# Timing in the ALICE trigger system

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## *Abstract*

In this paper we discuss trigger signals synchronisation and trigger input alignment in the ALICE trigger system.

The *synchronisation* procedure adjusts the phase of the input signals with respect to the local Bunch Crossing (BC) clock and, indirectly, with respect to the LHC bunch crossing instant. The synchronisation delays are within one clock period: 0-25 ns.

The *alignment* assures that the trigger signals originating from the same bunch crossing reach the processor logic in the same clock cycle. It is achieved by delaying signals by an appropriate number of full clock periods.

We propose a procedure which will allow us to find alignment delays during the system configuration, and to monitor them during the data taking.

## I. INTRODUCTION

The ALICE trigger system [1] is designed to combine and synchronise the information from all the trigger detectors in ALICE, and to send the correct sequence of trigger signals to all detectors in order to make them read out correctly. The trigger inputs are divided into three different levels L0, L1 and L2, which have different associated latencies. The ALICE trigger system consists of three subsystems:

- The Central Trigger Processor (CTP) [2], which receives inputs from trigger detectors and makes trigger decisions,

- the Local Trigger Unit (LTU) [3], which uniforms interface between read-out detectors and the CTP,

- Trigger and Timing Control partition (TTC) which transmits the LHC bunch crossing clock and delivers trigger signals and trigger messages to detectors.

During the installation and commissioning of the ALICE detector, a number of timing operations need to be done, in order to ensure that trigger coincidences are correctly identified, that the correct signals are recorded in the detectors, and that events in each subdetector are correctly labelled with orbit and bunch crossing number.

In the first part of this paper the task of synchronising the signals of different subsystems is briefly discussed.

The second part deals with the procedure of trigger input alignment. We shall present an estimate of the time necessary to measure reliable alignment delays in different circumstances ( cosmic trigger, beam gas interaction and beam-beam interaction) and using different implementation of the method in the ALICE environment. A strategy for monitoring the synchronisation and alignment will also be presented.

Finally a procedure for setting the synchronisation parameters and the alignment delays will be proposed.

## II. SYNCHRONISATION

Synchronisation is necessary at two points of the ALICE trigger system. The phases of trigger inputs relative to the CTP bunch crossing clock and the LTU inputs relative to the LTU bunch crossing clock are to be adjusted. The system provides for an automatic measurement of the phase shift of all trigger inputs relative to the CTP clock and the phase of the LTU inputs relative to the local LTU clock. In both cases, following the measurement, a programmable hardware option is used to adjust the phase of the signals appropriately.

There are up to 60 trigger inputs to the ALICE CTP generated at nearly as many locations and all connected via individual cables. The phase measurement is done using the ADC on the L0, L1 and L2 boards and programmable delay line on the BUSY board. The generation of the ADC inputs is shown in Figure 1. At the time of measurement the trigger detectors are required to generate a pattern of alternating ones and zeros (Figure 1).

The right plot in Figure 1 shows the delay scan of a trigger input when the local BC clock is delayed in steps of 1 ns from 0 to 31 ns. The value of the delay when abrupt changes occur must be avoided in the final settings, since it can introduce an unacceptable time jitter.

After the measurement, synchronisation is achieved by setting the sampling of the input signal using either the rising or the falling edge of the BC clock to guarantee a safe margin outside the setup and hold time.

The CTP - LTU synchronisation is done in very similar way. There is a delay line in the LTU input which allows to perform scan and set the optimal value for the input signal delay. The ADC mechanism is the same as on the L0, L1 and L2 boards.

The procedure allows for automatic monitoring of synchronisation, which will be done outside the physics run.

