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DETECTION EFFICIENCY OF THE MULTIPLE MUON CATALYSIS

2000

1 Introduction

The MCF experimental study is being conducted now on the JINR phasotron by a large international collaboration (the project MU-CATALYSIS). Recent results have been published in [1], [2] and [3]. The scheme of this process is shown in Fig. 1.

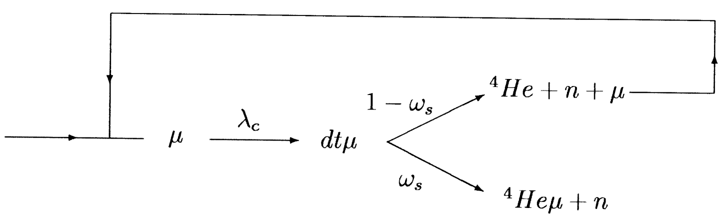

Figure 1: The scheme of the process of the multiple muon catalysis in the D-T mixture

A negative muon stopped in the D-T mixture can cause up to 100 d+t fusion reactions in each of which a 14 MeV neutron escapes. Intensity of the process is determined by the cycling rate (λ_c). It can be $\geq 100\,\mu s^{-1}$ under optimal conditions.

Novel methods are used in [1], [2] and [3] both to register the fusion reaction and for the data analysis. The main parts of the experimental setup are the high pressure tritium target and full absorption neutron spectrometer (FANS) [4] which consists of two identical scintillation detectors of large sizes ($\phi 31\,cm\,x\,15\,cm$) symmetrically located around the target.

The duration of the neutron detector (ND) signal is formed to be 30 ns. Obviously, for the above mentioned very high neutron appearance rate their signals can overlap one another. To avoid the distortion caused by the pile-up effects flash ADC are used to measure *charge* Q of the neutron detectors. The number of *detected* neutrons N_d is extracted using the value of the *unit charge* q, which is related to a single neutron:

$$N_d = Q/q$$

To determine q a special calibration exposure should be carried out under conditions providing a sufficiently low cycling rate when the ND signals ("**cluster**" of codes) are confidently separated from one another. In this case the number of detected neutrons is equal to the number N_{cl} of clusters, hence

$$q = Q/N_{cl}$$

The absolute number of neutrons is determined as

$$N_0 = N_d/\epsilon = (Q/q)/\epsilon, \tag{1}$$

where ϵ is the neutron detection efficiency.

2 Motivation

The main idea for the flash ADC use is that the total charge per number of neutrons is conserved even in the case when the ND signals are mostly overlapped. However, it is true only for the zero charge threshold. Really, the cluster charge should be limited to reduce the low-energy background. The value of ϵ as a function of the threshold was calculated in [5]. It turned out that the factor of the efficiency loss due to the threshold, is $\epsilon_t \simeq 0.5$ for the real threshold used for the data analysis.

At a high neutron multiplicity clusters of small charge can overlap with other(s) and, hence, can be accepted (non-effective threshold). Obviously, this results in an increase in the detection efficiency as compare with the low neutron multiplicity. The real increase depends on several factors, such as the shape of the ND signal, the form of the response function, magnitude of threshold and measured cycling rate. Since one would expect the essential correction to the value of ϵ_t the problem requires the special consideration.

3 Approximately conserved total charge

It follows from the previous consideration (Eq. (1)) that if the total charge Q per number of neutrons was conserved for any threshold then one should use just the same calculated value of the ϵ, which corresponds to the measured value of q. Really, the total charge decreases with the threshold. Fortunately, this change is not large, which makes efficiency corrections relatively small.

This is most clearly seen for the simplest response function uniformly distributed from a to b (Fig. 2, left). In this case the total is charge is

$$Q = C \cdot (b^2 - a^2)/2, \tag{2}$$

where C is the normalization parameter. In the real case the boundary recoil proton energy for $14 - MeV$ neutrons is $E^b_{ee} = 8.7\,MeV$ (on the scale of equivalent electron energy), and the chosen threshold corresponds to the energy $E^t_{ee} \simeq 1/6\,E^b_{ee} = 1.5\,MeV$. It follows from Eq. (2) that a 17% change in an efficiency corresponds only to a 3% change in the total charge.

