Nuclear Instruments and Methods in Physics Research A263 (1988) 249–254
North-Holland, Amsterdam

MONOPOLE TRIGGER FOR THE STREAMER TUBE SYSTEM IN MACRO

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We report the study done on the streamer tube trigger for monopoles to be used in MACRO. The acceptance, trigger rate and electronic efficiency of the trigger system are discussed.

1. Introduction

MACRO [1] is a large detector at the Gran Sasso laboratory dedicated to the search for monopoles and to study extensively cosmic rays and astrophysics.

The detector consists of two layers of liquid scintillator counters, ten layers of plastic streamer tubes and a sandwich of plastic track-etch detectors. These sensitive elements are inserted within a thick absorber structure shown in fig. 1a. The four vertical sides are closed by one layer of scintillator counters and four layers of plastic streamer tubes as shown in fig. 1b.

The apparatus consists of several units, supermodules, aligned along hall B of the Gran Sasso Laboratory. The active dimensions of each supermodule are 12 × 12 m^2 surface, 4.8 m high.

The streamer tubes, sensitive to total ionization above $\sim 10^{-2}$ that of minimum ionizing particles, will be filled with a He–N-pentane (3 : 1) mixture.

For a monopole with $\beta > 10^{-3}$ the ionization mechanism will provide signals for detection [2]. For $10^{-4} < \beta < 10^{-3}$ the monopole magnetic charge causes Zeeman splitting of the He levels. The collisional de-excitation of the He (Drell–Penning effect [3]) and the N-pentane ionization allow efficient monopole detection. The monopole signature is a spatial alignement of several hits in a slow time sequence.

2. Trigger logic

The general approach of the MACRO search for monopoles, requiring redundancy in techniques, does not allow to subordinate the acquisition of the streamer tubes to a trigger based on the response of the scintillator system. For low β particles a trigger based on crude coincidence requirements fails because the coincidence width is determined by the time of flight between the

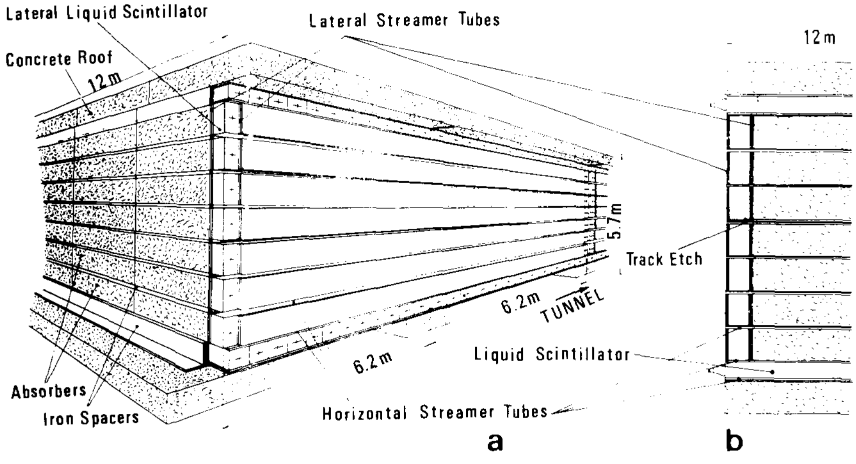

Fig. 1. (a) Pictorial view of a MACRO supermodule. (b) Lateral detectors in MACRO.

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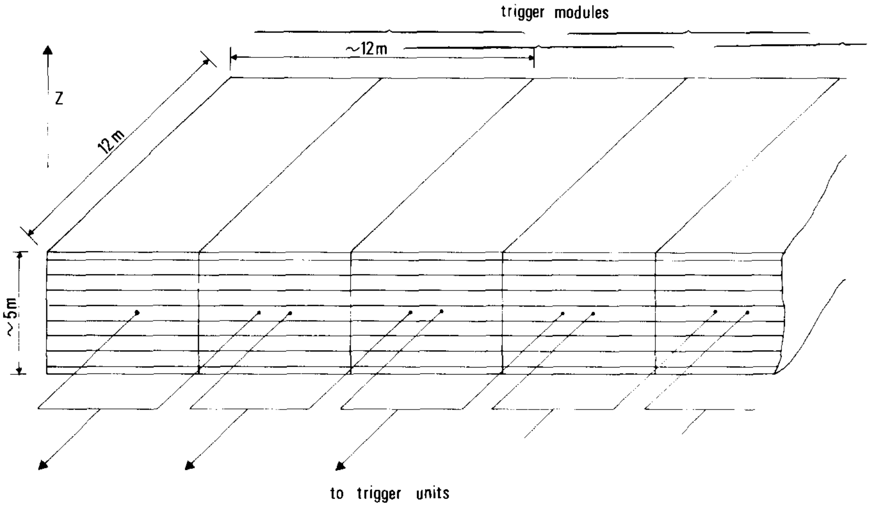

