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IMPROVEMENT OF THE TOFUS APPARATUS

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ABSTRACT

The TOFUS experiment was started in order to detect 2.45 MeV neutrons emitted from a Ti/D system in the gas phase. Improvements in the electronics of the neutron detector, based on the double scattering technique, and in the performances of a new cell are described.

1. INTRODUCTION

The TOFUS detector was designed and realized at the beginning of the studies on the Cold Fusion phenomena in order to detect the 2.45 MeV neutrons from the reaction D+D -> ^{3}He+n which seemed to be the undoubtable signature of the nuclear origin of the phenomenon. The goal of the TOFUS experiment (performed at the I.N.F.N. Laboratories in Torino) was to measure the energy of each detected neutron, instead of counting their number in correlation with the time or/and with thermodynamic conditions of the D/metal system.

In the following we will describe the features of this detector together with its performances and the most recent improvements on the electronics and on the gas loading monitor system.

2. THE DOUBLE SCATTERING TECHNIQUE

The detector and its operating principle were already described elsewhere [1,2,3]: let us recall just the geometry of the set-up, consisting of a block (START) of three scintillators for detecting the first scattering of a neutron arriving from a cell put in front of it and two arrays A and B (STOP) for detecting the second scattering.[see fig.1 in ref.1] The scheme of the flux of information coming from the detector signals up to the neutron energy reconstruction algorithm and to the correlations with other kinematic variables is shown in fig.1.

The signals from the PM's at both ends of the scintillator slabs are sent to an equal number of TDC's and ADC's channels, through Constant Fraction Discriminators (CFD). These channels are read by the computer on-line acquisition system, buffered and stored into a mass memory unit (disk or magnetic tape). The computer is a MicroVax II, the acquisition system is the DAQP package developed at C.E.R.N. Data Division and the magnetic tape unit is a CYPHER-6500 bpi.

Together with the ADCs and the TDCs, a number of scalers is recorded: they count the number of logical operations (AND, OR, XOR) amongst signals, which have a physical meaning. A Pattern Unit (P.U.) accounting for the multiplicity in the START array is recorded too.

From this information it is possible to evaluate the Time of Flight (TOF) between the START and the STOP and the impact points of the neutron in the START and in the STOP slabs. With the kinematical relations other physical quantities (n energy before and after the first scattering, the first scattering angle, the recoil proton energy ...) can be calculated. The neutron energy, as emitted from the Cold-Fusion cell, which is the relevant physical variable, is reconstructed with an incertitude due to the TOF error (±1ns) and to the impact position approximation on both detectors. This uncertainty has a double origin: ±4.5 cm in the horizontal direction for the START slabs and ±1.0 cm in the vertical direction for the STOP slabs, due to the finite granularity of the scintillators and ±2.0 cm in the vertical direction for the START slabs and ±2.0 cm in the horizontal direction for the STOP slabs, due to instrumental precision.

The reconstructed energy distribution for a 2.45 MeV neutron [see fig.2 in ref.1] has a FWHM ≈1.1 MeV, as evaluated both from a Monte Carlo simulation and a calibration with the neutrons emitted from an Am-Be source in coincidence with the associated γ's. The overall efficiency of the detector, including the solid angle and the acceptance, has been measured as a function of the distance between the neutron source and the START by mean of the same Am-Be source and is reported in fig.2.