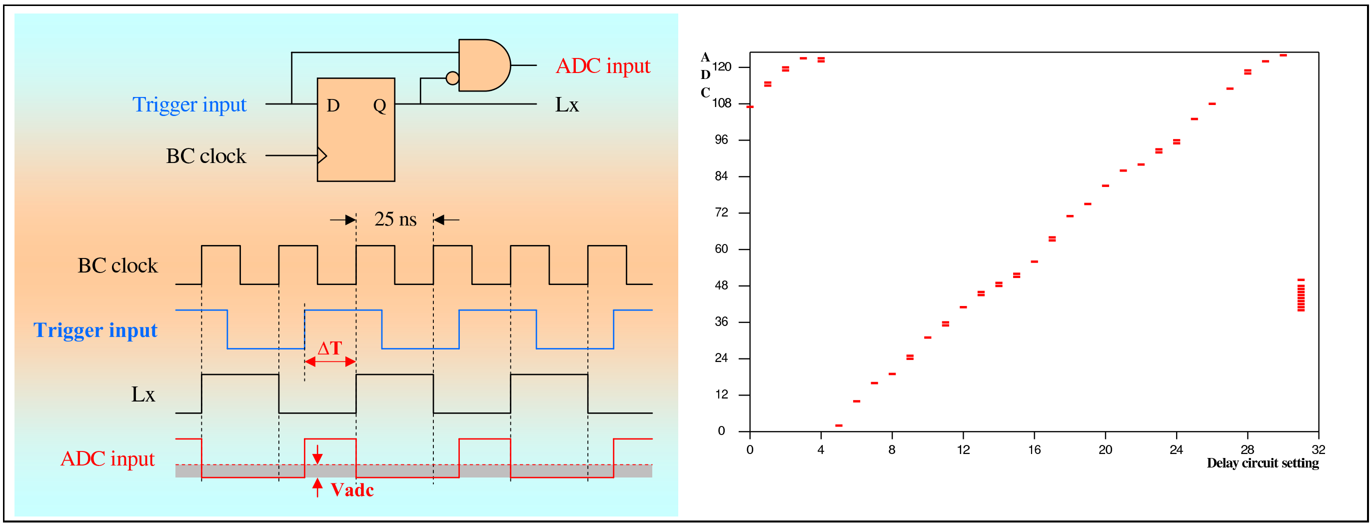

Figure 1: Left panel: measurement of the trigger input phase. The width of the ADC input signal is converted to a DC voltage $V_{ADC}$ with a low pass RC filter (integrator). The $\Delta T$, and the corresponding amplitude $V_{ADC}$ of the DC voltage measured by the ADC, are proportional to delay between the trigger input and its CTP analogue - Lx - clocked by the local BC clock. Right panel: a delay scan of the ADC. The abrupt changes around $\Delta T = 4ns$ and $\Delta T = 30ns$ occur when the transition of the signal coincides with the rising edge of the BC clock.

## III. ALIGNMENT

Once synchronisation of signals has been achieved, it can still happen that signals produced by the same event are separated by an integer number of bunch crossings. The process of alignment consists of adjusting these signals so as to make them coincide. While it would be straightforward enough to do this with low intensity collisions, it is more difficult to align signals with only one beam or high intensity collisions with background.

The starting point of alignment is to estimate the time intervals between collision and arrival of the trigger input signals to the CTP including the passage of particles through the trigger detectors, front end electronics response and signal propagation over the cable. The CTP hardware provides a 16 BC time window for arrival of the trigger input signals from the different trigger detectors.

We discuss the automatic alignment procedure based on a correlation analysis of different trigger inputs. The method is suitable in the case of high intensity collisions and in the presence of noise. The method is introduced in section A. The feasibility of the method for different beam conditions is discussed in section B. The different scenarios for implementation of the correlation analysis are evaluated in section C.

### A. *Correlation analysis*

First we describe the idea of correlation analysis in the case of a detector with efficiency $\epsilon$ and no noise. We try to align two detectors A and B. The detector A produces a time sequence of input signals $a_i$, where $i$ is the time when signal arrives at CTP. The time $i$ measured in bunch crossings is an integer number. The $a_i$ can have only two different values: $a_i = 0$ (no signal present at time $i$) and $a_i = 1$ (detector A produces signal at time $i$). Similarly for detector B we have a time sequence $b_i$. We define the correlation function

$$C_N(\delta) = \frac{1}{N}\sum_{i=0}^{N-\delta} a_i b_{i+\delta} \qquad (1)$$

where $\delta$ is a delay of signal from detector B with respect to detector A and $N$ is the number of bunch crossing available for analysis. It is obvious that function $C(\delta)$ has a maximum when detectors are aligned:

$$C_N(\delta = d) = r\epsilon_a\epsilon_b$$

where $d$ is correct delay, $r$ is the probability to have interaction in a bunch crossing and $\epsilon_a$ ($\epsilon_b$) is the efficiency of detector A (B). The efficiency includes both the geometrical acceptance and the efficiency to produce a signal if a particle passed the detector. In the case when the delay is not equal to the correct value the correlation function is

$$C_N(\delta \neq d) = r^2\epsilon_a\epsilon_b.$$

In both cases the $C_N$ has a binomial distribution (normal for large $N$) with standard deviation $\sigma^2 = C_N(\delta)/N$.

