A multiplicity trigger based on the Time of Flight detector for the ALICE experiment

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Abstract

The goal of the ALICE Time of Flight detector, based on MRPC technology, is to perform charged particle identification in |η|<1. This large area (150 m^2), finely segmented detector (~160,000 channels), provides fast signals which will contribute to the Level 0 and Level 1 trigger decisions. We use the TOF detector information to perform an online estimate of the total track multiplicity and to identify simple and peculiar topologies like those produced by peripheral collisions and by cosmic muons. The system architecture foresees a first layer of 72 VME boards interfacing the detector front-end to a second layer, which receives and processes all the information and takes trigger decisions.

I. INTRODUCTION

The design of the trigger of the ALICE experiment foresees a multilevel architecture, with three hardware levels implemented. The trigger decisions are asserted by the CTP (Central Trigger Processor) module, receiving the input from different sub-detector triggers. The first decision (L0) is taken 1.2 μs, the L1 decision is taken 6.5 μs and the L2 trigger is issued 88 μs after the collision.

Taking advantage of the MRPC (Multigap Resistive Plate Chamber) detector, the ALICE Time of Flight provides very fast signals with low noise. The idea is to use the information from this large area (150 m^2), finely segmented detector (~160,000 channels) for a fast estimate of the event track multiplicity. The signals from the detector are available in a short time, so that the TOF trigger can comfortably contribute to the ALICE L0 trigger decision. The large granularity of the TOF and the low noise of the MRPC allow to trigger on several configurations:

- events with very large/low track multiplicity corresponding to central/peripheral ion-ion collisions;
- events with large and localized track multiplicity as jet events in pp collisions;
- back to back patterns as cosmic events, which will be very useful during the commissioning of the detector itself.

II. THE FIRST LAYER: THE LTMS

The TOF detector [1] is made of 18 supermodules. Each supermodule contains 5 modules, equipped with a number of MRPC strips varying from 15 to 19. The ionization taking place in the gas volume of the MRPC produces a signal, which is picked up by 96 pads, ~9 cm^2 area. Each supermodule is equipped at each side with two 9U VME crates and covers an azimuthal angle of 20^o. The architecture

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of the TOF trigger uses a first layer of 72 VME (9U) boards, called LTM (Local Trigger Module). Four LTMs are needed to process the data produced by one supermodule.

The LTMs act as an interface between the front end electronics and the second trigger layer, called CTTM (Cosmic and Topology Trigger Module), made of a small number of VME boards.

A dedicated calibration is foreseen to allow the LTMs to compensate for the relative time misalignments among the 3456 input signals. This is achieved by using commercial delay lines units, 3D3418-0.25, programmable through the VME interface (PDLs). These PDLs will operate in a magnetic field of 0.5 T. They will be exposed to a charged hadron rate of ~ 100 Hz/cm^2 and will absorb in 10 years a total dose of 1.1 Gy. To test the PDL performance in such environment, we exposed six PDLs to a 60 MeV proton beam at the PSI PIF facility. A total fluence of $3.2 \cdot 10^{11}$ p/cm^2 has been collected, corresponding to ~ 450 Gy. No SEU or latch-up have been detected. We also tested the PDLs in a dipolar magnetic field, having the maximum intensity of the magnetic field in the ALICE solenoid, B=0.5 T. A test was performed, orienting the three PDL main axes parallel to the magnetic field. The field did not affect the PDLs performance.

The LTM is connected to 8 boards called FEACs, through 8 cables (24 wires, 28 AWG), whose average length is ~ 4 m. Each FEAC, located inside the modules, is connected with 12 Front End cards (FEAs) and contains a temperature sensor. The LTM (see figure 1) will monitor the FEAs low voltage and the FEAC temperature; it will provide the voltage thresholds to the 12 FEAs. Each FEA receives, amplifies and discriminates the signals coming from 24 pads and produces an OR signal of these 24 channels for trigger purposes. The OR of 2 contiguous FEAs are daisy-chained and sent to the FEAC. The FEAC gets 6 ORs and sends them to the LTM. Each OR corresponds to an area of ~ 500 cm^2.