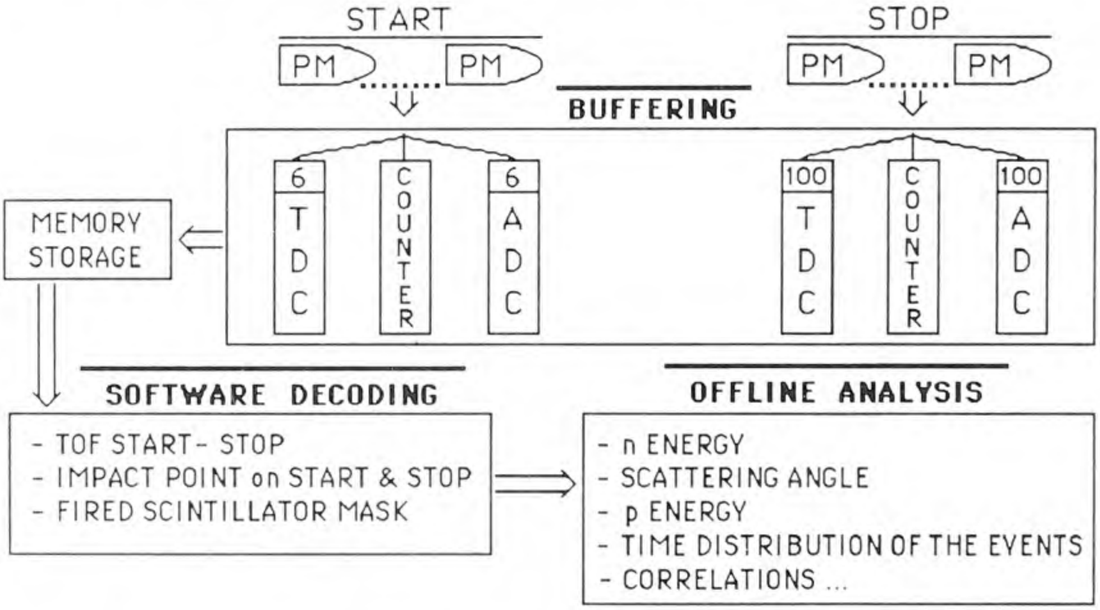

Fig.1 The TOFUS experiment information flow diagram.

3. THE TRIGGER OF THE DETECTOR

From the physical point of view a "good" event, i.e. a 2.45 MeV neutron emitted from a pointlike source in front of the detector, must satisfy the following requirements:

1) one and only one scintillator in the START array must be fired in coincidence with one and only one in the STOP (A.XOR.B): in this way events suffering multiple scattering are rejected and spurious events due to cosmic rays are minimized;

2) the time interval between the START and the STOP signals must be suitable to take into account the time spent by the neutron to travel from the START to the STOP arrays: this time is spread over 35 ns due to the different velocities of the fastest

neutrons which lose few KeV in the START and the slowest ones which lose ≈1 MeV at a scattering angle of ≈ 50°.

The hardware trigger is schematized in fig.3 : it is divided into two parts, the right one concerns the START signals while the left one concerns the STOP signals.

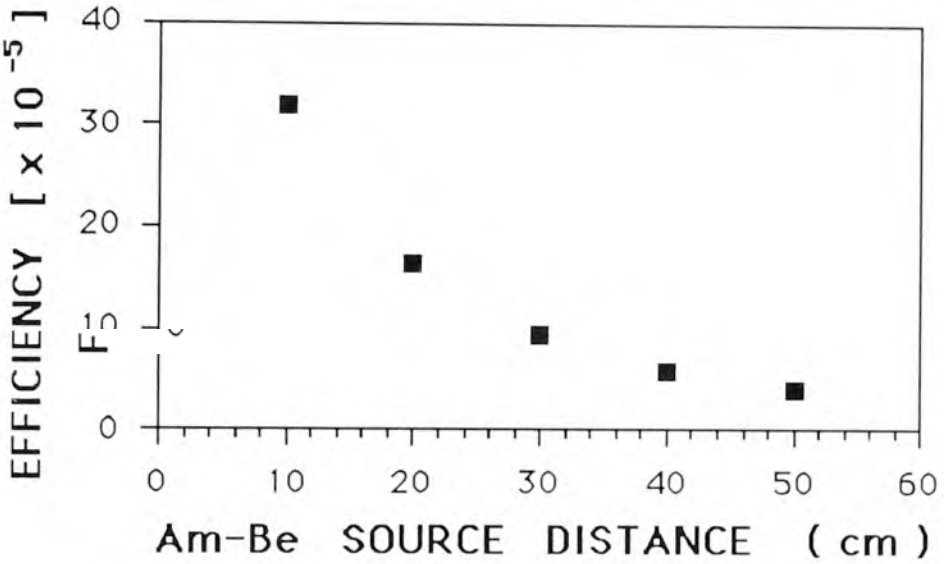

Fig.2 Detector efficiency versus Am-Be source distance.

