The Drift Distance Trigger

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Abstract

A simple real time event selection method is proposed for the DIRAC experiment that is based on the new Micro Drift Chambers (MDC) placed upstream the experiment's dipole magnet. The method is using the wire hit maps of all the MDC planes to choose events with two close-by tracks, without any reference to other DIRAC detectors. Pion pairs form pionium breakup are selected with an efficiency higher than 95%. Coulomb pion pairs are also accepted by the system with 90% efficiency whereas background two particle events is reduced by a factor of 3. An appropriate hardware implementation of the proposed algorithm would evaluate an event in about 100 ns. An additional slower step is also proposed which is based on the time measurement in each MDC sector. The corresponding better two track resolution allows a selection of 97% of atomic pairs while reducing the data rate by a factor of more than 8.

1 Introduction

In the near future a new drift chamber will be installed in the DIRAC experiment upstream the dipole magnet of the spectrometer. This Micro Drift Chamber (MDC)[1] consists of 9 double planes, three along the x direction, three along y and 3 along w (a plane inclined by 5 degrees with respect to the x plane). Each double plane is made of two superimposed drift chamber planes of 32 cells. The second plane is displaced with respect to the first one by half a cell width to allow a fine double track resolution. Given the small size of each cell (2.54 mm wide and 2 mm deep) and the operating conditions (gas and high voltage applied), the maximum drift time expected is less than 25 ns. One can therefore use this chamber for online purposed considering each cell as a detector giving a signal in a 25 ns window whenever a particle crosses it. Figure 1 shows an overview of the MDC chambers with respect to the incoming beam. Figure 2 zooms in two superimposed sectors of a super-plane for a detailed view of the signals induced by a single particle passing through them.

A new trigger scheme is proposed (Drift Distance Trigger, DDT) that uses these signals to discriminate close lying particles from background.

Furthermore the fine two track resolution of the chamber can be exploited fully by a more precise (and hence slower) trigger level (DDT-2). It uses the timing information from each hit in the chamber to detect events with very close-by tracks (a signature typical of atomic pion pairs).

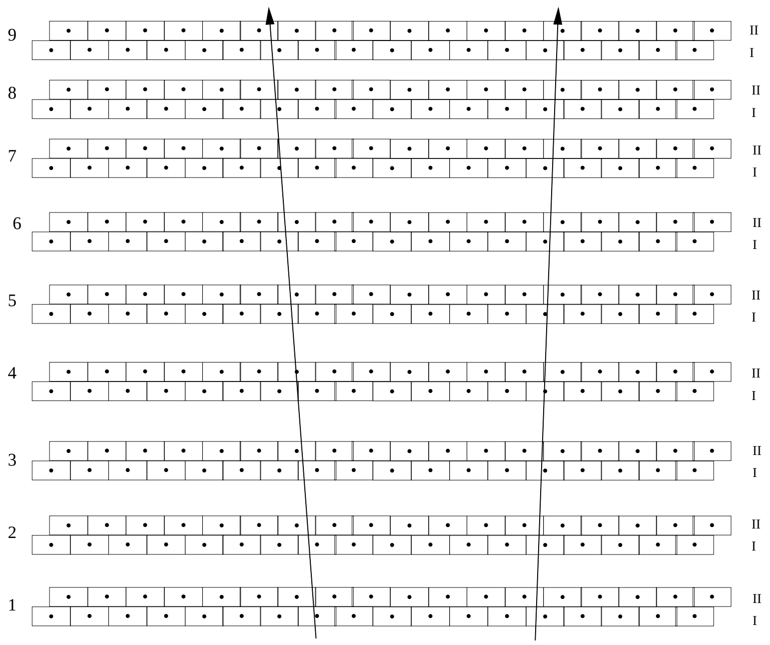

Figure 1: An overview of the 9 MDC super-planes. For convenience all planes are drawn with their sense wires in the same direction. In reality three different directions are used: x, y and w (a planes rotated with respect to x by 5 degrees). For the present trigger study the relative orientation of MDC super-planes is of no importance. On the same figure two particles coming from the interaction region are drawn. Also for clarity not all 32 sectors per plane are drawn.