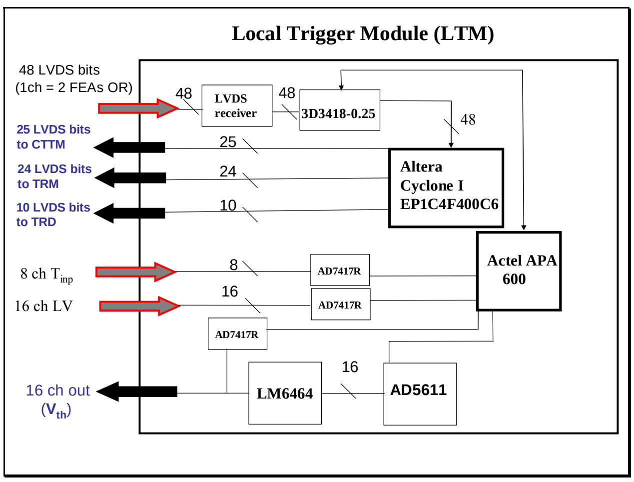

Figure 1: LTM block diagram

The LTM makes use of 2 FPGAs: an Actel APA 600 and an Altera Cyclone I EP1C4F400C6. The Actel APA will be used to monitor the low voltage and the temperature, to provide the voltage threshold to the Front End card and to set the PDLs, while the Altera Cyclone I will handle the OR signals. The radiation effects on the Altera Cyclone I have been measured at PSI PIF facility. As a result we expect a mean time between failures of the Cyclone I configuration bits of 4.4 hours on the full trigger system.

The system flexibility allows to choose the trigger segmentation at software level: in the finest granularity configuration any trigger channel in input to the CTTM is the OR of 96 pads (~ 1000 cm^2).

The clock sampling the 48 input signals is synchronized with the LHC machine clock (40.08 MHz) to associate correctly the input data to the corresponding bunch crossing and to provide to the CTTM the full set of information required to assert a L0 trigger decision. Several outputs are planned from the LTM (see table 1):

- a 25 bit information to the CTTM;
- a 24 bit information to the TRM [2] (TDC Readout Module) for debugging purposes;
- up to 10 bit information to the ALICE TRD (Transition Radiation Detector) for pre-trigger;
- 16 Voltage thresholds, (0.÷1.6) V, to be sent to the FEAs through the FEACs.

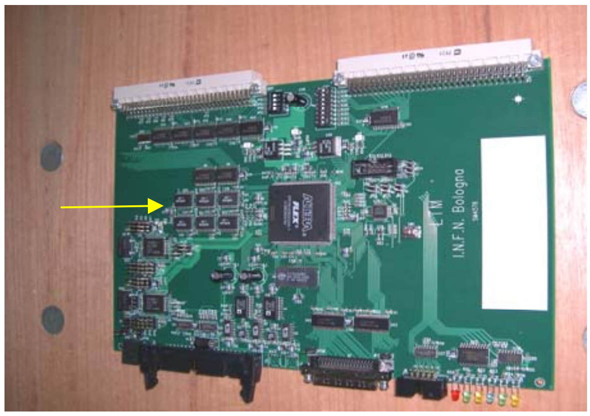

Figure 2:The first LTM prototype. The PDLs are indicated by the arrow.

Table 1: LTM Input/output signals

Origin	Destination	Signals	Description
LTM	CTTM	25	Data to CTTM
LTM	TRM	24	Data debug
LTM	ALICE TRD	up to 10	Pre-trigger
FEAC	LTM	48	OR signal
FEAC	LTM	8	Temperature
FEAC	LTM	16	Low Voltage
LTM	FEAC	16	Threshold

A LTM prototype (see figure 2), with a reduced number of input/output channels, was built in July 2004 and was tested shortly after at the CERN PS-T10 beam line. Good results were found for all the tasks of the board. In particular the trigger efficiency was compared with that of the beam line plastic scintillators, whose transverse area was fully contained within the MRPC area. A probability $P < 10^{-3}$ was found to get a scintillator trigger unconfirmed by the LTM trigger, showing the full capability in latching the MRPC signals.

