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Synchronization of the Muon Detector

G. Wrochna

CERN, Geneva, Switzerland

Abstract

Synchronization of the Muon Detector is discussed. After some general considerations concerning synchronization methods, the RPC system is described in detail from the synchronization and timing point of view. Drift Tubes and Cathode Strip Chambers are also briefly discussed.

1 Introduction

The issue of synchronizing the CMS *Trigger and Data Acquisition System* (TriDAS) was addressed on many occasions (see e.g. [1]). The most complete analysis of the problem is presented in Ref. [2]-[4]. Most of the considerations contained in those papers have rather general nature. However practical solutions described there are concentrated on the Calorimeter Trigger. In this paper we are going to discuss the specific case of the Muon System. We particularly focus on the *Pattern Comparator Trigger* (PACT) for *Resistive Plate Chambers* (RPC), because it is perhaps the most demanding one from the point of view of synchronization. On the other hand it is relatively simple, which makes the discussion easier. *Drift Tubes* (DT) and *Cathode Strip Chambers* (CSC) are briefly discussed at the end. We begin, however, with some general considerations (Sec. 2-Sec. 4) which are valid in principle for any kind of detector.

2 Trigger synchronization

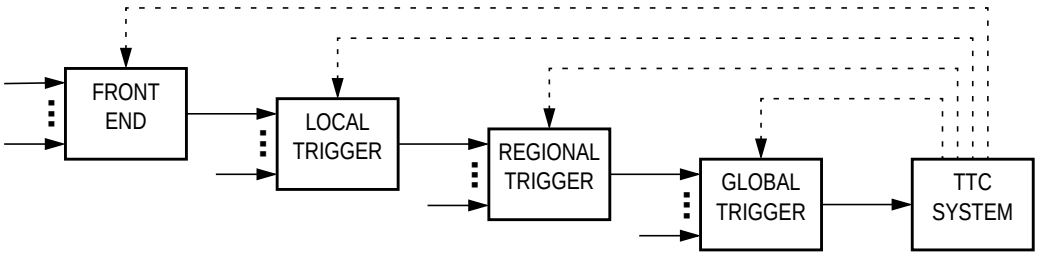

Figure 1: Generic trigger structure.

The CMS Trigger System has a tree-like structure which is schematically shown in Fig. 1. The data flow through the entire chain should be synchronous, driven by the 40.08 MHz clock. This implies that the data should be synchronized at each destination (local, regional, global trigger, etc.). The synchronization at each level can be factorized to

- phase adjustment — fine tuning within one clock cycle of 25ns,
- bunch crossing synchronization — shift by multiple of 25ns.

The synchronization can be ensured at different levels by different means. For example, all electronics in a single crate should be driven by a common clock, therefore the synchronization must be ensured by proper hardware design. Short connection (<2m) from crate to crate may need phase adjustment, but it should not require bunch crossing synchronization if the data are coming from already synchronized sources. Special attention should be given to the longest connection in the chain, which is realized by an optical link running from the experimental hall to the control room. In different trigger subsystems it runs either from Front End and Local Trigger or between Local and Regional Trigger.

The most important synchronization tool is the *Timing, Trigger and Control* (TTC) distribution system [7]. It is a network of optical links distributing the LHC clock (40 MHz), bunch crossing number, LV1 trigger signal and some fast control commands. In the case of the RPC PACT the *TTC receivers* (TTCrx) will be placed on each Link Board and in each crate in the Control Room. An important feature of the TTCrx is the possibility of adjusting the phase of the LHC clock.

2.1. Phase adjustment

There are two different cases:

- phase adjustment at digitisation
- phase adjustment of digitised signals

2.1.1 Phase adjustment at digitisation

Analog signals from the detectors have to be in a right phase with respect to the clock in order to be correctly digitized and processed. The signals often have a jitter due to time of flight, detector response and the signal propagation. The synchronization procedures and precision requirements are different for different kind of detectors. Some of them (e.g. Resistive Pate Chambers RPC) require precision as good as 1ns.

2.1.2 Phase adjustment of digitized signals

Once the signals are digitized they have no jitter, except for the electronics jitter which is usually below 1ns. However, when the signals are sent to another board they might have a constant shift in phase in respect to the local clock at the destination. The rule to be followed is

synchronize the phase of the signal at the destination to the local clock.

2.2. Bunch crossing synchronization — relative and absolute

Consider a board or crate to which data are coming from remote (>2m) sources. The following requirements have to be fulfilled:

- incoming data should be in phase with the local clock (clock phase adjustment, discussed above)
- **data from different sources should correspond to the same b.x. (relative synchronization)**
- **the data should correspond to the b.x. given by the local TTCrx (absolute synchronization)**

The bunch crossing synchronization is ensured by delaying the data coming faster than others (e.g. due to shorter cable). Two methods of such a delay are being investigated:

- pipeline (shift register) with programmable length,
- FIFO with input driven by data and output driven by the destination clock.

2.2.1 Pipeline delay

The method is illustrated in Fig. 2. Shorter cable is compensated by longer pipeline. The length of the pipeline must be programmable. In practice the pipeline delay is often proceeded by a phase adjustment circuit.

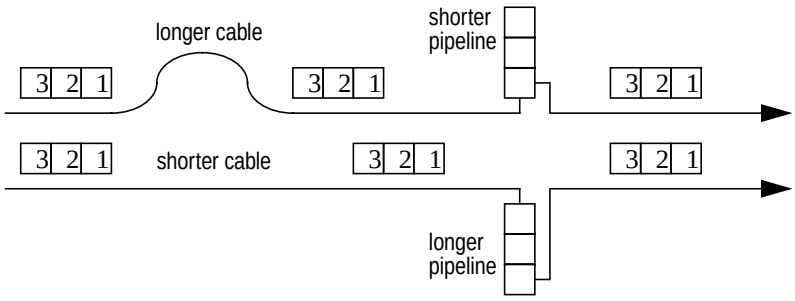

Figure 2: Bunch crossing synchronization by pipeline method.

