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A. V. Kulikov, M. V. Zhabitsky

# DEAD TIME LOSSES AND THEIR MEASUREMENT IN **DIRAC**

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# 1 Introduction

Losses of experimental data due to the dead time take place, to a certain extent, in any experiment. The size of losses depends on many factors, such as the counting rate of the detectors, performance of the electronics used, trigger selectivity, readout logic, data acquisition (DAQ) rate capability, time structure of the beam etc. Apart from reduction of the accepted event flux, which is directly observed during data taking, the dead time may also take effect at the off-line analysis stage, leading to rejection of potentially good events.

It is obvious that account of these losses is obligatory in experiments dealing with absolute cross section measurements. But even when the yield of some physical process is not planned to measure in absolute units, dead time losses may result in increase of systematical errors, because some essential distributions, for example, momentum or angular dependences, may be distorted due to variation of counting rates and hence varying dead time losses in different kinematical regions within the experimental setup acceptance.

In many cases dead time losses can be estimated by calculations if counting rates of the detectors and parameters of the trigger and data acquisition systems are known. Nevertheless, it is more reliable to measure these losses directly, as it might be difficult to take into account all the relevant sources, which, in addition, are sometimes correlated.

Below we discuss different sources of dead time and describe the measurements of dead time losses in the experiment DIRAC [1] at CERN. Though the consideration is based on the features of the DIRAC setup [2] and the running conditions of this experiment, many statements have general character and are valid for other experiments as well.

# 2 Dead time of front-end electronics

Front-end electronics is the first dead-time-generating stage of the electronic apparatus. The dead time of the leading edge discriminator depends on the enabled mode of its operation. In the non-updated mode the dead time is slightly larger than the width of the output signal, from 20 to 60 ns for the DIRAC electronics.

In the updated leading edge discriminator mode the dead time, in its original meaning, is very small as, in the case of overlapping signals, the second pulse prolongs the output signal started by the first one. However, with such a two-signal overlap, the leading edge of the second pulse is not detected. This may (or may not) result in a loss of the trigger signal, depending on a particular trigger scheme. Moreover, even with the trigger not lost, such an event may be rejected in the further off-line data analysis (see Sec.4).

In a constant fraction discriminator (CFD) the dead time value usually is programmable within the limits defined by the module specifications. In CFDs of DIRAC it is set at the lowest possible value of 20 ns.

In a meantimer the dead time can be essentially larger than its output pulse width. The meantimer generates the signal when two pulses at its two inputs are received within a limited time interval $t_{max}$. This interval can be as long as several tens of nanoseconds and thus can dominate in the meantimer dead time if the output pulse width is short. In DIRAC the dead time of meantimers is $\sim$70 ns.

The dead time fraction $F$ in the overall measurement time can be calculated for any front-end electronic unit. In the case of a uniform statistical distribution of the particle flux and low losses ($F \ll 1$) it is about $F = N \cdot \tau$, where $N$ is the counting rate at the input, $\tau$ is the module dead time. However, the beam intensity (and hence the counting rate) happens to be not constant but varying within the accelerator cycle or even to have a microstructure. It is not always easy to monitor these factors, so the precision of calculations is rather limited.

# 3 Dead time due to trigger processors and DAQ

Data from any accepted event have to be digitized and transferred to the computer. These operations consume essential time. The DAQ rate capability is defined by readout logic, hardware used and software DAQ solutions as well. At some level the deadtime losses due to DAQ processes are inavoidable in principle, but one has to take measures to minimize them.

To cope with a high event rate a multilevel trigger is often used in the experiments, in particular, in DIRAC [3]. With the multilevel trigger configuration, a fast first level trigger starts acquisition of an event and simultaneously enables the higher level trigger processor(s). The event selection algorithm implemented in the processor can be rather complicated and event evaluation may take rather long time. For example, in DIRAC there are two trigger processors used. One [4], based on a neural network algorithm, is rather fast, it takes a decision in about 250 ns and decreases the trigger rate by a factor of 2. The other processor, reconstructing tracks in the drift chambers, is more powerful, it provides a more than five-fold rate reduction, but the time to take the decision about an event may be as long as 10 $\mu$s (decision time here depends on the complexity of the event and is equal to 3.5 $\mu$s on average).