III: DATA TRANSMISSION FROM LTMs TO CTTM

The CTTM receives the input signals from 72 cables coming from the LTMs: each cable transmits 24 signals and the sampling clock. Since the L0 decision must reach the CTP within 800 ns after the interaction, data must be transmitted in parallel. A long R&D has been performed to transmit along 60 m the LVDS signals safely from the 72 LTMs to the CTTM. As far as the LVDS driver is concerned, we chose the Texas SN65LVDM1677. This is a LVDM transceiver giving a doubled current with respect to the standard LVDS driver, successfully tested under radiation at PSI. The need of a small attenuation at 40 MHz suggested the use of a large wire diameter, while the cable flexibility, the connector dimensions and the CTTM mechanics required a small diameter one. A key point is the protection against the EMI, requiring a shielding of each single pair and at least a double shielding of the cable. In addition these cables must pass through the magnet door and therefore must be deployed without pre-mounted connectors. Such choice excluded the use of a high performance connector, mounted with dedicated technique, like laser welding.

After several tests, we found a cable from Amphenol, known as Skewclear 166-2499-971, coupled to a Centronics 50 poles connector, satisfying our requirements. Such cable has 25 shielded pairs, 100 Ω impedance, an attenuation ~ 0.15 dB/m (40 MHz) and a time skew < 35 ps/m (pair to pair). Figure 3 shows an open eye pattern of such cable. The BER (Bit Error Rate) measurement was performed sending a pattern of bits through the 60 m long cable. In Pb-Pb collisions, the expected event rate is:

$$N = L \cdot \sigma = 10^{27}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1} \cdot 8\ \mathrm{barn} = 8\ \mathrm{kHz}.$$

Assuming that the average multiplicity in Pb-Pb central collision on TOF is M=8000, considering that the total number of bits to the CTTM is 1728 and the bunch crossing frequency is 8 MHz, the probability for a single bit to be "on" in any transmission is $\sim 10^{-3}$. We sent through the cable a pattern of bits at 40 MHz, set to "1" according to this probability. We compared the pattern before and after the transmission. We obtained a bit error rate BER $(0 \rightarrow 1) < 2.7 \cdot 10^{-10}$ (90% C. L.) and a BER$(1 \rightarrow 0) < 2.7 \cdot 10^{-7}$ (90% C.L.).

IV: THE SECOND LAYER: CTTM

The CTTM receives 1728 data bits from the 72 LTMs and asserts the L0 and L1 triggers. This large number of input signals cannot be handled by a single FPGA. The CTTM is organized in two layers: in the first one the 1728 data bits are

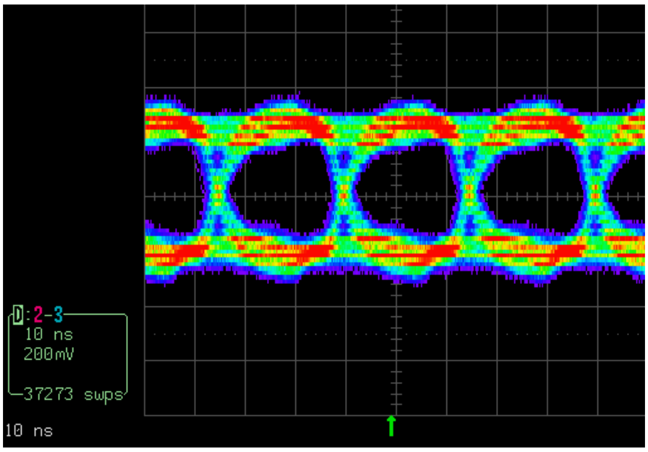

Figure 3: Open eye pattern of a LVDS signal through 60 m of the Amphenol 166-2499-971 cable, at 40 MHz.

sent to two Altera Stratix (hereafter FPGA11, FPGA12), each receiving 864 bits. In the second layer a third Altera Stratix (FPGA 21) processes the data from FPGA11 and FPGA12. In addition, in the first layer, two FPGAs of the same type (FPGA13, FPGA14) get the identical input signals of FPGA11 and FPGA12 and multiplex them into five connectors, so that the signal relative delays can be measured with a dedicated TDC and compensated. As far as the L0 generation is concerned, just simple operations can be made in the short time available. FPGA11 and FPGA12 perform the following operations:

- hit total multiplicity counting for minimum bias and Pb -Pb peripheral collision tagging;
- quasi-vertical and "back to back" coincidence counting for cosmic muon detection (see next paragraph);
- data buffering and empty channel suppression. Once the L0 is received from the CTP the non empty channels for that event are transmitted to FPGA21 and processed to assert the L1 trigger decision.