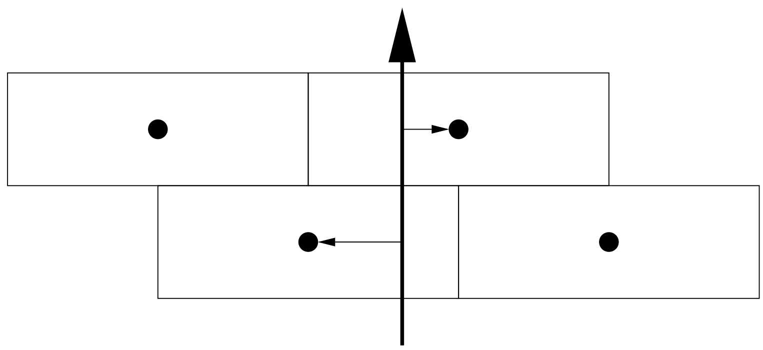

Figure 2: A zoom in two superimposed sectors of an MDC super-plane, with a single particle transversing it. In such a case the sum of the distances between the particle and the sense wires is constant independent of the particle's entry point in the chamber (assuming it crosses the chamber perpendicularly). Given the thickness of the chamber (2mm per plane) this assumption is quite reasonable.

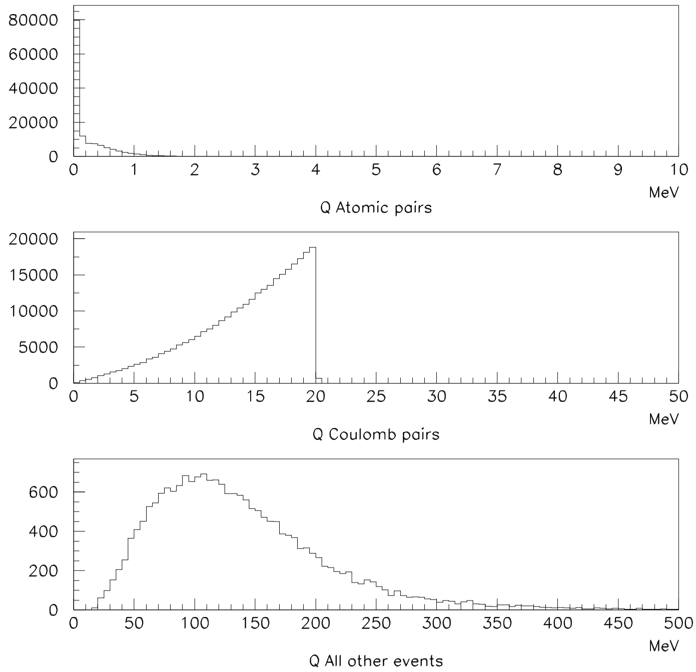

Figure 3: The Q_{tot} distribution for atomic and coulomb pairs (events to be selected) and other two track events (to be rejected). For clarity the scale of each plot is different.

2 Event Classes

For a proper study of an event selection algorithm the events that have to be selected as well as the one to be rejected have to be properly defined in advance. For the present study three kinds of events were evaluated:

1. Atomic pions: Pions pairs originating from a pionium breakup.
2. Coulomb pairs: Pion pairs with coulomb interaction at the target, and $Q_{tot} < 20$ MeV/c.
3. Accidentals: Two track events with Q_x and Q_y more than 10 MeV/c

All events evaluated had at least one hit in each Vertical Hodoscope (downstream the DIRAC magnet). This restriction allowed an evaluation of the selection algorithm for events with 2 tracks in the detector, and a realistic estimation of the rate reduction. It is however not obligatory to implement it together with the selection algorithm based on the MDCs. In addition it was also required that all 18 MDC planes had at least one hit. This restriction can also be relaxed without altering any performance conclusions (as it was implemented for internal consistency reasons). After these preliminary cuts, the event sample contained approximately 70000 events of class 1, 70000 of class 2 and 4000 of class 3. Clearly an event selection method should distinguish classes 1 and 2 as GOOD, and class 3 as BAD. Figures 3 and 4 show the Q_{tot} and Q_x distributions of the three event classes used for this study. The Q_y distributions are almost identical for each event class and hence are not presented.

The mean multiplicity in the MDC for the three kinds of events is shown in figures 5, 6 and 7 for the atomic pairs, coulomb pairs and accidentals correspondingly. The