Fig. 2. Layout of trigger module. The wire ORs from the streamer tube planes are rearranged in the logic in order to realize overlapping trigger modules.

first and the last streamer plane that, for slant tracks, can be several hundreds of μs. With a background rate of 50–100 Hz/m^2 induced by the local radioactivity, the total single counting rate for the streamer tube system is ~ 1 MHz. So, during the maximum crossing time of a monopole, several background hits would give spurious coincidences.

In order to deal with lower rates, the trigger logic includes several identical trigger units working in parallel. Each trigger unit processes the data coming from the corresponding trigger module (12 × 12 m^2).

The overlap of the trigger modules (fig. 2) reduces significantly the loss in acceptance for throughgoing particles. The most slant track in a trigger module will travel ~ 18 m, that at $\beta = 10^{-4}$ corresponds to ~ 600 μs. During this time of flight about 10 hits for a plane (12 × 12 m^2) will be induced by the local radioactivity.

Due to the constant monopole velocity, an efficient way to perform a fast pattern recognition is possible by means of parallel masks each one searching for a differ-

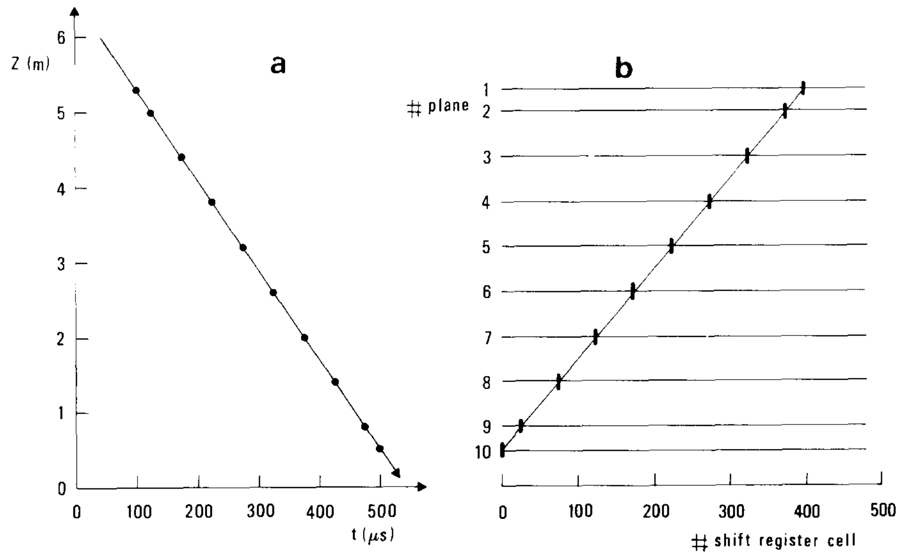

Fig. 3. (a) Z vs time diagram for a downgoing particle. (b) The same track appears in the shift register matrix as a straight line crossing the first cell of the last plane.

ent β range. A monopole crossing the apparatus with uniform speed appears in a Z vs time diagram as a straight line whose inclination corresponds to a β value, while the background is randomly distributed.

For each trigger module two distinct circuits are used for upgoing and downgoing particles. Hereafter we will refer only to the downgoing ones.

The OR of the signals from the tube wires of each plane is sent to a shift register chain (serial in–parallel out). These shift register chains store the arrival time of each event. A compromise between the number of shift register cells and the time resolution is obtained with 480 cells and 1 MHz clock frequency.

When a particle crosses the last plane, the constant speed will appear in the shift register matrix as a track crossing the first cell of the last shift register (fig. 3). To each β-projected value corresponds one angle in the shift register matrix.

The whole shift register matrix is divided into 160 intervals (β-slices) each one corresponding to a different β value. For each plane the shift register parallel outputs corresponding to the same β-slice are ORed.

The outputs of the 10 ORs of each β-slice are fed into a 10 input majority, that can send a trigger signal when the number of the signals at the inputs (i.e. the number of planes that give a response at the right time) is greater than a preselected threshold.