The FPGA21 performs a sum of the FPGA11 and FPGA12 data, takes the L0 decision and sends a LVDS signal to the CTP within 800 ns after the interaction takes place. Table 2 shows the different sources of the TOF trigger L0 latency.

Table 2: TOF L0 latency sources.

Source	Time of flight	MRPC, FEA	FEA to LTM cable	LTM	LTM to CTTM cable	CTTM	Total
Delay (ns)	20	10	30	160	260	250	730

The flexibility of the system allows to search for several topologies, even in coincidence with other sub detectors. Anyway the number of L0 topologies is limited by the ALICE CTP that can receive a maximum of 24 L0 inputs. For the L1 decision, once a L0 is received from the ALICE CTP, the hits stored in the RAM are retrieved and processed. The longer time available to assert L1, T= 6.5 μs – 1.2 μs = 5.3 μs, allows more complex operations in FPGA21. A dedicated simulation is under study to estimate the efficiency in searching for jets in the p-p collisions.

V: TRIGGER PERFORMANCE

A. Cosmic Rays

By triggering on cosmic rays a sample of events having both a physics and a technical relevance can be selected. The ALICE experiment interest in cosmic ray physics is described in [3]; on the other hand cosmic muons are a powerful tool during the detector commissioning. Considering that the detector background, measured with the module prototype, is about 5 Hz/pad, a simple coincidence of an upper TOF module with a lower one, within a 50 ns gate, would give a fake trigger rate of ~8 kHz [3]. This rate has to be compared with the cosmic muon rate at ALICE depth of few Hz/(m^2·sr). Such trigger could be useful only if used in coincidence with another sub-detector, like ACORDE, a scintillator array placed on the top side of ALICE.

An interesting possibility for the TOF in standalone mode is offered by the multiple muon events. The multiple muon event rate depends both on the detector geometry and on the depth. We plan to implement a trigger based on the events with muon multiplicity $N_\mu \geq 2$. Keeping in mind that the cosmic muon angular distribution in the ALICE pit follows a $\cos^x \theta$ law, where x~2, a straightforward approach is to focus on vertical muon events. Considering the OR of a TOF module, made of ~2000 pads, the rate of dimuon events generated by the background is 10^{-3} Hz, which is three orders of magnitude smaller with respect to the quasi-vertical dimuon rate (see figure 4). The key point is that while any coincidence of a TOF-TOP and TOF-BOTTOM module pair is enough to mimic a single track, at least four aligned fired modules are required to the background to mimic a quasi vertical multiple muon event. Another possibility is offered by multiple muons in which each muon hits two TOF modules placed at $\Delta\Phi=180^o$ (back to back) and at the same position along the beam axis. Such topology relies on muons orthogonal to the TOF pads and is therefore very interesting for the TOF calibration. Figure 4 shows the expected fake trigger rate as a function of the single pad rate; the rates of the quasi-vertical and of the back-to-back multiple muons are also shown.

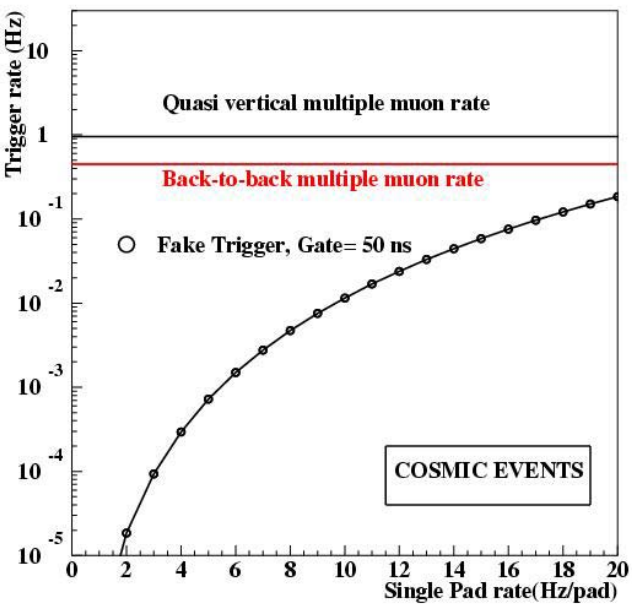

Figure 4: Multiple muon fake trigger rate as a function of the single pad rate. The genuine cosmic muon trigger rate is shown for quasi-vertical and "back to back" events.