The real response function is shown in Fig. 2 on the right [5]. As is seen, there is an intensive tail in the region of low energy (charge). It leads to a sufficient efficiency loss even for a relatively low threshold. However, as simple estimations show, the corresponding change in the total charge with a threshold is not large. Hence, one should expect that corrections to the detection efficiency are relatively small.

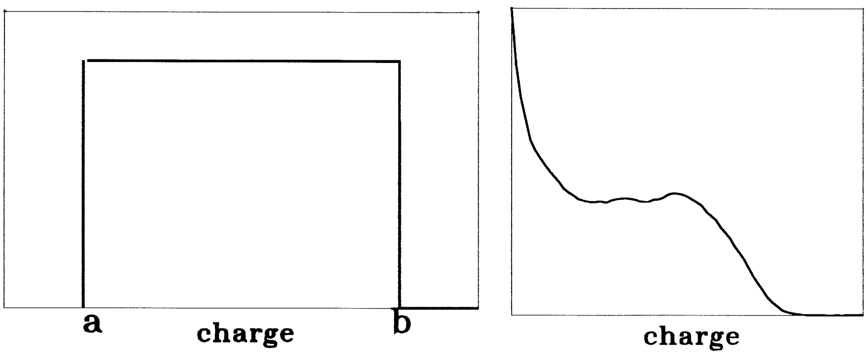

Figure 2: Uniform (left) and real (right) response functions

4 Corrections to the neutron detection efficiency

Detailed calculations were carried with the Monte-Carlo program package [6] fully simulating the MCF process in a D-T mixture and neutron detection and registration. In accordance with the procedures used in the real data analysis the calculations were carried out by three methods [1].

1."Standard" method.

The time distribution of all detected neutrons is analyzed. Calculations with programs [6] yielded the number of detected neutrons accepted for zero threshold N_n, number of clusters N_{cl} and total charge Q. Cycling rate λ_c and the neutron detection efficiency without the threshold ϵ_0 were input parameters. The threshold was a variable parameter.

Calculations were made for low $(1 \cdot n/\mu)$ at high $(30 \cdot n/mu)$ multiplicity. The unit charge was determined for low (l) multiplicity case: $q = Q^l/N^l_{cl}$. The reconstructed relative efficiency $\epsilon_{rr}(\equiv \epsilon_t)$ was calculated according to expression

$$\epsilon_{rr} = (Q/q)/N_n$$

Some results are presented in Fig. 3. The simplest case with a uniform response was considered for checking. For the maximum measured value $\epsilon_0\lambda_c \simeq 40\,\mu s^{-1}$ the relative correction to the efficiency is $\simeq 12\%$.

2. Neutron multiplicity in a definite time interval.

The distribution of the number of neutrons in the definite time interval T is considered. Events are selected according to the condition that the muon does not disappear in this interval. Those events which correspond to nonsticking of muon to helium in reaction (1) give rise to the Poisson distribution with the mean value $M = \epsilon\lambda_c T$.

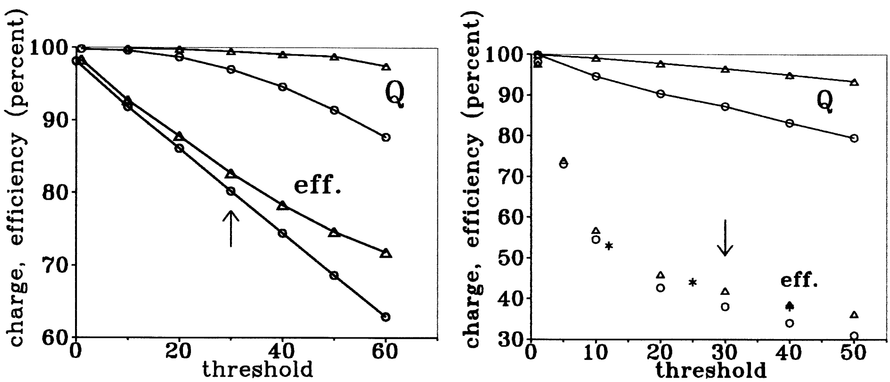

Figure 3: Dependencies of the total charge Q and the relative detection efficiency (eff.) on the threshold for the low (circles) and high (triangles) neutron multiplicity. Left: for the uniform response function, right: for the real response. Stars correspond to the real data analysis with the appropriate thresholds.

