Double armed TOF spectrometer for fission studies

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Introduction

We report development of a position sensitive, high-resolution double armed time of flight (TOF) spectrometer developed for the detection of fission fragments. The detection system is used for investigating heavy ion induced fission reactions. The main motive of developing these detector systems is to perform fission mass-angle, mass-kinetic energy distribution experiments, mass-gated neutron and light charged particle multiplicity measurements etc. This set-up uses the common technique of measuring the velocities (2v method) of binary co-incident fission fragments. The spectrometer contains two TOF arms based on multi-wire proportional counters (MWPC). The system has been tested with radioactive sources and has been used to perform fission measurements in GSPC facility of IUAC.

Description

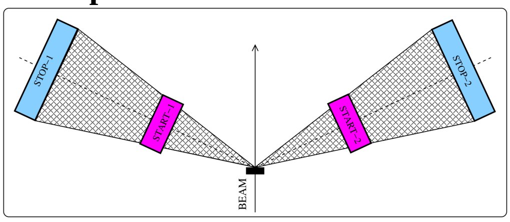

Fig.1: Schematic of double-arm TOF spectrometer

Fig.1 shows the schematic diagram of the spectrometer. The detector system consists of two start detectors (transmission type) and position sensitive stop detectors. The arms can be positioned at different angles *w.r.t.* the beam axis depending upon the reaction under investigation. The distance between the start and stop detectors of each arm is generally between 20-30 cm and start detector is placed 7-10 cm from the target. Active area for the start detector is 4 x 4 cm^2, and that for stop detectors is 16 x 11 cm^2 [1]. For a double arm TOF spectrometer, measuring the absolute timing, mass is given by the relation :

$$m_1 = m_{CN}/[1 + (v_1\sin\theta_1)/(v_2\sin\theta_2)]$$

where m_{CN} is the mass of compound nucleus, $m_{1,2}$, $\theta_{1,2}$, $v_{1,2}$ are respective fission fragment mass, angle and velocity. Stop detector has a 3-electrode geometry as described in [1] with position (θ) information extracted using delay line technique.

Three different designs for the start detector have been explored to get the best possible performance in terms of time resolution, which than dictates the mass resolution of the spectrometer. Mass resolution Δm for nuclear mass m, in a TOF system is given by : $\Delta m = (2\Delta t/t).m$, where Δt is the time resolution of the system and t is the flight time. Δt can be estimated using the following relation : $\Delta t \propto V_{rms}.t_R/Q$ where t_R is the rise time, Q is the charge generated and V_{rms} is the electronic noise. The amount of charge generated depends upon the avalanche gains in MWPC and t_R is a function of charge collection times, and dependent on the actual design of the MWPC.

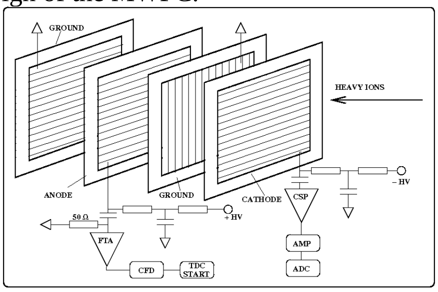

Fig.2 : Schematic of a MWPC

Fig.2 shows a typical schematic of a MWPC. This design is a 4-electrode multi-step design made out of wire frames. The electrodes are namely cathode-ground-anode-ground. The first region of cathode-ground operates in drift region and second region of ground-anode-ground operates in avalanche region. Wire pitch dictates the avalanche gain and charge collection times, and thus the timing resolution of the detector. A start detector with this configuration was fabricated with 0.025” wire pitch [2]. This sub-mm reduced wire pitch gives higher avalanche gains. Rise times of the signals were ~ 3-4 ns. Entrance and exit foils were 0.5 μm mylar. The time resolution of this detector was estimated to be about 250 ps. Deterioration in performance is observed with increased flux (~ MHz) of delta electrons at forward angles, when placed very close to target. This is due to avalanche multiplication of delta electrons at anode wire surface which results in increased currents. At the same time, due to multi-step operation, the detectors can be operated at very low pressures (~ 1 Torr) with higher gains, which is very useful for the detection of very low energy fission fragments at extreme backward angles (~ 170°).