2.2.2 FIFO delay

The method is illustrated in Fig. 3. The data are written to the FIFO according to the their own clock. This might happen at different times in different channels (e.g. due to different cable lengths). However, the data are readout from the FIFO at the same time, according to the local clock. Shorter cable propagation time is compensated by longer waiting time in the FIFO. More details on this method can found in Ref. [2]-[5].

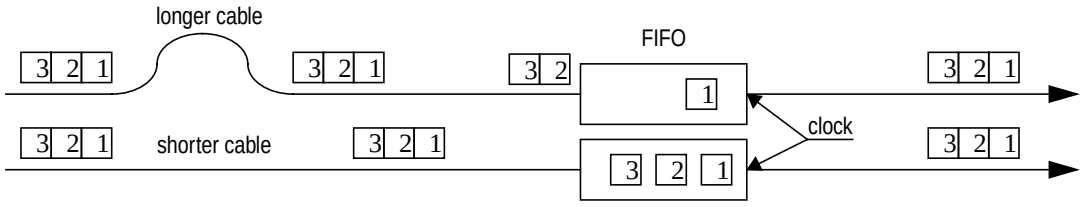

Figure 3: Bunch crossing synchronization by FIFO method.

2.3. Internal link synchronization

An optical link itself, which run with a clock of ~1 GHz, requires also an internal synchronization. The tools for that are usual provided by a vendor, in the Tx/Rx chipset. A user only needs to invoke the procedure, which may last several microseconds.

3 Synchronization methods

Simplified signal flow diagram is shown in Fig. 4. Only one trigger device (e.g. Local Trigger) is shown. The LHC Control system determines the interaction moment by driving RF and magnet currents (dashed line). Its clock is distributed by the TTC system to Front End and Trigger electronics (dotted line). Particles created at the Interaction Point are flying towards detectors (thick solid line). Generated detector signals are sent from the Front End boards to the Trigger Processors (thin solid line).

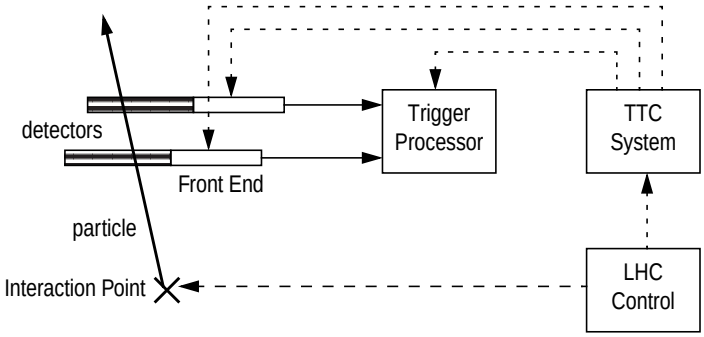

Figure 4: synchronization with real data and test data.

In order to synchronize the system one can use **real data** or **test data**. The first iteration, however, should be done **without data**, by measuring and calculating all the delays in the system. Test data provide an efficient way for partial synchronization of the system. However, final synchronization can only be done with real data, because there is no other way to measure precisely the path

LHC Control → Interaction Point → particle flight → detector → Front End.

3.1. Synchronization without data — "cutting the cables"

Synchronization of a complex system such as the CMS Trigger must be an iterative procedure. Its success largely depends on the precision of the starting point. It does not necessarily mean that all the cables have to be cut to a specific length. They can be measured and calculated delays can be compensated by electronics. It should not be too difficult to achieve precision better than 5ns, which corresponds to ~1m of cable. Special care should be taken with TTC fibres. Good knowledge of their length will facilitate synchronization with test data.

3.2. Bunch crossing synchronization with test data

The test data can be generated and transmitted on request broadcasted by the TTC. They can be used for relative channel-to-channel synchronization as well as for the absolute synchronization of data to the LHC clock.

3.2.1 Relative synchronization

In order to test relative channel-to-channel synchronization one needs to generate test patterns at the source (e.g. Front End board) and examine them at the destination (e.g. Trigger Processor board). The received data pattern should be compared to the generated one. Let us consider a simple example — a sequence (00100) sent through all channels. The same sequence should be observed at the destination, namely the "1" should come at the same time, defined by the bunch crossing number provided by TTC. If in one of the channels, the "1" was observed e.g. one b.x. later, it means that this channel is delayed by one b.x. in respect to others.

3.2.2 Absolute synchronization

Test data can be used for absolute synchronization of data to the LHC clock at the destination if the absolute synchronization was already done at the source. Generated test pattern should unambiguously mark one bunch crossing. Let us denote by *N* its number given by the TTC at the source. Again one can use the sequence (00100) as an example. The "1" should be sent in bunch crossing *N*. The delay of the signal or the TTC clock at the destination should be adjusted in such a way, that the "1" is received in bunch crossing *N*, according to the local TTC.

3.3. Bunch crossing synchronization with real data

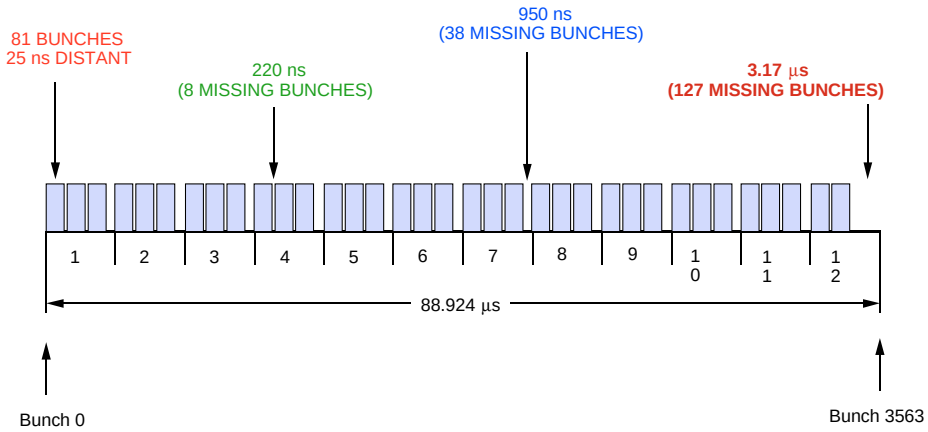

Figure 5: LHC bunch structure.