The OR of the outputs of all majorities provides the final trigger.

The definition of the β-slices required a careful optimization. The shift register matrix is divided in identical $1/\beta$ intervals to have equal rates from each β-slice. Taken into account the time quantization introduced by the shift registers and the time jitter of the streamer tube signals, several cells are shared by different β-slices.

All these effects lead to higher rates but cannot be avoided without affecting the trigger efficiency. We minimized the expected rate optimizing with a simulation program the definition of the β-slices (i.e. the ORing of the shift register cells).

To avoid the complex wiring and the high number of circuits required by standard techniques we used the very large scale integration of the gate array technology.

Ten chips are put in cascade, each one containing only a fraction of the shift register matrix (48 μs memory depth) and the corresponding ORs and 16 majorities.

By imposing symmetry and periodicity to the horizontal streamer tube plane heights we designed identical chips in such a way as to strongly reduce the gate array realization cost.

In this way only 10 signals from the shift register outputs of one chip are fed into the shift registers of the

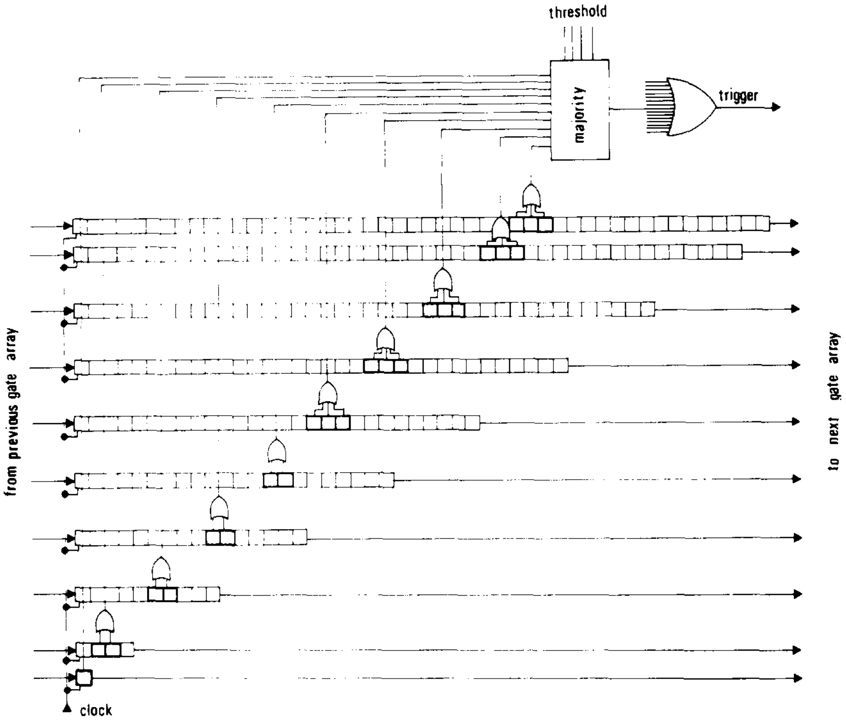

Fig. 4. Layout of a gate array. For the sake of simplicity only one of the 16 β-slices is drawn.

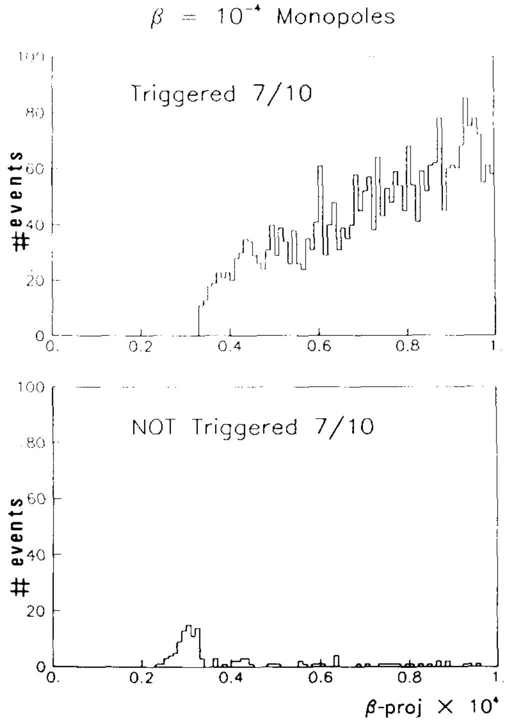

Fig. 5. Effect on the efficiency due to the 480 μs memory depth of the shift register chains. The 3% of events at the right of the cut are due to the jitter inside the 3×3 cm^2 streamer tubes.

next chip (see fig. 4). An external circuit provides the final OR of the signals from the majorities of all the chips.