To estimate the number of events necessary for alignment we define the separation function as the difference of the correlation function in the aligned case and nonaligned case divided by the sum of variances of the aligned correlation function and nonaligned correlation functions:

$$S(r,\epsilon_a,\epsilon_b) = \sqrt{N}\frac{C(\delta = d) - C(\delta \neq d)}{\sqrt{C(\delta = d) + C(\delta \neq d)}} \qquad (2)$$

To get a 3 $\sigma$ separation with $r = 0.005$ (200 kHz) and efficiencies 0.8 thousand events need to be collected. The situation is less favourable taking into account the noise. Noise is defined as trigger detector signal produced without the collision. The formulae with random noise taken into account are in Appendix. The correlated noise can be identified by an autocorrelation function analysis

$$A_N(\delta) = \frac{1}{N}\sum_{i=0}^{N-\delta} a_i a_{i+\delta}$$

and taken into account.

Additional information of the beam crossing structure can be used to improve the method.

### B. Beam conditions

While the synchronisation is a fully internal procedure of the trigger system, alignment relies on the presence of external physics signals. The feasibility of the method is evaluated in three different cases:

- without a beam (cosmic trigger),
- with one beam (beam gas interaction),
- with both beams.

The cosmic particles are coming mostly in the vertical direction. On the top of the ALICE detector there is an array of scintillators - ACORDE- which will produce efficient cosmic trigger with the rate few Hz/m$^2$ [8, 7]. The use of this source of particles for other subdetectors is limited by their acceptance. Low intensity cosmic trigger would allow the alignment of trigger detectors with the oscilloscope.

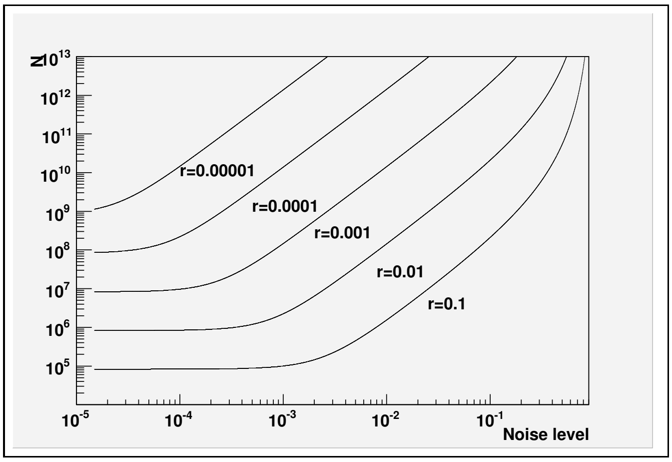

Figure 2: The number of events necessary for 1 $\sigma$ separation as the function of noise level $\nu = \nu_a = \nu_b$ for different values of probability of interaction in a BC $r = 0.1$, 0.01 and 0.001, 0.0001 and 0.00001. The number of filled bunches $k_b = 43$. The detector efficiencies are $\epsilon = 0.1$ and $\epsilon_b = 0.1$. The formulae from the appendix are used to produce this plot.