In order to synchronize the system with real data one can make use of the LHC bunch structure is shown in Fig. 5. The LHC frequency of 40.08 MHz corresponds to a 25ns period. One LHC orbit consists of 3564 periods. They are often call "bunches" although some of them do not contain protons. The *bunch number* always run from 0 to 3563, no matter how many real proton bunches are in the machine. The proton bunches are grouped in 35 trains, 81 bunches each. The structure of gaps between them can be used for the absolute synchronization. It is illustrated in Fig. 6. Events containing data in a given detector region (e.g. a muon hit in a given RPC) are histogrammed according to the bunch crossing number, i.e. event number modulo 3564. Accumulated histogram can be compared to the expected bunch structure, shown in Fig. 5.

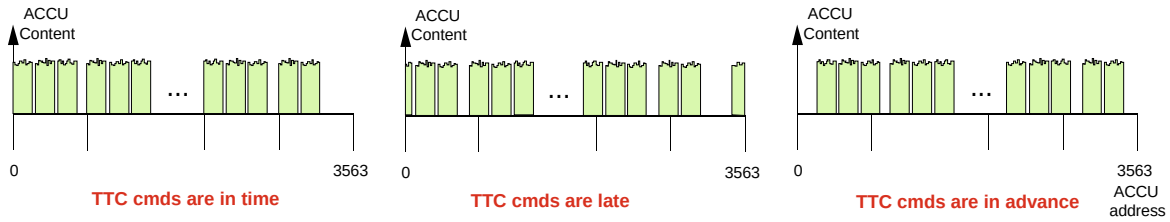

Figure 6: Absolute synchronization using real data.

In order to collect enough statistics, so the bunch structure is clearly visible one needs to wait for many orbits. However, even with relatively low statistics one can find the delay x by looking for the maximum of the correlation function $f(x)$ of the expected and measured histograms, denoted as $h(t)$ and $g(t)$ respectively.

$$f(x) = \int h(t)g(t-x)dt$$

An example is shown in Fig. 7. The same method can be used for relative synchronization of two channels by comparing their histograms.

At the early stage of the LHC running in it might be useful to create a bunch structure more convenient for synchronization purposes. For example single bunch running in the machine would be a very clean synchronization marker. The price to be paid is very low luminosity of the order of $2 \cdot 10^{29} \mathrm{cm}^{-2}\mathrm{s}^{-1}$, which may result in a very long time needed to collect required statistics. More optimal bunch configuration could have individual bunches of protons separated by several "empty bunches".

3.4. Phase adjustment at Front End

This can be done with real data only, because the delays due to particle time of flight, detector response, etc. have to be taken into account. In general one has to record the data from several consecutive bunch crossings and look at the distribution of signal among them. Details, however, depend significantly on the kind of detector and they will be discussed later, in dedicated sections.