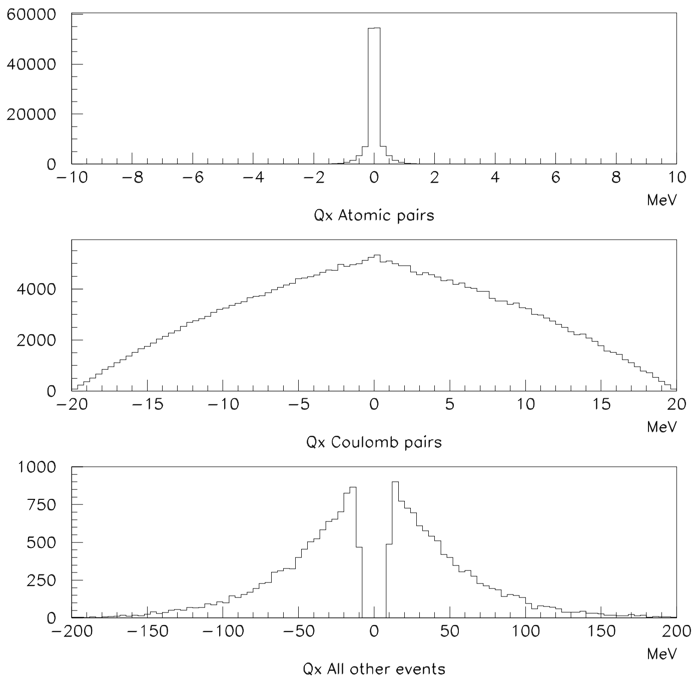

Figure 4: The Q_x distribution for atomic and coulomb pairs (events to be selected) and other two track events (to be rejected). For clarity the scale of each plot is different.

figures show the mean number of particles through an MDC plane, not to be confused with the number of sectors hit, as for example in the case of atomic pairs most probably both particles will cross the same MDC sector in a given plane. Each figure contains 4 distributions obtained with different event requirements. The first shows the distribution of all the events analyzed. The second the one of the events that have at least one hit in each VH arm downstream the dipole magnet. In addition if the events have one hit in each x-plane of the IH detector upstream the magnet the corresponding distribution is shown in the third plot. The last one concerns only those events that have at 17 or 18 MDC planes with at least one hit. These different conditions may well correspond to different 'pretrigger' requirements for events to be analyzed by DDT. In any case the results shown in what follows remain valid. In addition the multiplicity obtained for accidental pairs compares well with measurements performed lately with an MDC prototype chamber in the DIRAC setup. The mean hit multiplicity was measured to be around 1.3 to 1.4, a value that is close to the one in plot (a) of fig7 (1.11) if one takes into account that for the present study only two track events were evaluated, and no effort has been made to simulate realistic multiparticle background.

In all what follows, only events with at least one hit in each VH downstream and at least one hit in each IH x-plane upstream are used. Results for other kinds of preselected events are however similar.

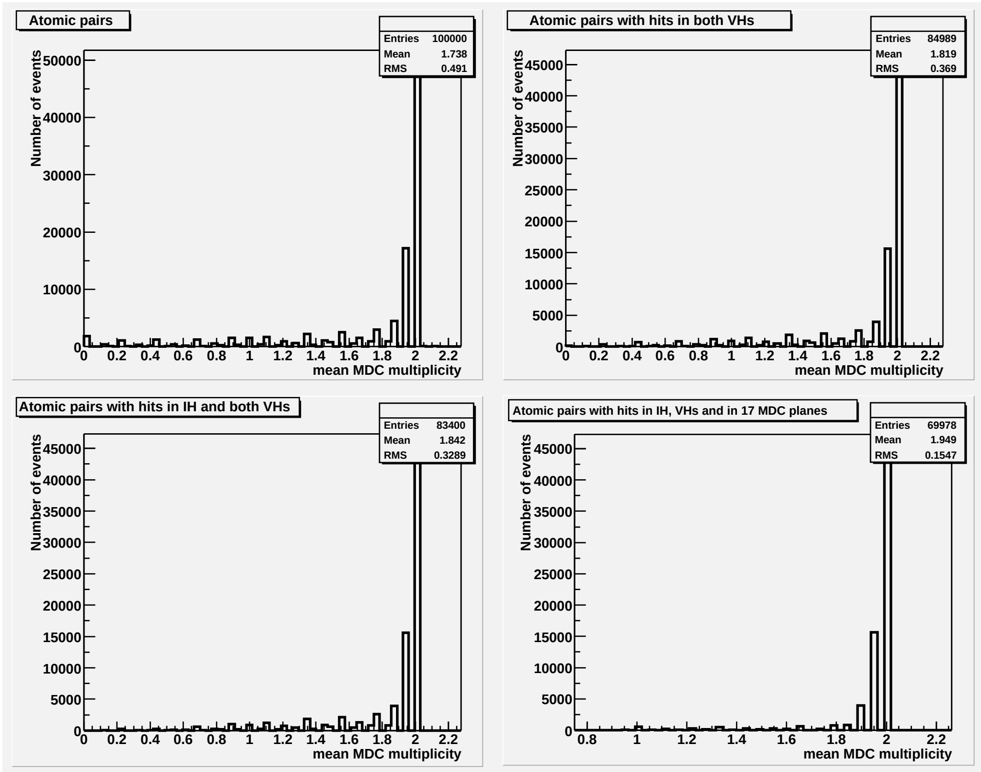

Figure 5: The mean MDC multiplicity (for all the 18 planes) for atomic pair events under various selection criteria.