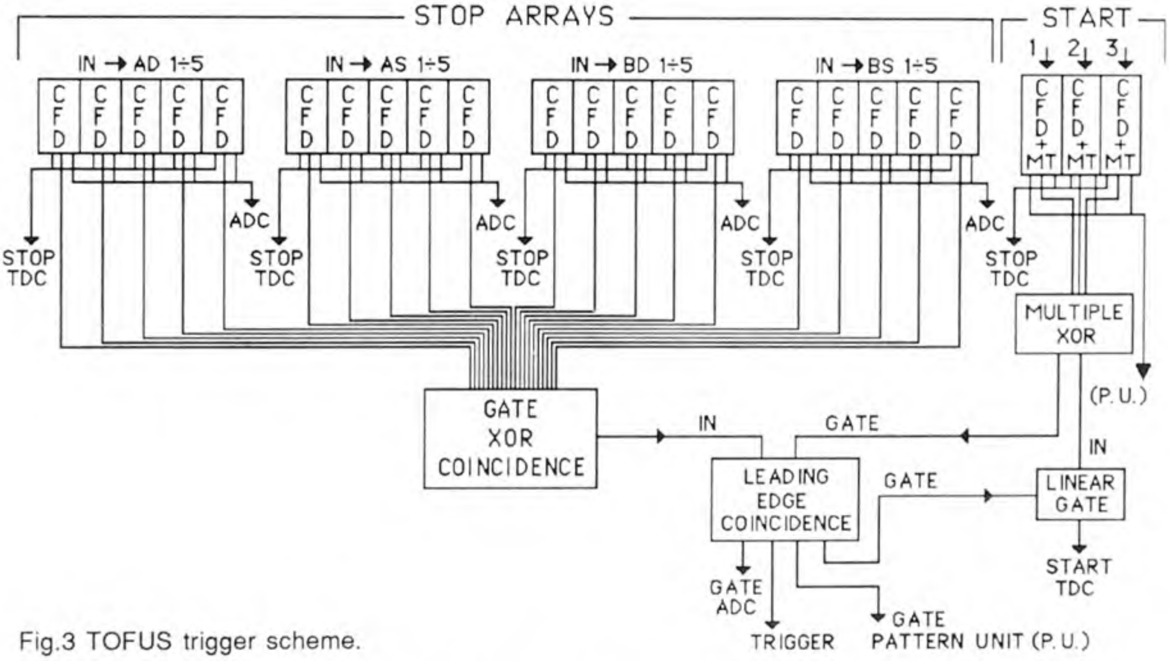

Fig.3 TOFUS trigger scheme.

The discriminated Mean Timer signals (CFD + MT) of each START slab are sent to a module which performs an exclusive OR amongst them (Multiple XOR): the output signal opens a 35 ns gate on a Leading Edge Coincidence. Looking at the left part of the figure, the signals from the five PM's for each side of the STOP arrays are sent, through CFD channels, to a GATE-XOR module which selects those events with a pattern of signals with one and only one fired PM at both sides of one and only one array, A or B. The output of this module is sent to the Leading Edge Coincidence, forming then the trigger.

Concerning the small amount of energy lost by the neutron inside the scintillators it must be noticed that the thrèshold of the PM's have been set at very low values: as a consequence a high amount of spurious signals due to the large electronic noise comes out from the PM's.

On the other hand the selective combination of logic AND and XOR in the trigger strongly reduces such a noise and a further reduction arises from the kinematical correlations in the software off-line analysis.

The last remark about the detector performances concerns the dead time for the whole event acquisition. The time for the formation of the signals (PM's) and for the electronic read-out (TDC, ADC, COUNTERS and P.U.) is less than 200 ns, while the time used by the computer for recording a triggered event is about 3.9 ms: this means that the maximum neutron rate that can be recorded is 250 hz, while neutron bursts for which the time interval between two detected neutrons is greater than 200 ns can be detected at the counting level (and then time correlated).

4. SPURIOUS BURSTS REJECTION

As an exemple of both the burst counting and the spurious rejection, the results of a particular data taking run, in which electronic troubles occurred, are illustrated.