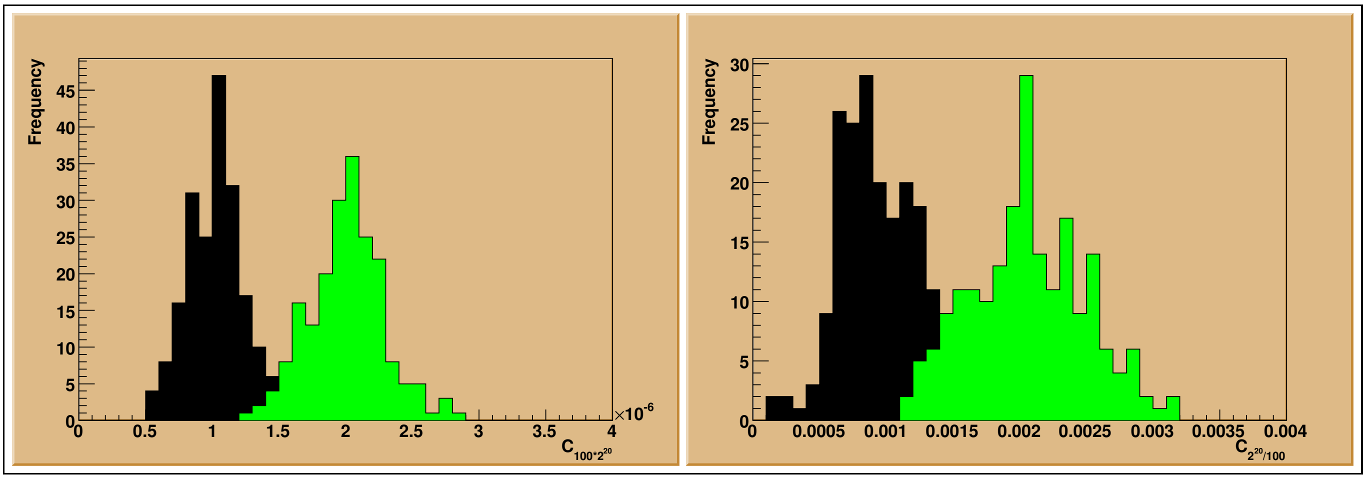

Figure 3: Left panel: The correlation function for the parameters probability of interaction in a BC $r = 0.001$, detector efficiencies $\epsilon_a = 0.8$, $\epsilon_b = 0.1$, and noises equal to $\nu_a = r$, $\nu_b = r$, number of filled bunches $k_b = 43$. The correlation function is sampled for $20 \cdot 2^{20}$ events in order to see the spread of the distribution. Right panel: The correlation function with probability of interaction in a BC $r = 0.15$, ($L = 10^{30}$, $k_b = 43$) detector efficiencies $\epsilon_a = 0.8$, $\epsilon_b = 0.8$ and noises $\nu_a = r/5$, $\nu_b = r/5$. The black (dark) histogram corresponds to correlation function for detectors not aligned. The green (light) histogram corresponds to correlation function for aligned detectors. The correlation function is sampled for $2^{20}$ events in order to see the spread of the distribution.

The beam gas interactions which would be available during the LHC commissioning with one beam circulating should be used for alignment of trigger detectors. The probability of beam-gas interactions in one BC clock is estimated as

$$r = n\sigma L N_p$$

where $n$ is the residual $H_2$ equivalent gas concentration in the beam pipe, $\sigma$ is the p-p inelastic cross section, $L$ is the length of the LHC straight section at interaction point and $N_p$ is the number of protons in a bunch. Taking $H_2$ equivalent gas density $1.9 \cdot 10^{14} m^{-3}$ [5], p-p inelastic cross section $\sigma = 70$ mbarn, $N_p = 9 \cdot 10^{10}$ protons per bunch [6], and $L = 20m$, the probability of interaction in a single bunch is $r = 0.0024$. This is equivalent to 27 Hz rate per bunch. The spread position of interaction vertex may lead to sizable difference in detector efficiencies, especially in the case of a detector with sensitive volume perpendicular to the beam (V0) with respect to a detector with sensitive volume parallel to the beam (Pixels). The additional background from beam halo particles would produce a noise. About $10^8$ bunch crossings are to be collected in this case, (Figure 2), assuming a large relative noise and low detector efficiencies. On the left panel of Figure 3 the results of the Monte-Carlo simulation are presented in this extreme case.

In the standard situation with two beams the beam gas background would be reduced by a factor of 30 [5] relative to LHC start-up. The well defined position of interaction vertex and left-right symmetry of collisions and detectors would increase detector efficiencies. The probability of an interaction in a bunch crossing is $r = \sigma L / f_{LHC} / k_b$ where $\sigma$ is p-p inelastic cross section, $L$ is the LHC luminosity, $f_{LHC}$ is the LHC revolution frequency and $k_b$ is the number of filled bunches. About $10^5$ bunch crossings are necessary (Figure 2) for alignment. The Monte-Carlo results in this case are shown in Figure 3, right panel.

### C. *Implementation of the method in ALICE*

There are three different ways of implementation of the correlation analysis in the ALICE trigger system:

- trigger input recording in the CTP (snapshot memory),
- trigger class counting,
- data recording through the ALICE data acquisition system (DAQ).

The time needed to complete alignment depends on the number of bunch crossings $N(r, \epsilon, \nu)$ we need to collect for given separation (2), which is a function of interaction rate, detector efficiencies and a noise.

The trigger input recording in the CTP is the most robust of these methods. It enables unbiased collection of the trigger input signals on every trigger level. The case of trigger input recording in the CTP relies on the use of the snapshot memory. Each board contains a memory with a capacity of 1M word which records the trigger inputs (and also other signals for testing and monitoring purposes). The snapshot memory can be read via the VME in about $1.25s$ time. The time necessary to collect $N$ bunch crossings is therefore

$$\frac{N}{2^{20}} \cdot 1.25sec$$

The scan of the delay $\delta$ would be done offline.