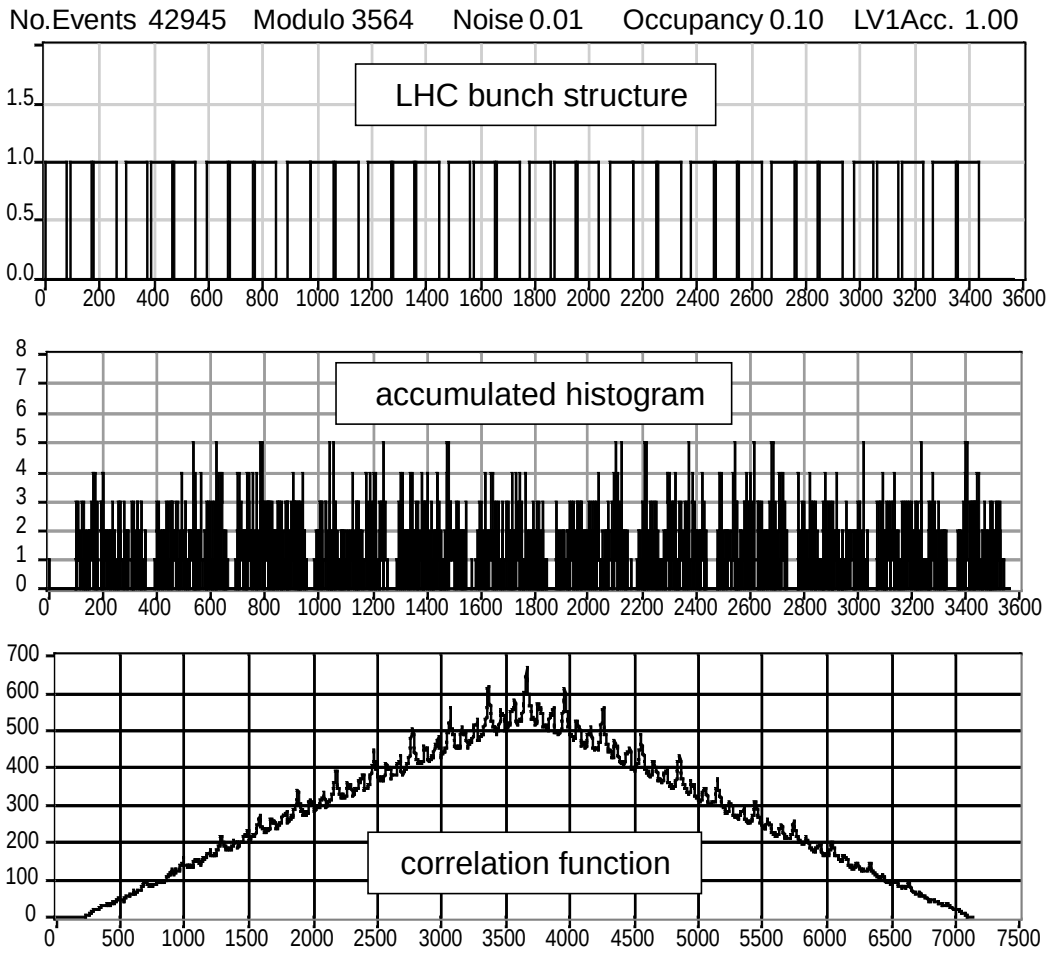

Figure 7: Calculating the absolute delay of a given channel.

3.5. DAQ bunch crossing synchronization

There are two places crucial for synchronization in the DAQ chain

- phase adjustment at Front End
- trigger - data matching at the end of DAQ pipelines

The first item was discussed in the previous section, so we concentrate here on the second one. Data in a given DAQ channel are waiting for the LV1 decision in the pipeline. They are read out from the end of the pipeline if there was a positive LV1 response. The "LV1 Accept" corresponding to a given b.x. has to match the data from the same b.x. This can be achieved by delaying the "LV1 Accept" or adjusting the length of the pipeline. The value of the delay can be established using one of the following methods.

3.5.1 Multi-crossing readout of real data

This method is especially suitable for low occupancy detectors participating in the trigger, e.g. RPC, CSC and Drift Tubes. A given detector region is read out if there was a "LV1 Accept" caused by the data from this region. Several consecutive b.x. are read out in order to discover a possible misalignment of data with respect to "LV1 Accept". High occupancy may disturb this method if probability of having data in consecutive b.x. is high.

3.5.2 Multi-crossing readout of test data

This method is suitable for any detectors participating in the trigger, i.e. muon detectors and calorimeters. A test pattern causing a trigger is generated in a certain detector region. The data from this region, covering several consecutive b.x. are read out in order to discover a possible misalignment of data with respect to "LV1 Accept".

3.5.3 Histogramming real data

This method is similar to the trigger b.x. synchronization with real data described in Sec. 3.3. Whenever there was a trigger, the data are stored in a histogram according to the b.x. number given by the trigger. Possible misalignment can be discovered calculating correlation function of obtained histogram and LHC bunch structure. This method can be used by any detector, not necessarily participating in the trigger, e.g. by the tracker. High occupancy is of advantage in this method, because needed statistics can be collected in a shorter time.

4 Synchronization procedures

4.1. Startup — without the beam

The first method to be used in order to synchronized the CMS trigger is synchronization without the data, described in Sec. 3.1. All particle and signal paths should be calculated or measured and all programmable delays in the system should be adjusted accordingly.

Next step is synchronization with test data (Sec. 3.2). At the beginning there is no absolute time reference, because this can only be done with real data. Therefore the LHC clock and bunch crossing number provided by TTC at Front End should be taken as a reference. Only relative synchronization can be done in this way. It relays on the knowledge of all delays in the TTC network. The main purpose of this procedure is setup the system, so it can fully operate with test data. In this way trigger hardware and algorithms can be tested before the LHC beam is available.

4.2. Special synchronization run

As soon as the LHC beam is available one should attempt synchronization with real data (Sec. 3.3 and Sec. 3.4). A special run dedicated to the synchronization might be very useful. It may differ from a normal physics run:

- special LHC bunch structure (e.g single, separated bunches) can be set up
- different trigger and DAS partitions can be run independently in order to facilitate internal synchronization of each one
- trigger algorithms may run in a “loose” mode to collect needed statistics in a shorter time
- DAS partitions may run in special modes, e.g. without zero suppression, reading out several consecutive bunch crossing, etc.

4.3. Normal physics run

During a normal physics run one can perform synchronization with both test data and real data. The gaps in the LHC bunch structure (Fig. 5), especially the biggest one (3.17 μs) at the end of the orbit, can be used for sending test data. Real data can be used to accumulate timing histograms, as described in Sec. 3.3. They can also be used to monitor the synchronization by observing efficiency maps of the trigger, because desynchronization of a certain part of a system will very probably result in efficiency loss in corresponding region.

4.3.1 Error detection

The first symptom of any synchronization problem will probably be higher bit error rate. Therefore, an error detection is a very useful diagnostic tool. For this the data must be accompanied by some error detection code, like e.g. the Hamming code which enables detection of all single- and two-bit errors. The Hamming code was proposed to be used for Calorimeter Trigger data [4].

4.3.2 Internal link synchronization

The most fragile part of the data transmission chain is the internal synchronization of the optical link, because it runs with the frequency as high as 1 GHz. Every time an error is detected one should invoke the resynchronization procedure. However, detecting an error, instructing the link to start the resynchronization and the resynchronization itself may cause a dead time of many μs. Therefore, it seems to be more practical to resynchronize the link periodically, regardless if an error was discovered or not. Of course, detected errors should be logged before the resynchronization and all the data transmitted through the given link since the previous resynchronization should be marked bad or at least suspicious.

The 127 b.x. long gap at the end of each LHC orbit is the best time for this kind of procedures. It occurs every 89μs and it last ~3μs. However, it has to be checked if this time is enough for resynchronization of a given chipset. Moreover the gap will also be used for other tests and careful allocation of the gap time among users is necessary.