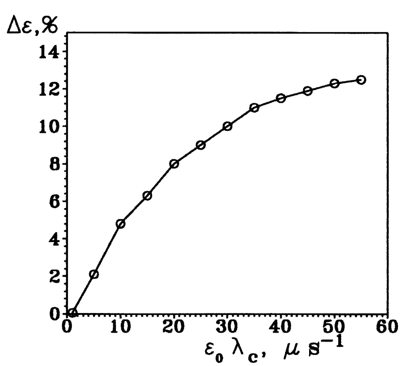

Figure 4: Relative correction $\Delta\epsilon$ to the detection efficiency as a function of the measured value of $\epsilon_0\lambda_c$ for the chosen threshold, of $1.5\,MeV$.

One should expect that corrections to the efficiency for this method are the same as for the previous one because of the charge distribution is measured again, and the same normalization procedure is used. Nevertheless, calculations of the multiplicity spectra were carried out for a set of threshold values. As one expected, the charge distribution weakly changes with the threshold, but, being normalized on the unit charge, shows substantial dependence on it.

It follows from the analysis of such distributions that the corrections to value of ϵ are practically the same as in the standard method. The relative correction to the detection efficiency as a function of $\epsilon_0\lambda_c$ for the chosen threshold $E_{ee} = 1.5/, MeV$ is shown in Fig. 4. These results were used in the analysis of real data.

3. $t_e - t_n$ - spectra.

The distribution of time between the muon decay electron t_e and the last detected neutron t_n is considered. The value of $\epsilon_0\lambda_c$ is determined from the slope of the fast component of this spectrum. Corrections to the efficiency due to the threshold are of the same nature as in the previous methods. A cluster of low charge, rejected in the low multiplicity case, can be accepted being overlapped with another cluster.

Calculations were carried out with the programs [6] aimed to obtain and analyze $t_e - t_n$ - spectra for various $\epsilon_0\lambda_c$ and the thresholds. The results for the low $(1 \cdot n/\mu$ and high $(30 \cdot n/\mu$ multiplicity are shown in Fig. 5.

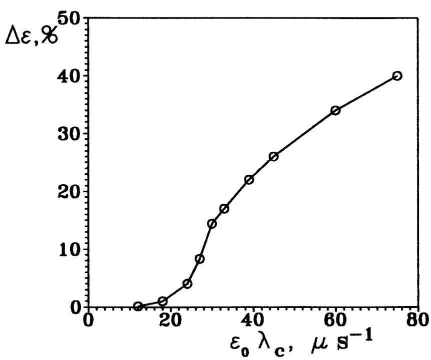

Figure 5: The same as in Fig. 4 for $t_e - t_n$ distributions.

5 Conclusion

This paper describes a part of the analysis procedure developed within the framework of the "MU-CATALYSIS" project. Its results are necessary to perform an accurate analysis of the data obtained. One of the important results is that corrections to the detection efficiency are essentially different for the multiplicity and $t_e - t_n$ methods. For the maximum measured values $\epsilon\lambda_c \simeq (40-50)\, \mu s^{-1}$, these corrections are $\simeq 10\%$ and $\simeq 20\%$ respectively. This work will be useful for several groups in different laboratories dealing with the MCF data analysis. Also, the results obtained would be interesting for other specialists using the charge measurement technique.

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Фильченков В.В. E15-2000-224
Эффективность регистрации реакций множественного мюонного катализа

Работа является дальнейшим развитием экспериментального метода, с успехом используемого в ЛЯП ОИЯИ при исследовании мюонного катализа. Рассмотрено влияние эффекта наложения сигналов продуктов катализа на эффективность их регистрации. Показано, что эффективность слабо зависит от множественности процесса.

Работа выполнена в Лаборатории ядерных проблем им. В.П.Джелепова ОИЯИ.

Сообщение Объединенного института ядерных исследований. Дубна, 2000

Filchenkov V.V. E15-2000-224
Detection Efficiency of the Multiple Muon Catalysis

This work is devoted to further development of the experimental method successfully used at JINR (Dubna) for the muon-catalyzed fusion (MCF) study. Influence of the pile up effects on the MCF product detection efficiency is considered. It is shown that the efficiency slightly depends on the MCF multiplicity.

The investigation has been performed at the Dzhelepov Laboratory of Nuclear Problems, JINR.

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