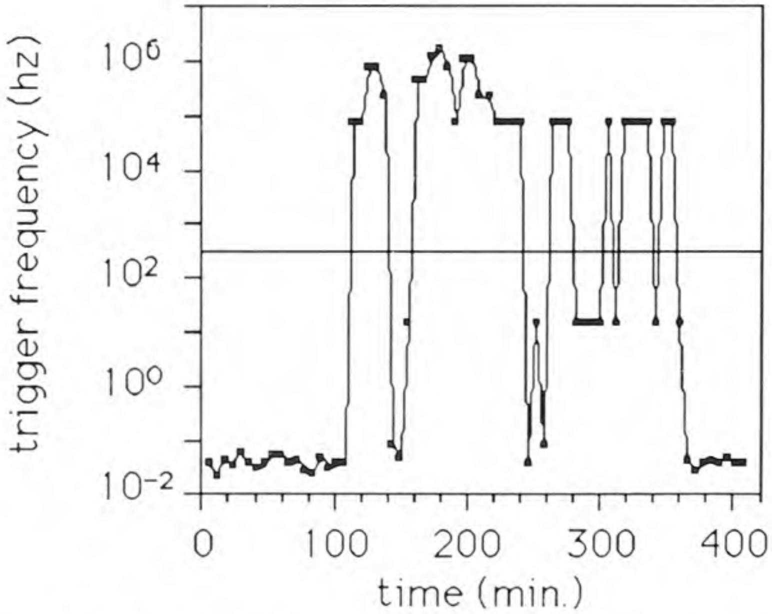

Fig. 4 Frequency of the hardware triggers versus time, in a data taking with bursts of spurious signals from electronic malfunctioning.

During a set of measurements (≈ 7 h) the overheating of a CAMAC-BUS produced a series of random spurious triggers in coincidence with the PM's usual noise. The trigger frequency increased up to values greater than the recording maximum frequency, 250 hz, as shown in fig. 4 as a function of the time. The straigth line at 250 hz separates the recorded and reconstructed events (lower half) from the only counted events (upper half): one can see that frequencies of the order of Mhz are detected at counting level.

As said before this run contained an anomalous amount of spurious events with average frequency ≈ 10 $\sec^{-1}$ at the trigger level: the capability of rejection of such spurious was fully satisfying, as demonstrated by the fact that the frequency of the accepted events after the kinematical reconstruction was ≈ 0.015 s^{-1} (≈ 0.006 s^{-1} in the interesting range 1.5÷3 MeV), the same average value obtained in all the other analogous runs 4).

5. THE Ti/D CELL AND THE VACUUM SYSTEM

For the 1991 runs a new cell has been designed (see Fig. 5a) in order to improve the control of the thermodynamic variables of the Ti-D system (temperature, pressure and gas concentration). This cell, containing 20 g of high purity Ti sponge, is the core of a sophisticated vacuum circuit entirely made in UHV material (SS304L) and sketched in fig. 5b. The cell with its contents can be heated and degased (up to 10^{-6} Torr at 750 °C by means of a turbomolecular pump) or filled by D_2 or H_2 alternatively: the pressures inside the circuits are monitored by a Piezoresistive Transducer, a Cold Cathode Gauge, an Ionization Gauge Penning Tube and a Pirani Gauge and all the temperatures are measured by K-type thermocouples.