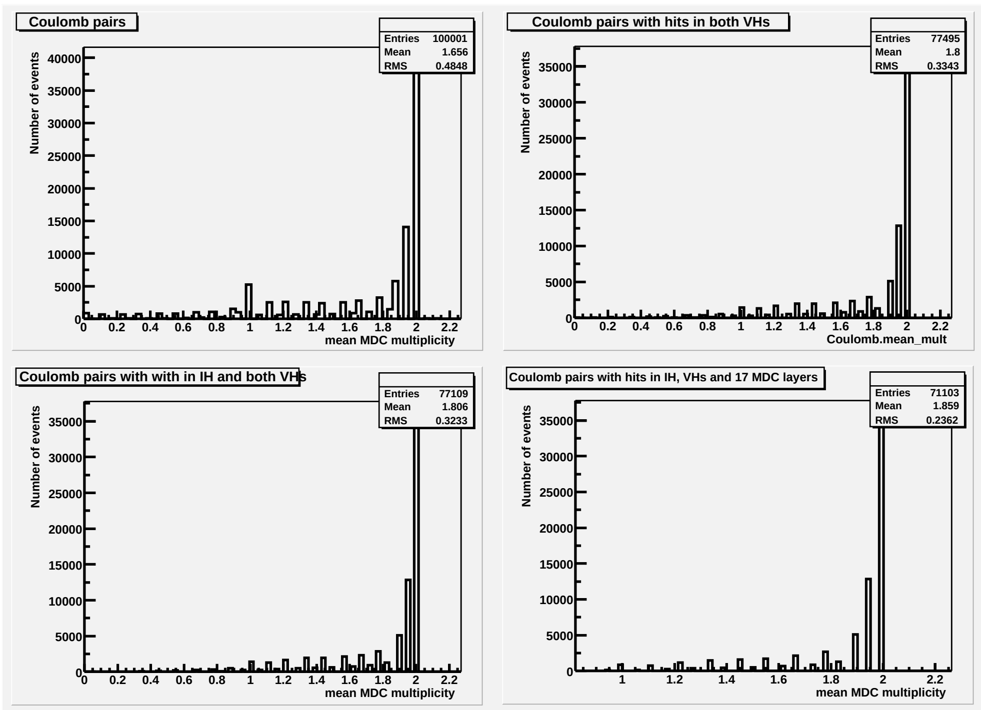

Figure 6: The mean MDC multiplicity (for all the 18 planes) for coulomb pair events under various selection criteria.

