up to 200 atm. Under these conditions, the tritium ionization currents at each anode are reduced by a factor of 19, while the charges produced by α and $\alpha\mu$ are collected mostly onto a single anode due to the short ranges of these particles.

Fig. 1 shows the geometry of the ionization chamber. The muons are stopped in the IC sensitive volume which is about 3 cm^3. In the electric field of ~50 kV/cm, the electrons produced by the stopping muons and by the fusion particles drift to the anodes at a drift velocity of 0.5 cm/μs. Each anode is read out via charge sensitive amplifier into FLASH ADC. The IC is filled with an equilibrium protium/deuterium/tritium mixture, and it can be cooled down to 40 K. The protium is added to the mixture to reduce the rate of unwanted background dd-fusion reaction. This reaction is reduced not

only due to the dilution effect but also due to the domination of HD molecules over the D_2 molecules in the mixture (note that $\lambda_{dd\mu}^{HD} << \lambda_{dd\mu}^{D_2}$). The setup includes also an array of 20 plastic scintillator counters that provide simultaneous detection of 14 MeV neutrons associated with dt-fusion. The efficiency of neutron detection is around 20%.

The whole setup was installed in the PSI muon beam. In April 1989 there was a two-week test run. Only 4 of the 20 neutron detectors were installed for this run. The main run (6 weeks) was performed in October—November 1989. During that run all parts of the setup were fully operated. The rate of muon stops in the sensitive volume of the chamber was about $600\ s^{-1}$. The efficiency of the stopped muon registration by IC electronics was 50%, while that of the α and $\alpha\mu$ signals was close to 100%. The trigger selected events with at least two signals from the IC (μ—α events or μ—α—α events as shown in fig. 2). The statistics of the first run was about 50000 μ—α events. In the main run about 10^6 μ—α events have been detected, with $2\ 10^5$ events accompanied by detected neutrons.

Here only some preliminary results are presented from the analysis of the data from the April run. The IC was filled with a triple mixture in equilibrium state with the following atomic concentrations: $C_p=0.895$, $C_d=0.105$, $C_t=0.00044$. The measurements were performed at T=300 K and T= =110 K.

1. It was shown that the background in the amplitude spectrum in the $\alpha\mu$ region is low enough, therefore one can hope to obtain quantitative results for ω_s after the analysis of the main data.

2. The time distributions of the μ-α events allowed to determine the rate of pdμ-molecule formation:

$$\lambda_{pd\mu} = (4.6 \pm 0.3) \cdot 10^6 \cdot s^{-1} \qquad \text{at } T=300 \text{ K},$$

$$\lambda_{pd\mu} = (3.8 \pm 0.7) \cdot 10^6\ s^{-1} \qquad \text{at } T=110 \text{ K}.$$

These results do not support the conclusion of the autthors of /3/ who reported on the rise of $\lambda_{pd\mu}$ with the decrease of T.

3. From the analysis of the yields of dt-fusion per muon it became possible to determine for the first time the dtμ-molecule formation rates in HD complex:

$$\lambda_{dt\mu}^{HD} = (130 \pm 30) \cdot 10^6\ s^{-1} \qquad \text{at } T=300 \text{ K},$$

$$\lambda_{dt\mu}^{HD} = 15 \cdot 10^6\ s^{-1} \qquad \text{at } T=110 \text{ K}.$$

The observed resonant behaviour of $\lambda_{dt\mu}^{HD}(T)$ offers some interesting possibilities for detailed studies of μ — catalyzed dt-fusion.

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