The issued first level trigger signal (T1) sets the Inhibit status to prevent the DAQ from retriggering till the end of the event processing, i.e. until the end of the data transfer of the accepted event to the collection memory, or until the end of Clear processes if the event is rejected by higher level trigger processors. The deadtime concerned is different in these cases as illustrated in Fig.1. For accepted events the dead time,

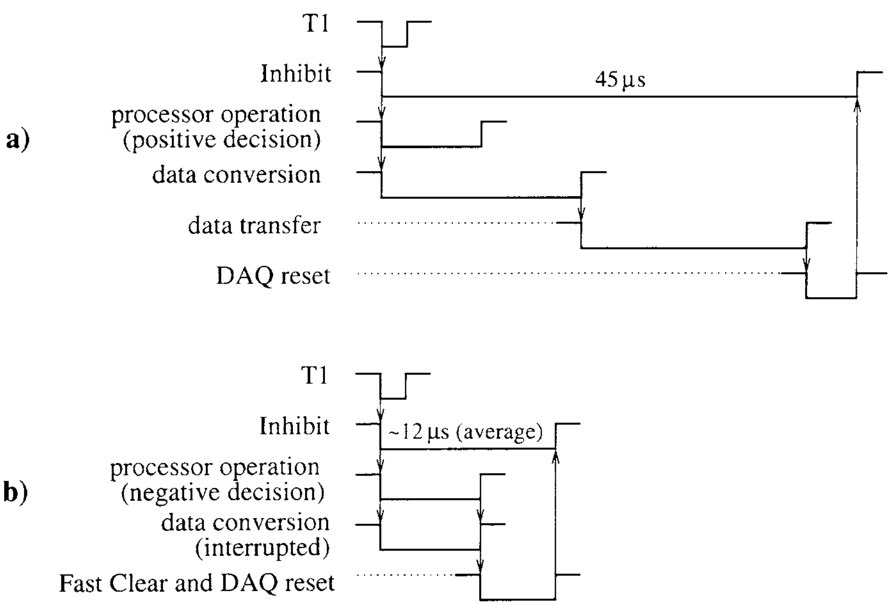


Fig.1. Simplified scheme showing the dead-time-generating stages in event acquisition for events accepted (a) and rejected (b) by the trigger processor. The dead time is equal to the Inhibit signal duration.

equal in DIRAC to $\sim 45\,\mu$s, is a sum of the time intervals, needed for conversion, data transfer and DAQ reset processes. For rejected events the dead time is essentially smaller and is equal to the sum of the trigger processor decision time and the DAQ reset time. For accepted events the trigger processors do not add any dead time as they operate in parallel with the data conversion, the latter being longer.

The total acquisition time of an accepted event ($45\,\mu$s), including its transfer to the collection memories, essentially exceeds (in our case) the time needed for the trigger processors to evaluate an event. The total acquisition time of a rejected event is about $12\,\mu$s on average. Hence, the more the rate is reduced by the trigger processors, the smaller the dead time involved.

Readout architecture is also a factor essentially defining the dead time. In DIRAC a beam is delivered to the setup in spills of 400-450 ms duration. The spills (up to 5 spills within a 15–20 s accelerator supercycle) are separated by intervals which can be as short as 1 s. Events accepted in one spill are accumulated in buffer memories. The event data from all the detectors are transferred to 12 buffer memories in parallel via separate readout branches [5]. During a spill only readout to the buffer memories is allowed, whereas the data transfer from the memories to the VME processor board, event building and other relatively slow processes are fulfilled in the intervals between the spills and between the supercycles [6]. This approach excludes any dead time from the computer operations. The use of 12 parallel readout branches decreases the data transfer duration and hence the dead time (the requirement to the memory capacity per unit is not so strict as well).

The Inhibit status, set by the first level trigger, is released when the event processing is finished. For accepted events this instant is defined by the longest data transfer among all 12 branches. If an event is rejected by one of the trigger processors, then a Fast Clear signal is applied to all the modules which have already started event acquisition. Different subsystems have different latency with respect to Fast Clear, so the delay of the Inhibit release is made selectively [5] (either $8\,\mu$s or $13\,\mu$s) depending of the source of Clear thus minimizing the dead time.