5 Muon rates

Muon proton-proton interactions provide the only way to make the absolute synchronization. Unfortunately the rate of muons, especially in the barrel, is very low. On average less than 1 muon per 1000 pp interactions enters the first barrel station MB1 and a few times less enter the last one MB4. At luminosity $10^{33}cm^{-2}s^{-1}$ the muon rate at MB4 of about 6 Hz/m^2 is expected. The area of MB4 RPC is 1.28×3.75m^2 ≈ 5m^2. Similarly, the area of the smallest Drift Tube chamber at MB4 (the one in the CMS leg) is 2.52×2.0m^2 ≈ 5m^2. This gives ~30Hz per chamber, i.e. ~1800 muons / minute / chamber.

In the endcap the rate expressed in Hz/m^2 varies rather fast with rapidity. Therefore, it is more useful to quote the rate per η-unit. The lowest rate will be seen by the CSC ME1/3, which is 10° wide and covers η=0.88-1.14. In this region the muon rate is about $4 \cdot 10^4$Hz/η-unit, which results in 300Hz/chamber. This is 10 times higher than in the case of RPC and Drift Tubes, therefore later in this paper we consider only the RPC/DT rate, as the worst case.

5.1. Relative synchronization

In order to make the relative station-to-station synchronization one can use all muons traversing a given detector region. It can be assumed that all channels of one chamber are aligned in time by construction with a precision better than 1ns. In such a case one needs to collect ~1000 muons per chamber. This can be done in 1 minute.

5.2. Absolute synchronization

Much more difficult is the absolute synchronization, i.e. the bunch crossing assignment. How do we know that a muon observed in the detector corresponds to a given bunch crossing number sent by TTC? The only way to know it is to ensure that there are no other bunches around. However, running with only one bunch in the machine would reduce the luminosity by factor ~5000 to the level of $2 \cdot 10^{29}cm^{-2}s^{-1}$. In such a case only 20 muons / hour / chamber are expected, i.e. 50 hours are needed to collect 1000 muons / chamber.

Much better solution is to run with the full available luminosity, e.g. $10^{33}cm^{-2}s^{-1}$ and make use of the LHC bunch structure. This kind of procedures will be discussed in detail in the next section. Here we only try to estimate needed statistics. Let us assume that only the muons at the edges of trains can be used. There are 35 trains per one orbit which consists of 3564 bunches. That means that roughly 1% of muons is useful. This gives an effective rate of 0.3Hz / chamber, i.e. 1000 muons / hour / chamber. It does not sound unreasonable.

The most effective bunch configuration should have individual bunches of protons separated by several “empty bunches”. For example 1 bunch of protons followed by 4 “empty bunches” would give the muon rate of ~6Hz per chamber, i.e. ~360 muons / minute / chamber. In such a case 3-5 minutes would be enough to collect reasonable statistics.

5.3. Background

Synchronization with muons can be disturbed by the presence of background. There are two major kinds of background to be considered (see Fig. 8)

- electrons — mainly from thermal neutron capture followed by γ emission and conversion,
- charged hadrons — mainly due to punchthrough from hadronic showers and backsplashes from the forward calorimeter (HF).

The single hit rate due to neutrons (n→γ→e) is 1-3 orders of magnitude higher than that of muons. CSC and Drift Tubes are able to eliminate this background by local coincidence of several layers in one chamber. The relative timing of those layers is ensured by construction, so the synchronization is not affected. The case of RPC is more difficult, because there is no local coincidence within one muon station. The only place when the neutron background can be suppressed is the Patter Comparator processor, looking for coincidence of at least 3 RPC planes. This implies that the RPC synchronization with real data (Sec. 3.3) must involve the trigger. That, in turn, means that the first iteration, done without the beam (Sec. 3.1 and Sec. 4.1), should be precise enough to enable trigger to work with at least 10% efficiency and thus to make the relative synchronization (Sec. 5.1) in <10 min.

The rate of charged hadrons is of the same order as the rate of muons. Charge hadrons can traverse several CSC or DT layers and satisfy the local trigger coincidence. However they often come in time, so their presence helps, rather than disturbs the synchronization process. Those created in HF can come 1 b.x. later. Their number, however, is too small to cause any synchronization problems.