The conventional three electrode design having cathode sandwiched between two ground anodes was also explored. Cathode is made out of 1.5 μm mylar foil, aluminized on both faces, and anodes are made out of wire frames, as explained earlier. Field are very uniform in such a design giving rise to faster charge collection. Fig.3 shows the trace of the cathode signal of this design. A rise time better than 2 ns is observed. Such a rise time is at par with MCP detectors (t_R ~ 1.5 ns). This is the fastest rise time observed with a MWPC. A time resolution < 100 ps is estimated from the characteristics of signals. Signal strength is lower as compared to multi-step design. Reducing the wire pitch further to .0125” will further enhance the performance. Major drawback of this design is the energy loss and straggling introduced in the cathode foil. An average energy loss of 25 MeV for the fission fragments has been observed, having contributions also from gas volume and entrance-exit foils. This energy loss/straggling needs to be corrected event by event to extract correct velocities and subsequent mass distributions.

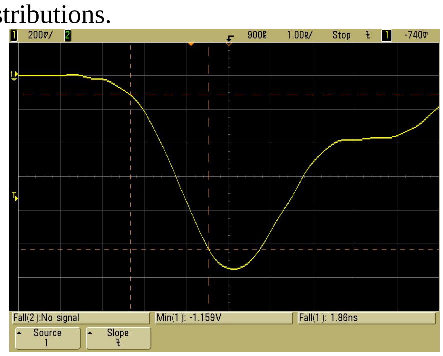

Fig. 3 : Trace of the cathode signal.

In the third design, cathode foil is replaced by a wire frame with a wire pitch of 0.0125”. Rise times observed with this design were ~ 5 ns, with signal strength lower as compared to the two previous designs. This design performs reasonably well with heavy fission fragments but signals are very inferior for lighter particles such as alphas. A time resolution of about 700 ps has been estimated for fission fragments. Inter-electrode separation for all detectors is 3.2 mm.

Performance

The TOF spectrometer was tested with ^{252}Cf fission source and used to perform mass-distribution measurements for the system ^{6,7}Li+^{238}U [3]. All detectors were operated with iso-butane gas at pressures of 3 mbar with operating cathode voltage of -430 V. Signals were extracted using in-house developed fast amplifiers [2]. Fig.3 shows the TOF spectrum with a short flight path of 5 cm for performance evaluation. A silicon detector was used behind the stop detector for energy measurement. Fig.4 shows the plot between TOF and energy of fission fragments from ^{252}Cf, displaying a clean separation between the two mass groups.

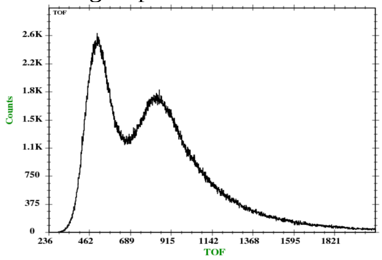

Fig.3 : TOF spectrum for 252Cf source

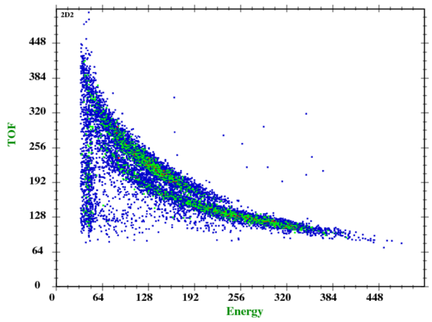

Fig. 4: Plot of TOF against energy

Time resolution of stop detector has been estimated to be 250 ps. More details about the performance will be discussed.

References :

[1] A. Jhingan et al., Proc. DAE-BRNS Symp. on Nucl. Phys. 60, 936 (2015).
[2] A. Jhingan, Pramana J. Phys., Vol. 85, 2015, 483-495 .
[3] A. Pal et al., Proc. DAE-BRNS Symp. on Nucl. Phys. 61, 376 (2016).