These majorities are realized in the gate array by using adders and comparators.

3. Performances

The finite memory depth of the shift register chains obviously reduces the efficiency for very low β and slant monopoles. This electronic efficiency grows rapidly with the β of the particle: it is close to 0% for $\beta = 10^{-5}$; goes to 97% for $\beta = 10^{-4}$ (see fig. 5) and is 100% already at $\beta \sim 2 \times 10^{-4}$.

The effect of the uncorrelated background rate is shown in fig. 6. For different coincidence requests the total trigger rate from a trigger module is represented as a function of the background rate.

Preliminary measurements at the Gran Sasso laboratory inside a concrete structure more radioactive than the final absorber, leads to a 1 Hz rate upper limit if we require at least 7 hit planes. The final trigger rate will be presumably 1 or 2 orders of magnitude less.

These rates are computed with a Monte Carlo program. The radioactivity is simulated by filling, according to the Poisson statistics, 10 arrays of bits representing the shift register layers of the gate array cascade. The partition in 160 β-slices is also simulated in such a way as to exactly reproduce the whole trigger logic.

This simulation takes a lot of CPU time, essentially for the scan of the hits in the β-slices: high coincidence levels at low background rates require several CPU hours (VAX 8600).

For this reason we performed analytical computation of the probability to obtain accidental coincidence. This probabilistic computation is done with some approximation due to the overlap of the β-slices. Moreover the error introduced vanishes at high coincidence levels.

The results of the two approaches fit rather well for

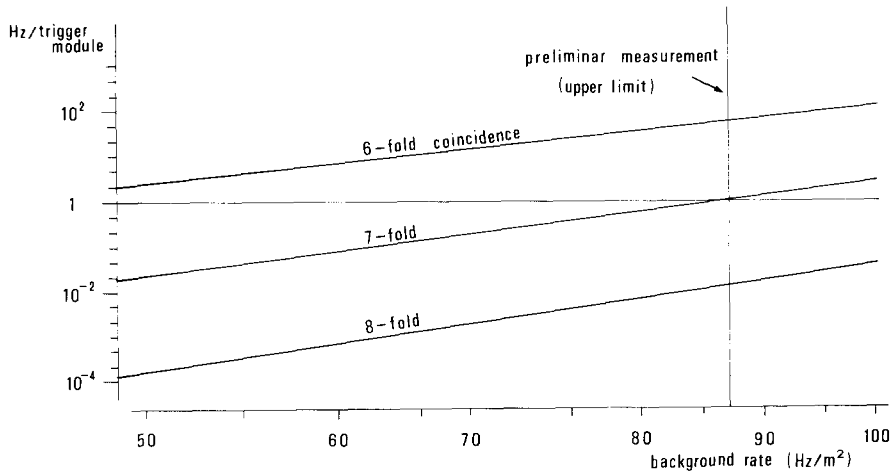

Fig. 6. Trigger rates for different horizontal multiplicity as a function of the uncorrelated background rate for several coincidence requirements.

at least 6-fold coincidence with a background rate between 50 and 100 Hz/m^2. So we can obtain reliable predictions by combining the Monte Carlo and the analytical computations.

4. Acceptance

A simulation program based on the GEANT3 code [4] has been used in order to study the acceptance of this trigger for an isotropic flux of monopoles. Full description of the apparatus and the streamer tube performances have been included in the code.

A slant monopole can give a signal in several trigger modules. To compute the acceptance we considered only the trigger module with the highest multiplicity of streamer tubes hit.

Fig. 7 shows, for a sample of 10 000 monopoles, the frequency of the streamer tube multiplicities. If we consider that trigger requests below 7 planes are quite unfeasible the acceptance of this trigger is ~ 55%.

To increase the acceptance we studied the effect of another trigger based on the signals from the lateral streamer tubes.

From a hardware point of view the mixing of the information from the horizontal and the lateral planes is difficult. The rate of coincidences of less than 5 horizontal hit planes is very high (~ 10^5 Hz) and the coincidence width is not well defined because the two streamer systems are orthogonal.