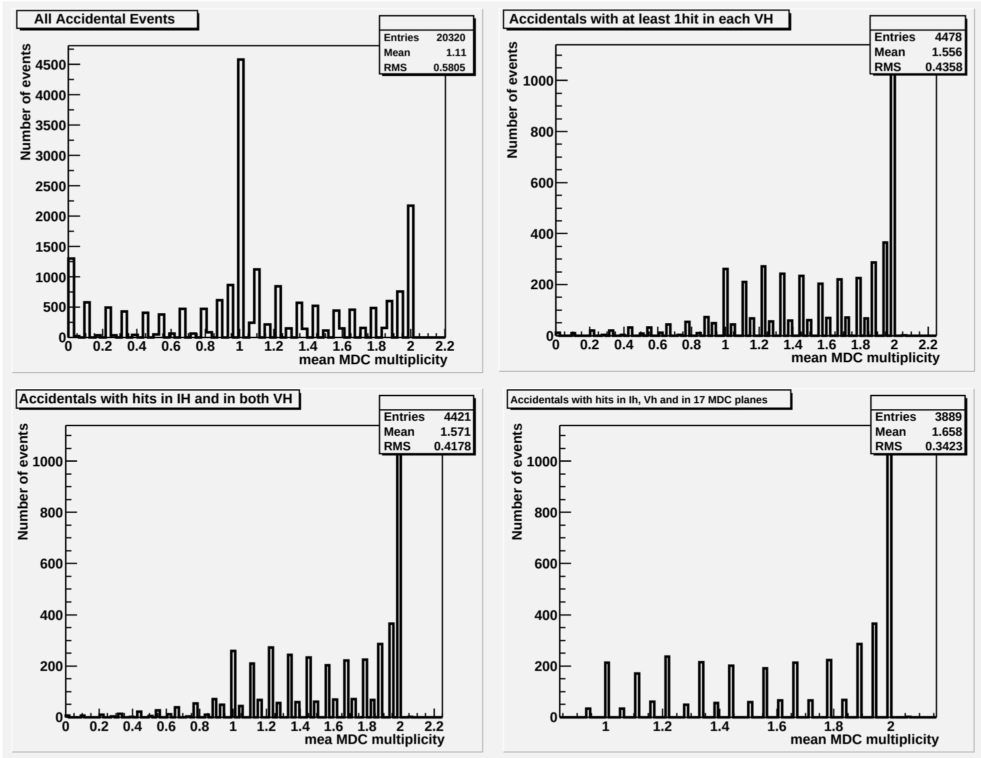

Figure 7: The mean MDC multiplicity (for all the 18 planes) for accidental events under various selection criteria.

3 DDT Selection Algorithm

The MDC signals arriving at the DDT are formated in 18 hit-maps, each one corresponding to an MDC plane. Furthermore a single hit-map is made out of the two for each double plane. This 'super-plane' has accordingly twice as much sectors, or in other words in this super-plane the double track resolution is half a MDC sector width. In what follows all distances between tracks are measured in these semi-sector units (s-sectors). In each super-plane the two closest hits are found and their distance is used to calculate the mean distance between closest by hits in all the 9 super-planes. This mean distance is the discriminant variable which allows an identification of GOOD events. It should be noted here that no particular search is performed for pairs of tracks with small or large opening angle (which would give a decreasing or increasing distance as the MDC super-planes are crossed).

4 DDT Selection Performance

Figure 8 shows the mean distance between the closest hits for the three classes of events under study. The power of this simple variable is evident. Quantitatively if event with mean distance less than 10 s-sectors are selected to be read-out, the following performance is expected (based on the event sample described earlier):