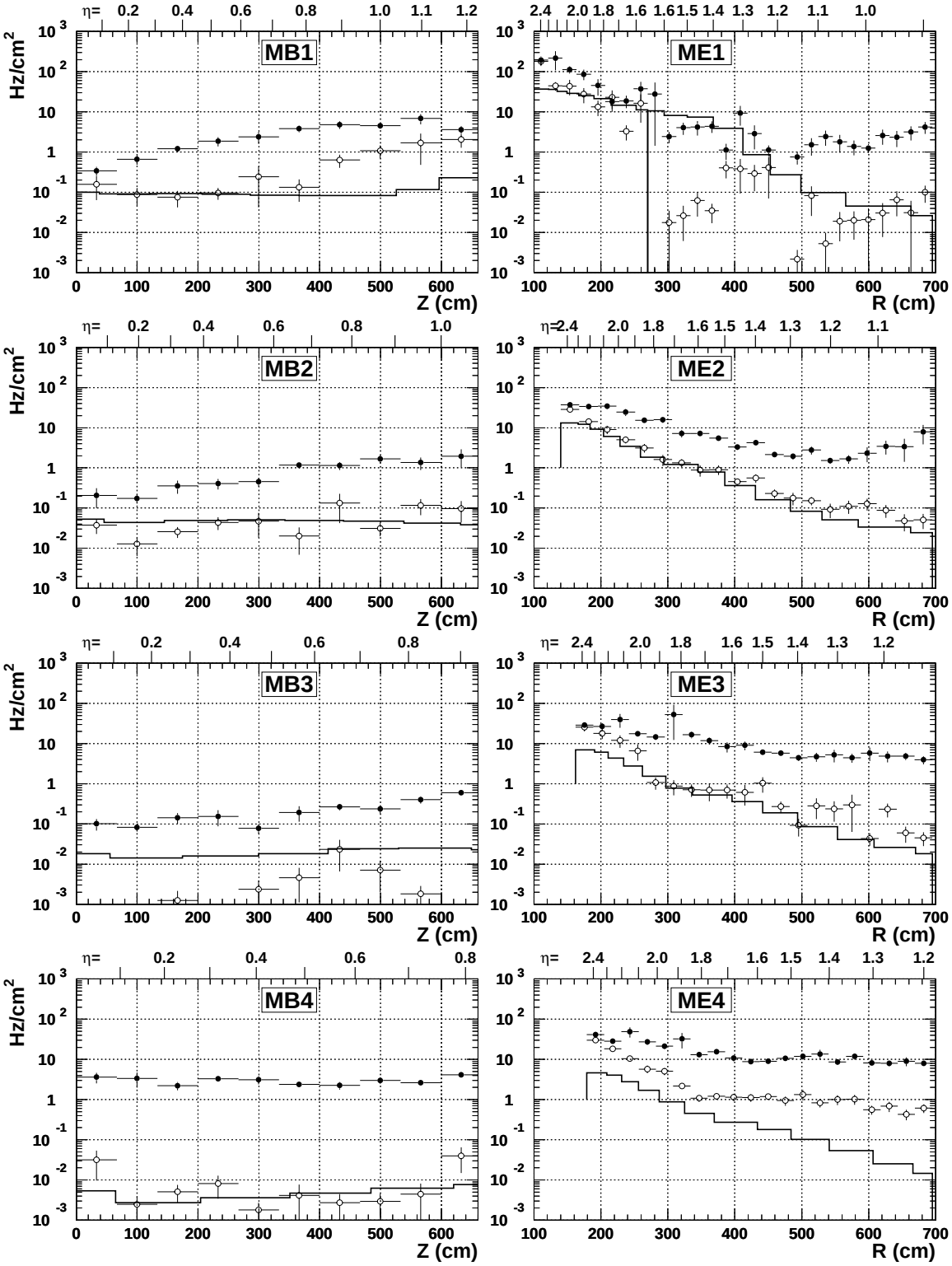

Figure 8: Rates in muon chambers: muons (solid line), charged hadrons (open circles), electrons - mainly from thermal neutron capture followed by γ emission and conversion (full circles).

6 RPC PACT synchronization

6.1. PACT block diagram

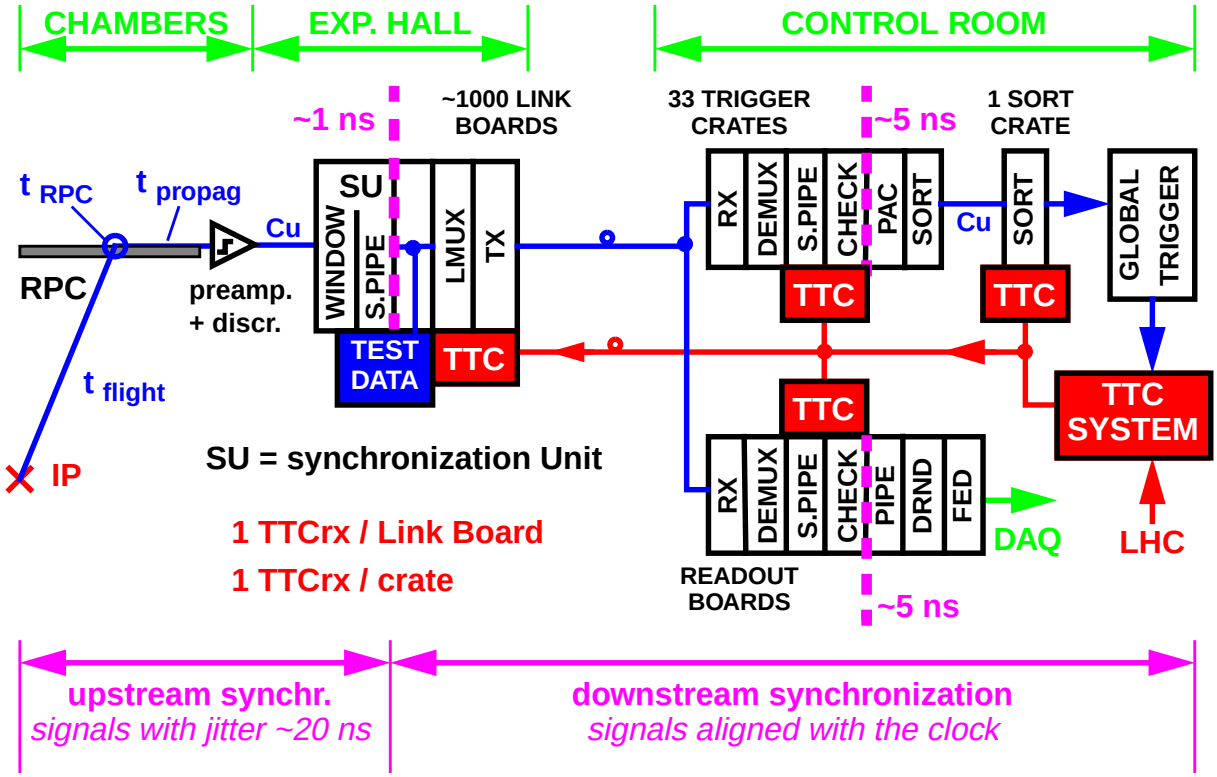

Figure 9: Block diagram of the RPC PACT.

Block diagram of the RPC PACT is shown in Fig. 9. Each chamber is equipped with *Front End Boards* (FEB) containing *Front End Chips* (FEC) with preamplifiers and discriminators. The signals are shaped and aligned with the clock by the *synchronization Unit* (SU). Signals from several Front End Boards are collected by a *Link Board* (LB) through twisted pair cables, up to 3 m long. Then, the data are compressed (LMUX)[a)] and transmitted (TX) through optical fibers to the Control Room. Here the data are split into two streams. The trigger stream data are decompressed (DEMUX) and processed by *Pattern Comparator* (PAC) processors. Recognized muon candidates are sorted according to their transverse momentum p_t and sent to the *Global Muon Trigger*. The DAQ stream data are stored, event by event, in pipeline memories (PIPE). Events selected by *Level 1 Trigger* (LV1) are derandomized (DRND) and sent by *Front End Driver* (FED) to the DAQ system.