B. Low multiplicity beam events

Minimum bias events in p-p collisions are characterized by a low multiplicity. Hereafter we consider the TOF trigger in the finest granularity configuration, where the CTTM receives in input N=1728 channels, each corresponding to an OR of 96 pads (~1000 cm^2). According to a simulation, based on the Phytia Monte Carlo [4] and on the GEANT3 [5] TOF simulation, about 50% (70%) of the minimum bias non diffractive events produces in the TOF at least 10 (5) channels on, $N^{on} \geq 10$ ($N^{on} \geq 5$). The TOF can give a remarkable

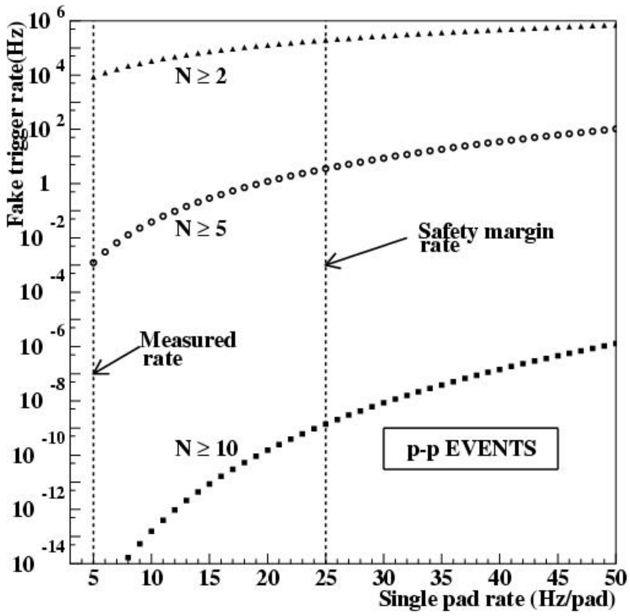

Figure 5: Fake trigger rate for $N^{on} \geq 2$ (triangles), $N^{on} \geq 5$ (open circles) and $N^{on} \geq 10$ (full squares) in p-p minimum bias events, as a function of the single pad rate.

contribution in triggering these events. Considering the MRPC background measured in the prototype, ~0.5 Hz/cm^2, and supposing that in the ALICE experimental area it will be a factor 5 larger as a safety margin, the fake trigger rate is just ~10^{-9} Hz. Figure 5 shows the fake trigger rate for events with a hit multiplicity $N^{on} \geq 10$ (full squares), for $N^{on} \geq 5$ (empty circles) and for $N^{on} \geq 2$ (full triangles) as a function of the MRPC rate. This fake rate has to be compared with the minimum bias rate:

$$R_{mm}(N^{on} \geq 10) = L \cdot \sigma \cdot \varepsilon = 3 \cdot 10^{30}\ cm^{-2}\ s^{-1} \cdot 60mb \cdot 0.5 = 90\ kHz.$$

A similar situation applies for Pb-Pb events where triggering on low multiplicity events, allows to select ultra-peripheral collisions. An interesting physics case is the vector mesons production (ρ^0, J/Ψ, Y). The STAR experiment at RHIC triggered on events with two back to back fired channels in an otherwise empty detector to select exclusive ρ^0 production [6]. The produced $\pi^+\pi^-$ by ρ^0 decay were approximately back-to back in the transverse plane due to the small p_T of the pair and to the low magnetic field B=0.25 T [6].

The fake trigger rate for the TOF trigger in the selection of events with N^{on} =2 is as high as 200 kHz, which is unmanageable at L0 level. Nevertheless a tighter selection on the two tracks topology can reduce the fake trigger rate. The decaying particle is almost at rest in the laboratory frame and the back to back geometry is preserved at some level in the low ALICE magnetic field, mainly for heavy resonances.

VI. CONCLUSIONS

We described the main features of the ALICE TOF trigger, based on the MRPC detector. Magnetic and radiation tests are now completed; the results obtained in these environments allowed a safe choice of the LTM components. The validation of a prototype during the test beam gave a green light for the industrial production of the 72 final modules. The CAEN Company will deliver the first LTM modules by the end of 2005; at the same time a first prototype of CTTM will be built. Further simulations are ongoing to study the capability of the trigger and to reduce the fake trigger rate in the selected events.

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