- Acceptance for atomic pairs: 99.2%,
- Acceptance for coulomb pairs: 87%,

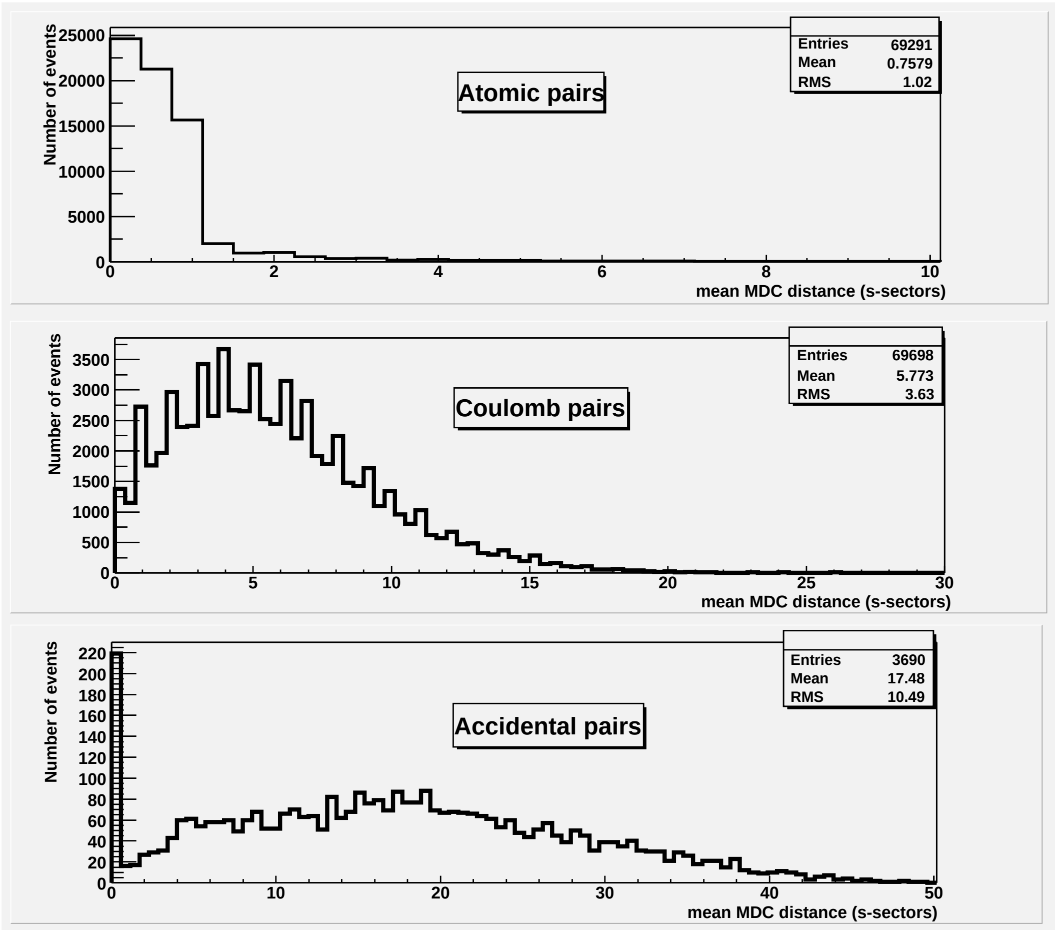

Figure 8: The mean distance between the two closest hits in the MDC for the three classes of events under study. The units are in semi sectors (s-sectors). Again for clarity the scale of each plot is different.

- Acceptance for accidental pairs: 25% (i.e a rate reduction of a factor of 4).

In case the acceptance for coulomb pairs is not considered high enough, one can easily change the selection threshold to 15 and obtain the following:

- Acceptance for atomic pairs: 99.7%,
- Acceptance for coulomb pairs: 98%,
- Acceptance for accidental pairs: 40% (i.e a rate reduction of a factor of 2.5).

For implementation reasons one can also use directly the available spare signal outputs from the MDC front end electronics without any hardware modification. These outputs provide the OR of four consecutive wires and hence each single MDC plane has only eight input signals. The same analysis an above can be performed with these signals without deterioration of the selection performance since the difference between GOOD and BAD events is considerable. Figure 9 shows the hit multiplicity expected in these ORed chamber signals, for various conditions as in figure 7. As expected the distributions do not change at all and the mean values are all the same. Figure 10 is the equivalent of figure 8 where once more s-sectors of a double plane are formed from the ORed signals. Again as expected the distances are divided by a factor of 4 without any other modification

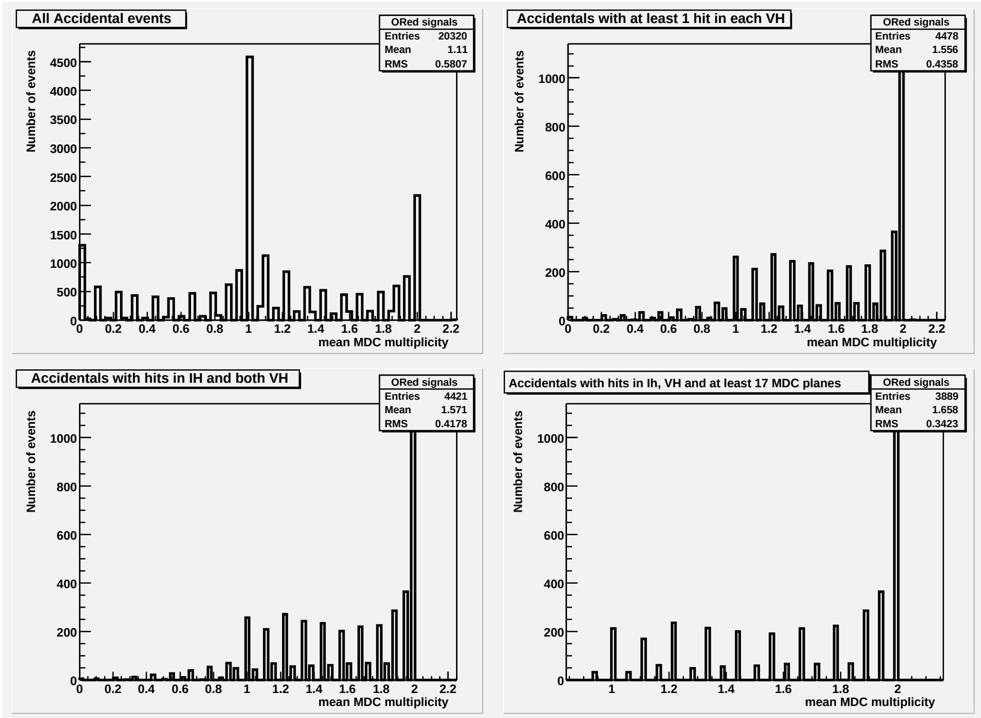

Figure 9: The mean MDC multiplicity (over the 18 planes) for accidental events under various selection criteria using the ORed signals (i.e. 8 signals for each MDC plane).

in the distributions. The selection performance using these ORed signals and selecting events with mean distance less than 2 such s-sectors, is expected to be the following:

- Acceptance for atomic pairs: 99.1%,
- Acceptance for coulomb pairs: 85%,
- Acceptance for accidental pairs: 24% (i.e a rate reduction of a factor of 4).