# 4 Losses during data analysis

The loss of signals in the front-end electronics due to a dead time not always leads to missing trigger. This depends on a particular trigger scheme. If, for example, the signals of a hodoscope-like detector enter the trigger logic not individually but after their logical summing and if the hit mulitiplicity in the detector is more than 1, then, inspite of probable loss of the "useful" signal from one of the detector elements, the signal from another element (correlated or accidental) may force the first level trigger. Some fraction of such events can pass the next, higher level trigger selection. In this case the event is accepted and recorded, but at the off-line analysis stage the requested response from the needed element will not be found thus leading to rejection of the event.

This is what occurs in DIRAC. The first level trigger [7] is produced by coincidences of $\pi^+$ and $\pi^-$ mesons in two magnetic spectrometer arms, each arm containing detectors consisting of 18, 16 and 8 elements. Signals of the elements are combined with an OR function before the coincidence scheme. An average hit multiplicity in these detectors is between 1.2 and 1.5. Hence, when a pion pair is accompanied by a third particle, then, even with one of the pions from this pair not detected due to a front-end electronic dead time, the first level trigger signal in a large fraction of events can be generated. In such cases the dead time does not result in losses of triggers.

Another kind of losses may take place if the detector is not included in the trigger but its information is analyzed off-line. To identify the process of interest, the signals of such a detector may be mandatory, but there is a chance that they are absent in the recorded data due to its front-end electronics dead time.

Finally, the event can be rejected at the analysis if it does not satisfy some selection criteria, in particular, on timing. This can be the consequence of the electronic circuitry. Such losses, though not directly related to dead time, are discussed in Sec.5, too.

# 5 Dead time measurements in DIRAC

The procedure to measure different sources of losses has been developed. It includes a permanent monitoring of the dead time losses due to the DAQ system and the trigger processors and dedicated measurements to estimate the event losses caused by the front-end electronics during the data taking and the off-line analysis.

As mentioned above, on receiving the first level trigger signal the next triggers are inhibited until the end of the event processing when the applied Inhibit level is released. During a beam spill, a multichannel CAMAC scaler counts the numbers of the issued first level triggers (T1) and those of them which are accepted by the DAQ ($T1_{acc}$), i.e. when no Inhibit signal is applied. In other two channels the signals of a 1 MHz generator are counted within the total spill width ($N_{gen}$) and in the dead time intervals ($N^{d.t.}_{gen}$) defined by the presence of Inhibit, Fig.2.

Dead time losses due to the trigger processors and DAQ are equal to ($T1-T_{acc}$)/T1. The ratio ($N^{d.t.}_{gen}/N_{gen}$) which, in principle, should give the same number for the losses at the condition of a flat intensity, in fact is smaller because it does not take into account the variations of the intensity within a spill. Information from the scalers is read out at the end of every spill and is recorded. It is also available in the on-line monitoring program.

At typical conditions of the data taking in DIRAC the T1 rate is about 5000 and the rate of recorded events is about 800 per 450 ms spill. At such conditions the dead time losses obtained from counting of the initial and accepted T1 triggers vary depending on the beam time structure in the range of 20–30%.

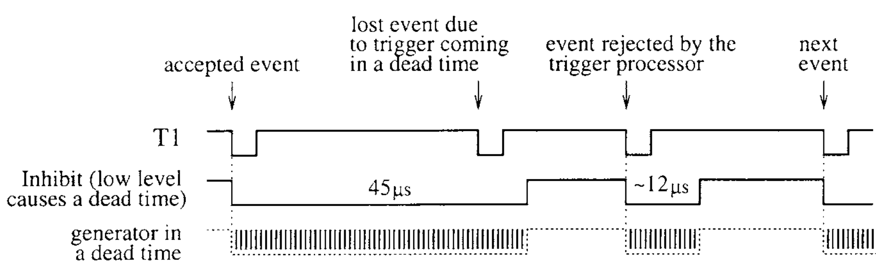


Fig.2. Measurement of the dead time from the DAQ processes and trigger processors using 1 MHz generator.