In the trigger class counting method the CTP is programmed to provide the trigger classes as coincidences of trigger inputs. The coincidences are actually hardware calculation of the correlation function (1). The delay $\delta$, which needs to be scanned, can be controlled by a hardware delay set on the L0, L1 and L2 boards for L0, L1 and L2 inputs respectively. The number of classes necessary for alignment of $n_{inputs}$ is $n_{inputs} - 1$. Let us assume that the signals are not misaligned by more than $\delta_{max}$ (the hardware allows for $\delta_{max} \leq 16$ ). The time necessary for alignment is in this case

$$N \cdot \delta_{max} \cdot 2.5 \cdot 10^{-8} sec$$

where $N$ is the number of bunch crossings for required separation of the correlation function. The trigger class counting method enables an unbiased calculation of the correlation function on the L0 level, while the bias introduced on the L1 and L2 levels due to the deadtime has to be taken into account.

The last option is the use of the ALICE data acquisition system. The correlation analysis in this case is more complicated since the data are biased even at the L0 level.

The estimates show that the trigger class counting method and the data recorded directly in the CTP require about the same amount of time to collect enough statistics, while the use of DAQ is more time consuming. Note also that the first two methods can collect data and calculate correlation function simultaneously. Figure 2 shows that even in the very extreme case of low detector efficiencies, a large noise and a low interaction rate, $10^{10}$ BCs would be enough for alignment which corresponds to one and half hour of measurement time.

The methods with trigger input recording and data recording by DAQ also provide a continuous monitoring of alignment without interference with data taking.

## IV. SETTING PROCEDURE

The algorithm which shall find the optimal settings for synchronisation and alignment is formulated.

1. Synchronise trigger inputs with arbitrary setting of BC delay, e.g. the value zero.
2. Align trigger inputs.
3. Find the latest arriving trigger input and set the BC delay to sample it as early as possible, allowing for a sufficient safety margin.
4. Using the measurement taken at 1. recalculate the synchronisation parameters with the adopted setting of the BC delay. Alternatively repeat the synchronisation procedure with that BC delay setting.

The condition that the latest input should be optimally delayed with respect to CTP bunch crossing clock guarantees a minimum delay time for the latest trigger input.

## V. SUMMARY

The synchronisation of the ALICE trigger system has been described. An automatic alignment procedure has been proposed. Method provides the alignment in the acceptable timescale (hours in the worst case). It also allows continuous alignment monitoring. Finally a procedure for setting the timing parameters for ALICE trigger system has been formulated.

## VI. APPENDIX: CORRELATION FUNCTION WITH RANDOM NOISE

The formulae for the correlation function are presented. The $\nu_a$ ($\nu_b$) is the probability to generate a trigger signal in detector A (B) for whatever reason in the absence of collision.

The aligned correlation function for LHC with all bunches filled is:

$$\begin{aligned} C^{alFULL} =& r\epsilon_a\epsilon_b + \\ & r(1-\epsilon_b)\epsilon_a\nu_b + r(1-\epsilon_a)\epsilon_b\nu_a + \\ & (1-r)\nu_a\nu_b + r(1-\epsilon_a)(1-\epsilon_b)\nu_a\nu_b \end{aligned}$$

where the first term is for signal coincidence, the next two terms are for signal and noise coincidence and the last two terms are for noise coincidence in the case of no collision and signal failure due to the detector inefficiency.

The misaligned correlation function in the case of filled LHC is:

$$\begin{aligned} C^{nalFULL} =& r^2\epsilon_a\epsilon_b + \\ & r(1-r\epsilon_b)\epsilon_a\nu_b + r(1-r\epsilon_a)\epsilon_b\nu_a + \\ & (1-r\epsilon_a)(1-r\epsilon_b)\nu_a\nu_b \end{aligned}$$

where the first term is for signal coincidence, the next two terms are for signal - noise coincidences and the last term is for noise-noise coincidence.

The correlation function with some bunch crossing empty depends on the distribution of the bunch crossings in the LHC orbit. The formula for uniformly distributed $k_b$ bunch crossings in the aligned case is

$$C_N(\delta = d) = fC^{alFULL} + (1-f)\nu_a\nu_b$$

where $f = k_b/3564$.

The nonaligned correlation in the case $k_b << 1$ is

$$\begin{aligned} C_N(\delta \neq d) = & f \cdot [r(1-r\epsilon_b)\epsilon_a\nu_b + r(1-r\epsilon_a)\epsilon_b\nu_a] + \\ & (1-2f)\cdot\nu_a\nu_b \end{aligned}$$

In general case the Monte-Carlo provides the correlation function calculation.

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