Again in order to increase the acceptance for coulomb pairs, one can easily change the selection threshold to 3,5 and obtain the following:

- Acceptance for atomic pairs: 99.8%,
- Acceptance for coulomb pairs: 975%,
- Acceptance for accidental pairs: 40% (i.e a rate reduction of a factor of 2.5).

5 Hardware Implementation

The DDT implementation in hardware should not pose any particular problem as the number of input signals is manageable ($18 \cdot 32$), the MDC drift time is short enough for on-line purposes without being to fast for standard electronics (25 ns). A decision for the quality of an event should in principle be provided in about 100 to 150 ns form the time MDC triggers. Figure 11 shows a simple DDT implementation based on Look Up Tables for the various data processing steps. For clarity the initial step of a register to store the input data is skipped. This register would make out of 10 ns pulses ones with 30-40 ns width so that at a given moment signals from all wires can be evaluated together.

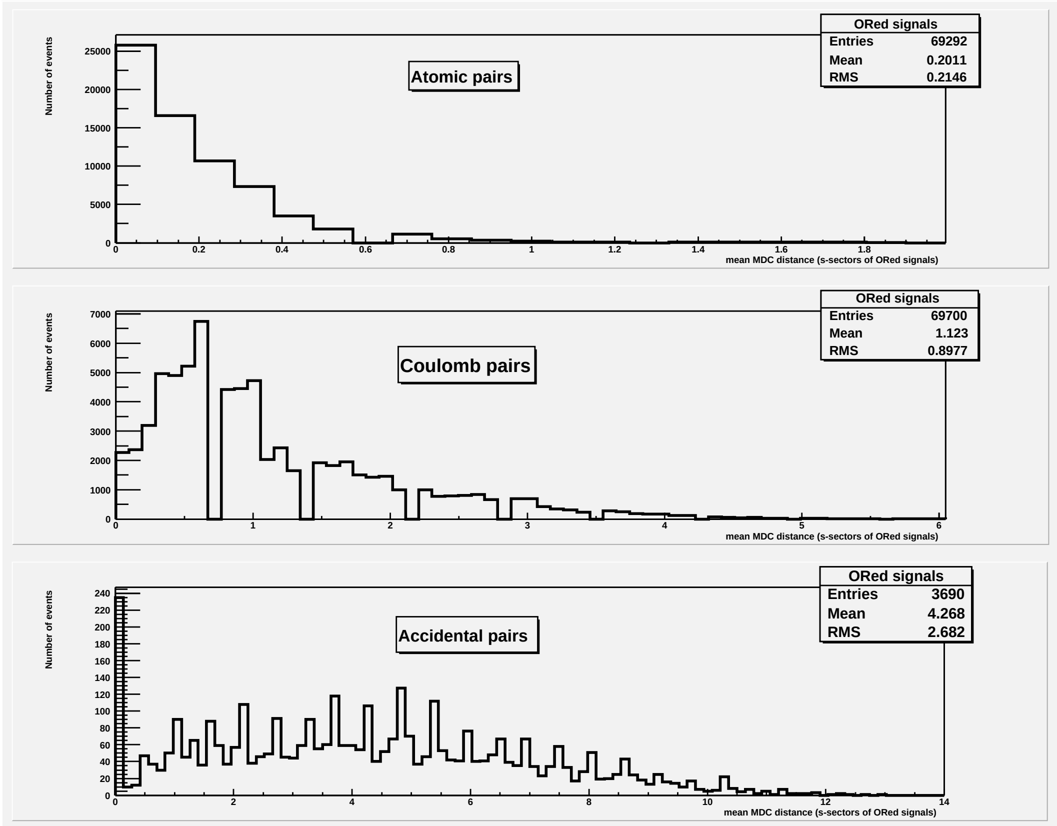

Figure 10: The mean distance between the two closest hits in the MDC for the three classes of events under study. The units are in semi sectors (s-sectors) of double plane formed form the 8 ORed signals available per MDC plane. Again for clarity the scale of each plot is different.