The obtained number, however, does not take into account the dead time of the front-end electronics, because due to this dead time the T1 signal may be not produced (and Inhibit is not set as well).

To estimate the total losses, dedicated measurements have been carried out. The idea is to admix test signals to real signals at the front-end electronics inputs and then to check in the recorded data, which fraction of such "test events" is accepted and how they pass the selection criteria in the off-line analysis. This method is close to used in [8–10].

As a source of the test signals a prescaled single rate of one of the DIRAC detectors is used. This rate is proportional to the beam intensity, therefore the variations of the test signal rate within a spill reflect variations of the intensity. The use of a constant frequency generator as a source of the test signals would result in underestimation of the losses.

Test signals with the rate of about 250 pulses per spill[1] are fed to selected channels of the hodoscopes participating in the trigger logic and/or used in the off-line data analysis, to one channel in each detector (the Vertical and Horizontal Hodoscopes VH and HH, the Preshower detector PSH and the Ionization Hodoscope IH) as shown in Fig.3. All the detector channels are then OR'ed before the trigger coincidences. Test signals are admixed at the inputs of the constant fraction (CFD) or leading edge (D) discriminators using linear fan-in/fan-out circuits (FI/FO) which also receive the photomultiplier (PM) signals. If the scintillators are viewed by PMs from both ends and the meantimers (MT) are used, then the test signals are fed to both channels. Relative delays between the test signals in different detectors are adjusted to be similar to those for real events, hence the test signal results in development of the first level trigger signal T1. The only reason for probable absence of T1 is the front-end electronics dead time.

The trigger processors do not suppress trigger T1 from the test signal as the latter switches the processors to the mode in which they are transparent for such triggers but fulfill standard selection for real events. Hence, all T1 triggers from the test signals, coming within the live time, bypass the processor selection and are accepted. The specific mark of this "test event" is recorded in one of the channels of the LeCroy TDC 3377 module ("trigger mark register"). This TDC is used in DIRAC for tagging of events accepted with different trigger types running in parallel [3].

[1]This rate is negligible compared with the single rates of the detectors and hence does not increase the front-end electronics dead time. On the other hand, the test events constitute up to ~20% of all accepted events and so increase the DAQ dead time. This is taken into account in the final result.

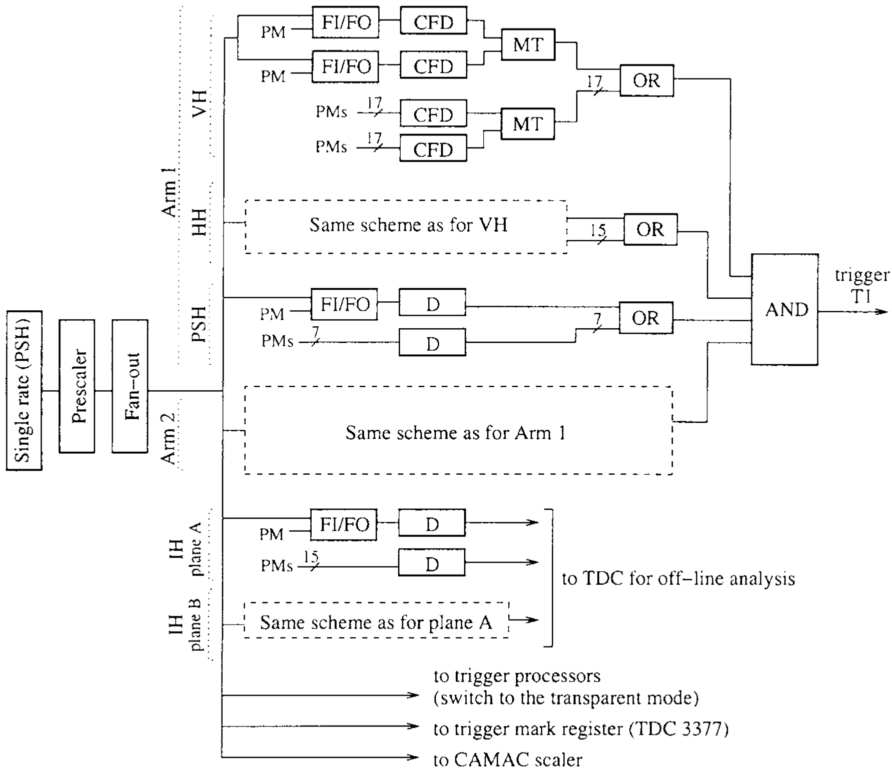


Fig.3. Scheme of the dead time measurements with test signals. The test signals are admixed to one element of each detector included in the scheme of the first level trigger (T1) and to one element of the detectors analyzed off-line. The outputs to TDC from VH, HH and PSH are not shown.