Main elements important for synchronization are also marked on the diagram. synchronization Unit (SU) consists of WINDOW electronics for phase adjustment (Sec. 2.1.1) and synchronization pipeline (S.PIPE) for bunch crossing synchronization (Sec. 2.2.1). Its action will be described in Sec. 6.3. synchronization with test data (Sec. 3.2) is done with test data generator (TEST DATA) and error detection circuit (CHECK). The TTC network is also shown. There is one TTCrx per Link Board and one per each crate in the control room.

6.2. PACT timing

From the timing point of view the RPC PACT system consist of two distinct parts:

- *upstream* — before synchronization Unit — signals are randomly spread in time with a jitter of ~20 ns,
- *downstream* — after synchronization Unit — signals are aligned with the clock.

The total signal propagation time in the upstream part t_{up} has four components

$$t_{up} = t_{flight} + t_{RPC} + t_{propag} + t_{preamp}$$

The time of flight t_{flight} is different for different chambers. It varies from 4m/c = 13ns for station MB1, to 12.6m/c

a. An option is being envisaged to compress the data already at the Front End in order to reduce the number of cables from FEB to LB by factor 4.

= 42ns. More important is variation within one chamber. The worst case is MB/2/1. The strip length of 1.26m cause the flight path variation of 1m and the time of flight variation Δt_{flight} = 3.5ns. The differences between various chambers can be corrected by adjusting the length of cables or electronics delay. The variation within one chamber cannot be corrected and it should be considered as a random jitter.

Second contribution is the time of intrinsic RPC phenomena: ionization, avalanche formation, drift to electrodes and pulse formation — denoted all together by t_{RPC}. It has quasi-gaussian random distribution with σ = 1-5ns. An example is shown in Fig. 10.

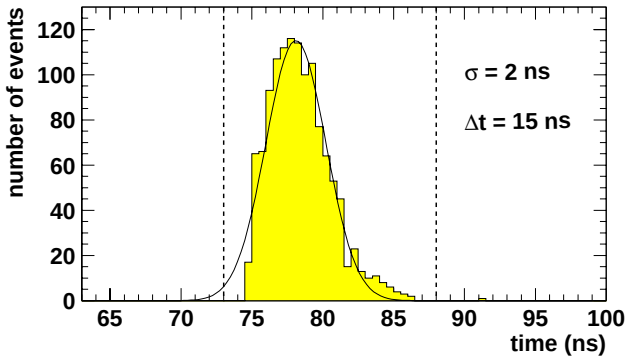

Figure 10: Typical distribution of the RPC response time t_{RPC}.

The third contribution is signal propagation along the strip t_{propag}. The signal induced on the strip at the particle impact point propagates towards the preamplifier with velocity of about 2/3 of c, i.e. ~0.2m/ns. The propagation time varies from 0 to *max* t_{propag}, which for the longest strips of 1.26m is ~6.3ns. One cannot correct for it on-line and from the trigger point of view it should be considered as having approximately flat random distribution. However, one can achieve partial compensation of Δt_{flight} and Δt_{propag} by a proper placing of the amplifier (see Fig. 11), such that

$$\Delta(t_{flight} + t_{propag}) = (min\ t_{flight} + t_{propag}) - max\ t_{flight} < \Delta t_{flight} + \Delta t_{propag}$$

In the worst case of MB/0/1 the combined variation $\Delta(t_{flight} + t_{propag})$ = 5.7ns.

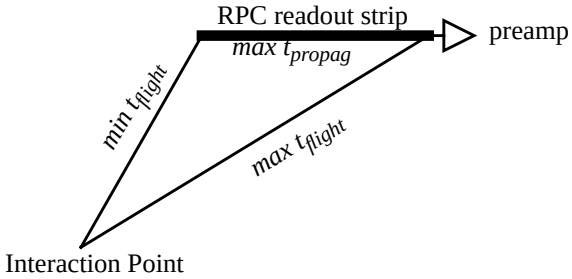

Figure 11: Partial compensation of time of flight Δt_{flight} and signal propagation along the strip Δt_{propag}.

The contribution from preamplifier and discriminator jitter Δt_{preamp} is usually much smaller than 1ns. Moreover, it is difficult to distinguish it experimentally from the intrinsic RPC jitter Δt_{RPC}. Therefore, the measured value of Δt_{RPC} often contains Δt_{preamp}, and we will follow this convention in this paper.

The total jitter of the upstream part Δt_{up} must be lower than 25ns in order to recognize the bunch crossing. We have seen that is has two major contributions: $\Delta(t_{flight} + t_{propag})$ and Δt_{RPC}. Assuming 1-3ns for the setup time of the synchronization electronics and taking the worst case of $\Delta(t_{flight} + t_{propag})$ = 5.7ns, one gets 15-18ns remaining for Δt_{RPC}. In the case of gaussian distribution this would correspond to σ_{RPC} < 3.0-3.5ns with 99% efficiency. This requirement is fulfilled by recently tested RPC prototypes [6].

In the downstream part all the signals are aligned with the clock and the only timing problem occurs when the data are transmitted form one board to another. At the destination they must be resynchronized to the local clock. The worst case is the transmission from the Link Board to the Control Room through 120m long optical fibers.