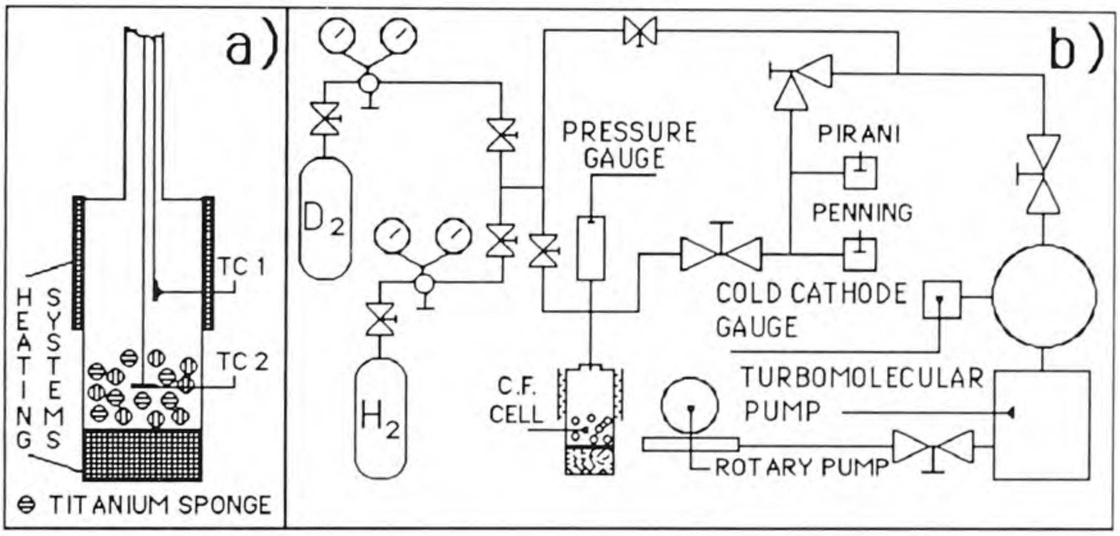

Fig.5 a) cell and b) vacuum system of the TOFUS experiment.

The typical phases of a cell cycle are: a) degasing of the Ti at 750 °C, b) filling of the cell with gas (D_2 or H_2), c) consecutive cycles of increasing (up to 540 °C) and decreasing (down to ≈ 28 °C) the Ti temperature. In the filling step a temperature rise of about 500 °C in few seconds was observed by TC2, in agreement with the exothermic formation of the hydride phase.

During these cycles the Ti temperature as a function of the time showed the caracteristic flat behavior in correspondance with the phase transition of the Ti/D system5), as shown in Fig. 6.

6. CONCLUSIONS

The TOFUS apparatus has been improved in the electronic trigger components and in the cell handling system. Performances on the time resolution in the acquisition and the control of the cell thermodynamic conditions are better than 1990 runs.

Further improvements are planned in the next future: they are a granularity of the START scintillators, in order to increase the neutron energy resolution, and the cooling of the PM's, in order to lower the electronic noise.

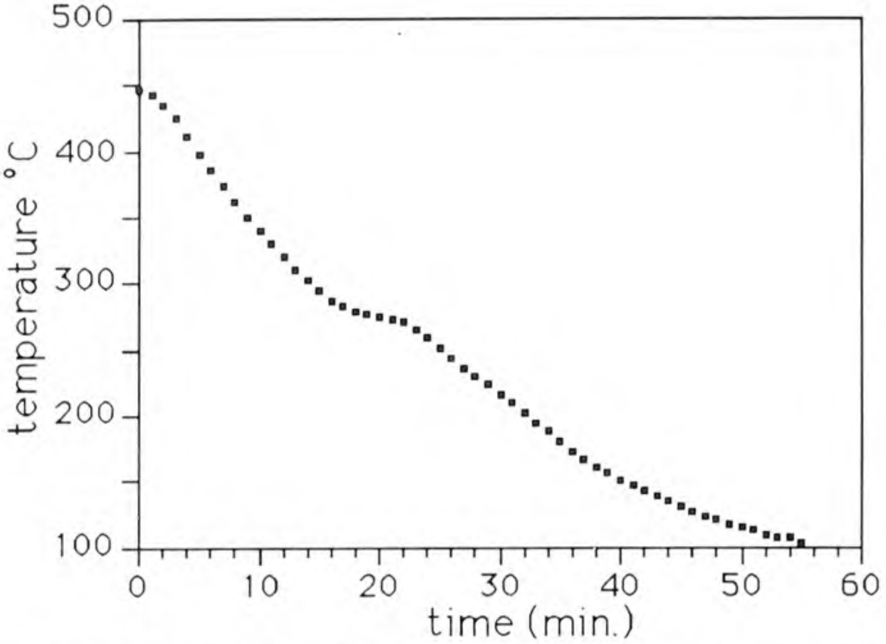

Fig.6 Typical temperature behaviour in the first hour of a run down as detected by the thermocouple TC2 in Fig. 5a). The phase transition around 280 °C is evident.

ACKNOWLEDGEMENTS

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