The test events are detected within the beam spills together with a flow of real physical events. All issued test signals are counted in a CAMAC scaler during the total spill width. The number of the accepted test events is smaller than the total number of the issued test signals due to all sources of dead time: arising in the DAQ processes and the trigger processor operations (what, as mentioned above, can be measured in normal data taking using the ratio (T1–$T_{acc}$)/T1) and also due to the front-end electronics dead time.

Since test signals are admixed to PM signals at the very beginning of the whole electronic channel, they are distributed over all the circuits in a standard way and are detected in TDCs of the corresponding detectors together with real PM signals.

For illustration, Fig.4 shows the time spectrum of the Vertical Hodoscope VH2 for all accepted events. A narrow peak from the test signals is clearly seen above a wide distribution of signals from particles detected in real (near channel 600) and accidental coincidences. In Fig.5 it is seen, how the spectrum changes when only events with a test signal mark are selected from the same event sample. Similar spectra are available for other detectors, too.

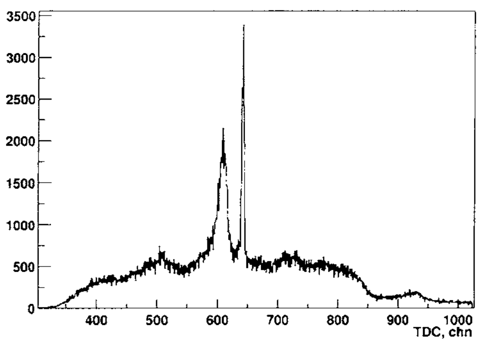


Fig.4. Time spectrum of the Vertical Hodoscope VH2 for all accepted events (coming from particles and the test signals).

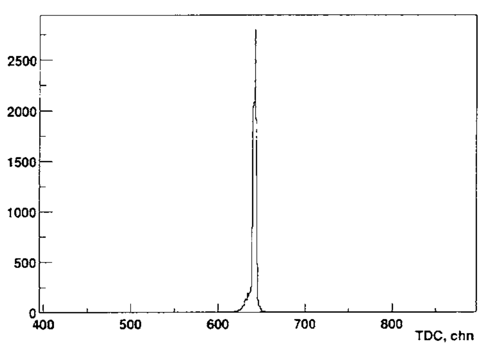


Fig.5. Same as in Fig.4, but only for events tagged with a test signal mark.

The analysis of thus collected data with respect to the dead time includes the following steps:
1. Comparison of the total number ($N_0$) of the issued test signals with the number ($n_m$) of the test signal marks found in the trigger mark register. A deficit of the test signal marks is explained by the trigger and DAQ dead time and by that fraction of the front-end electronics dead time which has led to a loss of trigger.
2. The events having the test signal marks are selected for further analysis.
3. Selection of events with correct test signal timing in all detector elements receiving the test signals. After step 2, in the majority of events the test signals form narrow peaks in TDCs of the corresponding detector channels (like in Fig.5). But sometimes a signal in TDC either is not found at all or (more often) has wrong timing. Probable absence of a signal is explained by the front-electronics dead time, which in this case has not led to a loss of trigger (this was considered in Sec.4). Wrong timing happens if in a given detector element a test signal overlaps a preceeding pulse from a particle, and the timing is then defined by this particle. The same takes place in normal data taking when signals of two particles overlap. This phenomenon does not result in additional dead time but deteriorates the time correlations between the signals of different detectors and so provokes rejection of events during the data analysis. For the present analysis of measurements with the test signals the same selection criteria for timing were used as in handling of real physical data.