6.3. Synchronization Unit

The synchronization Unit (SU) is an integrated circuit which shapes the detector signals and aligns them with the LHC clock. It is done in the following way (see Fig. 12). Form the LHC clock (denoted as CLOCK) provided by the TTCrx, a WINDOW signal is derived. Its width and phase can be adjusted from 0 to 25ns with 1ns step. They should be adjusted in such a way, that the rising edge of INPUT from the detector is always within the high level of WINDOW. The WINDOW should be wide enough to contain the jitter Δt_{up}, discussed in the previous chapter. The coincidence of the WINDOW signal and the rising edge of the INPUT generates the OUTPUT signal which is 25ns wide and is in phase with the CLOCK. The OUTPUT might be delayed by 0-3 clocks using *synchronization Pipeline* of programmable length. This is needed for the absolute synchronization, i.e. for associating the data with the proper bunch crossing number.

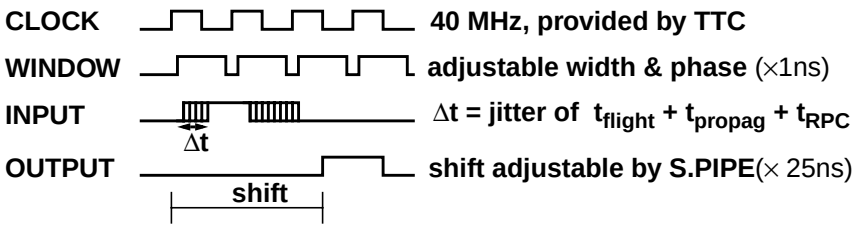

Figure 12: Timing in synchronization Unit.

6.4. Downstream Synchronization Pipelines

Once the signals are aligned with the clock by the synchronization Unit, one has to maintain this synchronization through the entire data processing chain. When the data are transmitted to another crate they need to be synchronized at the destination to the local clock. This is done by synchronization Pipelines of programmable length.

6.5. PACT synchronization procedures

6.5.1 Upstream synchronization

All the methods described in Sec. 3 will be used for setting and maintaining the synchronization in the upstream part of PACT. The full sequence of actions may look as follows.

Procedure without the beam (first iteration)

- Calculate the time of flight and measure the cables as precisely as possible — expected precision: < 5 ns
- Adjust the WINDOW phase and the synchronization Pipeline shift accordingly
- Set the WINDOW width close to 25 ns to maximize the efficiency

Procedure with the beam — special run (fine tuning)

- For each trigger collect data from several (e.g. ±2) consecutive b.x.'s
- Observe how the data are distributed among b.x.'s
- Correct the WINDOW position and the synchronization Pipeline shift accordingly
- Narrow the WINDOW width to the calculated jitter

Procedure with the beam — "physics" run (checking)

- Monitor efficiency map of the detector — inefficiency in certain regions may be caused by wrong timing

6.5.2 Downstream synchronization

Downstream synchronization procedures will follow the generic description given in Sec. 4.

6.5.3 DAQ bunch crossing synchronization

All three methods described in Sec. 3.5 can be used. Multi-crossing readout (Sec. 3.5.1 and Sec. 3.5.2) will be more effective than histogramming (Sec. 3.5.3), because of realtively low occupancy (see Sec. 5).

7 Synchronization of Cathode Strip Chambers

The timing structure of the CSC system has several components similar to those of RPC (Sec. 6.2). The difference is that the chamber response time t_{CSC} includes drift time, which makes the t_{CSC} distribution as wide as 50-70ns at the base (see Fig.4.4.13, page 183 of Muon TDR [8]). Because of that the bunch crossing identification is more difficult, but on the other hand, the synchronization requirement for the phase adjustment at the Front End can be slightly relaxed. Apart from that the synchronization procedures are similar to those of the RPC PACT.

The local trigger is based on a coincidence of at least 4 out of 6 layers within 75ns gate. The bunch crossing is identified by the second (in time) hit of those contributing to the coincidence. Prototype tests indicates that the distribution of the second hit arrival time is fully contained within 20ns (see Fig.4.8.20, p.228 of Muon TDR [8]). Assuming 1-3ns for the setup time of the electronics, about 2-4 ns remains for the phase adjustment precision.

In the DAQ path the anode (wire) signals are discriminated, whereas the cathode (strip) signals are sampled 8 times with 50ns step. Because the signal can arrive at any clock phase due to the long drift time, there is no requirement on the phase adjustment precision.

8 Synchronization of Drift Tubes

What was said for CSC is also true for Drift Tubes. Here the drift time is even longer — about 400ns. Bunch crossing recognition is performed by *Bunch and Track Identifier* (BTI) circuit, using generalized meantimer technique [9],[10]. This method relays on the clock phase adjustment relative to the incoming data. The required precision is about 5ns, as can be seen in Fig. 13. In order to determine the delay one has to find the maximum of the BTI efficiency for real muons.

There is no requirement on phase adjustment at the Front End in the DAQ path. The signals are digitized by TDC, so the exact time can be reconstructed off-line.

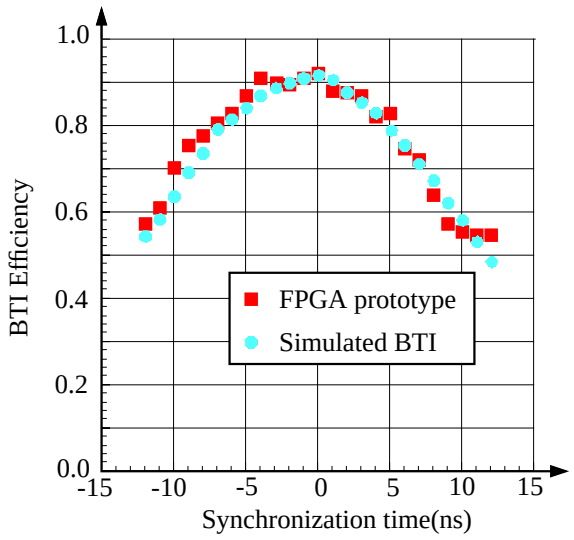

Figure 13: Drift Tube trigger efficiency vs synchronization time (i.e. clock phase shift).

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