Moreover, for the lateral streamer tube system it must be considered that the distance between the wires of the two inner planes and that between the two external ones is only 3 cm while the scintillator thickness in between is 25 cm. At $\beta = 10^{-4}$ 95% of the monopoles take ~ 4 μs to travel between the closest planes and ~ 40 μs to go through the scintillator.

During this time the rate induced by the radioactivity is low enough to be used in a standard trigger requiring at least 3 hit planes.

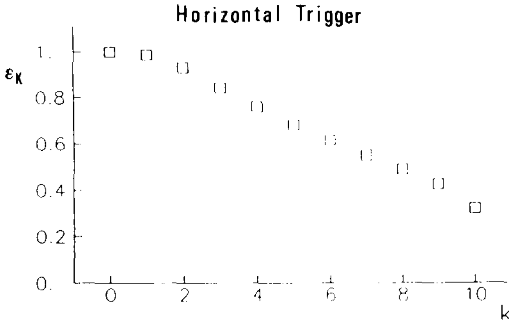

Fig. 7. Horizontal streamer tube acceptance as a function of the trigger coincidence level (k).

With the Monte Carlo program we computed the trigger efficiencies for the horizontal and the lateral planes defined as the ratio of the events accepted by the trigger over the total number of monopoles crossing the apparatus in the same angular region.

Figs. 8a and 8b show those efficiencies for 7-fold coincidences of horizontal streamer planes and 3-fold coincidences of the lateral one.

The Monte Carlo simulation suggests completely independent trigger systems for the horizontal tubes and the lateral one. From figs. 8a and 8b, one can see that horizontal and lateral trigger efficiencies are practically complementary and then we will recover part of the lost events with the lateral trigger: the 3-fold coincidence of laterals accepts ~ 30% of the events.

Obviously horizontal and lateral conditions are somewhat correlated and the overall trigger efficiency of the OR of 7-fold coincidence for horizontal planes and 3-fold coincidence for lateral planes is ~ 80%.

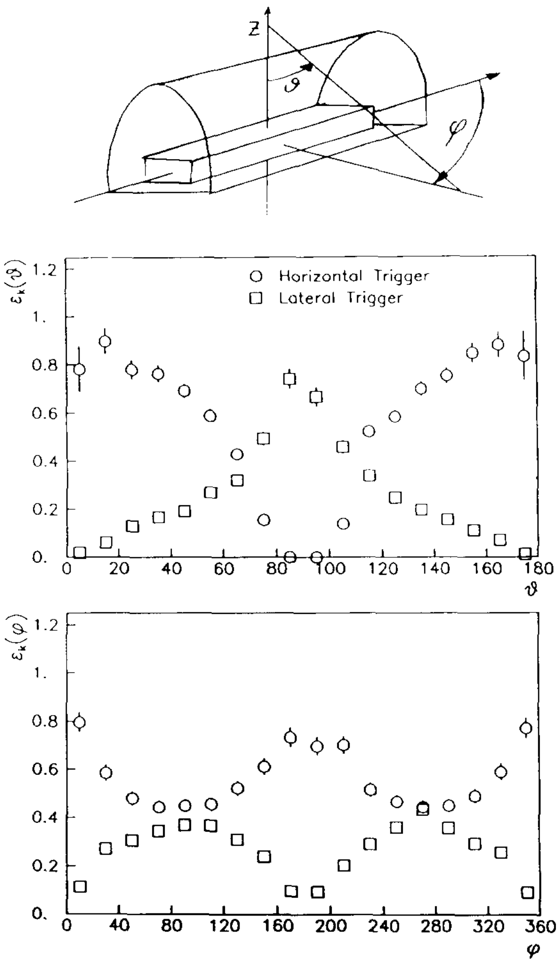

Fig. 8. Trigger efficiencies as functions of θ and φ for horizontal and lateral streamer tubes.

It should be noted that if we allow a track to be unambiguously defined when it hits at least 4 planes (horizontal or lateral) then the maximum achievable acceptance turns out to be 91% of the full acceptance.

5. Conclusions

We are realizing a trigger logic for the streamer tube system in MACRO that will be efficient for monopoles with β down to 10^{-4} and will reduce the background rate to few Hz.

The computed overall trigger efficiency for realistic conditions on horizontal and lateral triggers is ~ 90% inside a "fiducial volume" – defined by asking at least 4 hit planes for each track – which is ~ 90% of the total apparatus.

References

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