In Table 1 the results obtained from the analysis of the data with test signals are presented.

| 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|
| Total number of test signals, $N_0$ | Test signal marks found, $n_m$ | Correct timing in all detectors | Losses of marks (=missing triggers) | Total event losses | Corrected total event losses |
| 49716 | 28471 | 23810 | 43% | 52% | 50% |

Table 1. Event losses as obtained from the analysis of the measurements with test signals.

As seen from Table 1, the losses at the trigger level (column 4) are 43% (this value is calculated as $1-n_m/N_0$). The simulaneously measured dead time losses in the DAQ system and the trigger processors, (T1–$T_{acc}$)/T1, are equal to 33%. Hence, the front-electronics dead time adds 10% to the trigger losses. Imposing of selection criteria on timing in TDC spectra increases the event losses[2] to 52% (column 5).

Without test signals the losses of triggers and the total event losses corresponding to columns 4 and 5 would be slightly less. As mentioned above in the footnote, the transfer of the test events to the collection memories adds an extra dead time, so in normal data taking the losses are smaller by ~2% (column 6).

Counting rates per element (and hence the front-electronics dead time) in some of the DIRAC detectors depend on the covered momentum gap and are essentially different. For this reason the dead time measurements have been done in three configurations: with test signals sent to the elements of high, medium and low occupancy in these detectors (high and low occupancies differ by a factor of 2.0–2.2). Data analysis has shown that within the 1% accuracy no difference in losses is observed. This unexpected, at first glance, result is nevertheless well understood in view of high counting rates in other DIRAC detectors which have a homogenious occupancy and are responsible for the main part of losses. So, within this accuracy no correction is needed in our case for the detector regions with a different dead time.

Note that the present measurements were done at the beam intensity and the accepted event rate higher than typically in DIRAC by 20% and 30%, respectively. The major part of statistics in the experiment has been obtained at ~25% losses due to the DAQ and trigger systems and the total losses of 35–40%.

# 6 Conclusions

Different sources of dead time in electronics of DIRAC have been analyzed with a view to minimize it. The procedure to measure the elec-

[2]In Table 1 and further the "total losses" include those due to dead time and to wrong timing only. Of course, the actual losses in the off-line analysis are higher when many other selection criteria are applied.

tronics dead time has been developed and implemented, providing the information to be used in physical analysis of data.

# References


[1] B.Adeva et al. Lifetime measurement of $\pi^+\pi^-$ atoms to test low energy QCD predictions. Proposal to the SPSLC, CERN/SPSLC 95-1, SPSLC/P 284, Geneva 1995.

[2] B.Adeva et al. NIM A515 (2003) 467.

[3] L.Afanasyev et al. NIM A491 (2002) 376.

[4] P.Kokkas, M.Steinacher, L.Tauscher, S.Vlachos. NIM A471 (2001) 358.

[5] V.Karpukhin, A.Kulikov, V.Olshevsky, S.Trusov. NIM A512 (2003) 578.

[6] V.G.Olshevsky, S.V.Trusov. NIM A469 (2001) 216.

[7] L.Afanasyev, M.Gallas, V.Karpukhin, A.Kulikov. NIM A479 (2002) 407.

[8] O.U.Anders. NIM 68 (1969) 205.

[9] H.H.Bolotin, M.G.Strauss, D.A.McClure. NIM 83 (1970) 1.

[10] A.V.Kuptsov, D.M.Khazins. Pribory i Tehnika Eksperimenta v.3 (1972) 82 (in Russian).



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Потери из-за мертвого времени и их измерение
в эксперименте ДИРАК

Рассматриваются различные источники мертвого времени на установке ДИРАК, включая front-end электронику, систему выработки триггера и систему считывания. Описана процедура измерения мертвого времени и представлены полученные результаты.

Работа выполнена в Лаборатории ядерных проблем им. В. П. Джелепова ОИЯИ.

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Dead Time Losses and Their Measurement in DIRAC

Different sources of dead time in the DIRAC setup are considered, including front-end electronics, trigger and data acquisition systems. A procedure of measuring the dead time is described and the results are presented.

The investigation has been performed at the Dzhelepov Laboratory of Nuclear Problems, JINR.

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141980, г. Дубна, Московская обл., ул. Жолио-Кюри, 6.
E-mail: publish@pds.jinr.ru
www.jinr.ru/publish/