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The fragmentation trigger of the FOOT experiment

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Abstract

FOOT is a fixed target nuclear physics experiment in which O, C and He beams are shot on H enriched targets to study the projectile fragmentations; the measured cross sections will be used in medical physics and radioprotection in space applications. Beam fragmentation happens only on $\approx 10\%$ of the cases so it is convenient to develop a sophisticated trigger procedure to veto most of non-fragmented primaries passing through the detector.

In this paper we present the developed trigger algorithm operated on a WaveDAQ TDAQ system which is used also as DAQ for three of the FOOT detectors.

Keywords: Trigger, Nuclear physics, Hadron therapy
PACS: 07.05.Hd, 25.70.Mn

1. The FOOT experiment

The FragmentatiOn Of Target experiment [1] (FOOT) aims at measuring the nuclear fragmentation of carbon and oxygen nuclei to characterise the secondary products in hadron therapy. C and O beams of an energy in the range 150-400 MeV/u are shot on thin targets, the emerging fragments are reconstructed by the FOOT detector, as sketched in Figure 1. Data taking campaigns with He beam are also planned for both radioprotection in space applications and hadron therapy. Since the projectile fragmentation occurs in less than 10% of the events, a sophisticated trigger logic has been implemented to enrich the data sample with fragments which are distinguished from primaries by looking at the energy deposit in the scintillator detectors, the Start Counter and the Tof-W. The Start Counter consists of a thin squared foil of EJ-228 plastic scintillator 250 μm thick read by 8 groups of SiPMs. The Tof-Wall detector is composed of two layers of 20 plastic scintillator bars (EJ-200), arranged orthogonally, readout by SiPM on both bar ends.

The plastic scintillation detectors, and the BGO Calorimeter as well, are readout by means of the WaveDAQ system, a highly integrated trigger and DAQ system [2] which is also used as FOOT trigger system; in fact all physics triggers are generated by the WaveDAQ trigger board and then distributed to the general DAQ.

2. The fragmentation trigger

The maximum DAQ rate, up to 1 kHz, it is smaller than the usual beam rate available, leading to dead time. For this reason, a trigger algorithm to efficiently select fragmentation events among the most abundant background hits has been developed which logic is shown in Figure 2.

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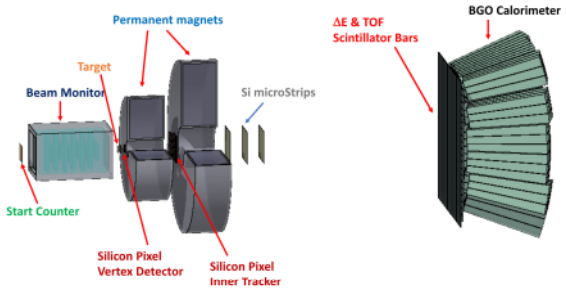

Figure 1: Sketch of the FOOT detector. The ion beam goes from left to right, the primary ion is detected by the Start Counter scintillation foil and then tracked by the Beam Monitor drift chamber, downstream the target fragments are tracked by silicon pixel and strip detectors and finally inping the Tof-Wall for the time of flight and dEdX measurements and the calorimeter.

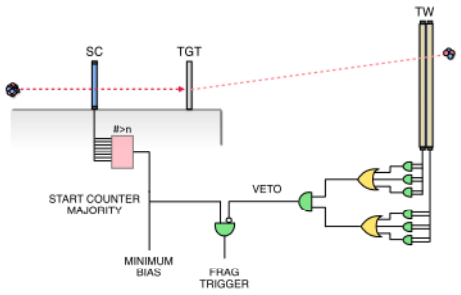

Figure 2: Sketch of a fragmentation event (drawing not in scale). The fragment is generated on the target and, in this example, hit the Tof-Wall out from the center.

A primary is detected by the Start Counter (SC) by counting the number of inputs being over threshold; in case they exceed a programmable value (majority) a Start Counter local trigger is generated, also called minimum bias (MB).

In the TW, the energy deposit of the primaries is significantly larger than any fragment due to the difference in the nucleus charge, fragments can be distinguished just by looking at the central bars (also hit by beam primaries) on both views of the detector [3, 4], as shown in Figure 3. If a signal amplitudes in the Tof-wall (TW) central bars are above a preset threshold, tuned to identify primary beam ions, then the MB trigger can be vetoed. Resulting triggers identify missing primary ions on the TW, that is fragmentation events.

2.1. *Configuration procedure*

The TW threshold calibration is necessary. It is performed at the beginning of each data acquisition after any beam property variation in terms of energy and primary Z as follows. A dataset of about 100 kevents ($\approx$ 5 minutes) of minimum bias data is recorded and immediately analysed to extract the thresholds. A second dataset of minimum bias events, with TW thresholds set on HW, is acquired to check hit distributions and trigger rates and, after the beam time, to be used *a posteriori* to measure the trigger efficiency with full analysis.

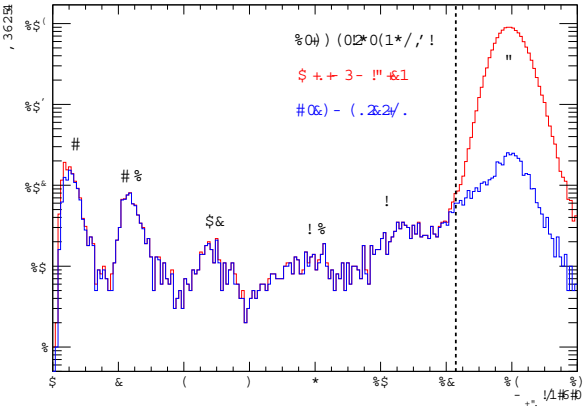

Figure 3: Charge spectra of a central bar for minimum bias (red) and fragmentation trigger (blu) events.

E [MeV/u]	Be	B
150	100 %	(99.75 ± 0.15) %
200	100 %	(99.67 ± 0.15) %
300	(99.94 ± 0.04) %	(99.60 ± 0.06) %
400	(99.7 ± 0.3) %	(96.6 ± 0.4) %

Table 1: Fragmentation efficiency for heavy fragments as obtained at CNAO with C beams of 4 different energies. The efficiency, defined as the number of fragments recognised at trigger level divided by the number of fragments reconstructed offline, is close to 100% in all runs, a smaller value is present for the 400 MeV run and the B fragment, a small issue in the calibration method and the threshold extraction was found and will be improved.

Fig. 3 shows the charge spectrum of a central bar of the TW for minimum bias events (blue) and fragmentation trigger ones (in red). The fraction of primaries, in this case carbon ions, is reduced by a factor ≈ 50, while very high efficiency is preserved for fragments.

3. Results and conclusions

The fragmentation trigger was successfully used for 2021 DAQ campaigns at GSI and CNAO, on ^{16}O and ^{12}C beams, respectively. In the latter case the reproducibility of the method was proven with 4 different beam energies as described in the Table 1. The DAQ rate is reduced by almost a factor 10 preserving full efficiency on signal selection.

By using the fragmentation trigger we collected in the same amount of beam time ≈ 6 times more fragments than what could be taken with minimum bias trigger, this will lead to reduction of the statistical uncertainty of 2.5 in the cross section measurements with the same DAQ integrated time.

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