6 DDT-2 Selection algorithm

The main input data for this trigger level are the TDC measurements of the drift times of the hits in all MDC planes. It is assumed that the time of the closest hit to the anode wire is recorded (and hence that later signals are ignored). For each recorded hit the MDC plane, sector and time are available for further processing. The drift time vs. distance function of the MDC can be approximated with high precision by a straight line and hence time measurements can easily be converted to space coordinate measurements. In what follows the actual spatial distance between a hit and the corresponding anode wire has been used. A realistic implementation however will be using the times measured. Since there is a linear relationship between the two, the algorithm and the selection results presented here are directly applicable to a real trigger system.

The fact that MDC planes are superimposed in pairs with one plane shifted with respect to the other by half a sector allows a very efficient identification of events with two tracks through the same sector. The discriminant variable is the sum of the times in the two planes of such a super-plane. If this sum is equal to half the sector width, the signals are produced form a single particle (assuming it crosses the chamber perpendicularly, a pretty weak assumption given the chamber's thickness). Sums less than this value correspond probably to two tracks passing through the same sector in an MDC plane. To generalize the idea to 9 MDC super-planes a multi-step algorithm id followed:

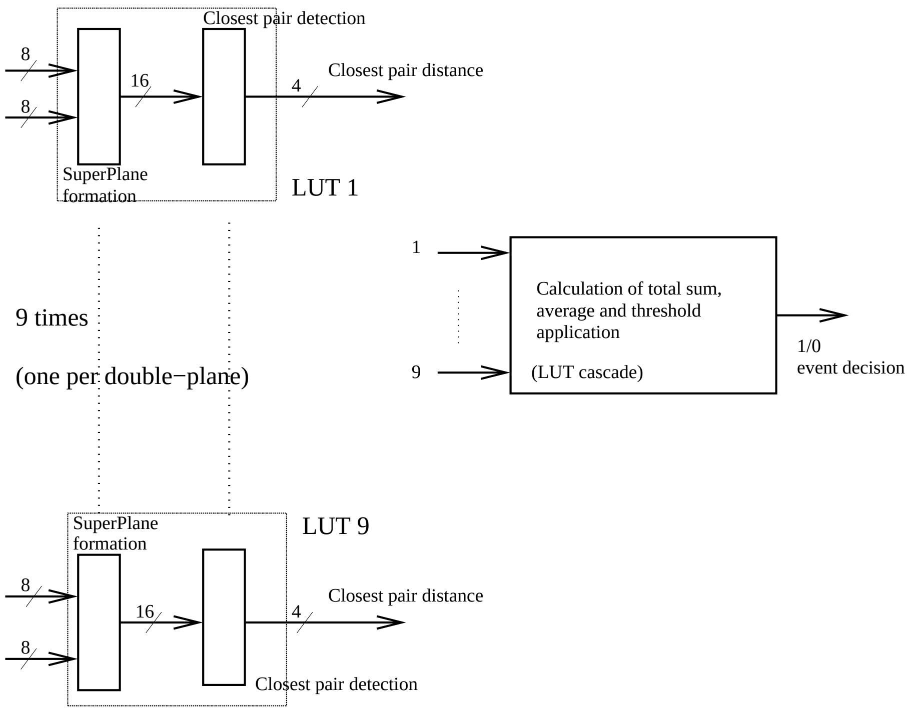

Figure 11: A simple DDT implementation using look up tables for the various proccesing steps.

1. The sums of the times measured in a plane with the ones in the corresponding second plane of the supper-plane are formed for all super-planes. In case there is no hit in one of the two adjacent planes a big value is assigned to the corresponding sum.
2. The minimum of these sum for each super-plane is found.
3. The average of the minima is calculated (excluding minima that correspond to the value indicating missing hits). By using this average and not the simple sum of the minima only pairs of hits are used in the event classification. In this way the event selection is improved as spurious hits are rejected.
4. A threshold is set that defines which events contain two close-by tracks that have to be eventually read-out.

7 DDT-2 selection performance

The graphs in figure 12 show the distribution of the average of the minima over the 9 nine MDC super-planes as defined in the previous paragraph. Each graph corresponds to one of the three event classes used for this study. The distributions for atomic pairs and accidentals are quite different and easily separable by a simple threshold. By setting this threshold to 0.124 (in the representation used here this is a value in centimeters) the following selection performance is obtained:

- Acceptance for atomic pairs: 97%,
- Acceptance for coulomb pairs: 40%,
- Acceptance for accidental pairs: 6% (i.e a rate reduction of a factor of 16.7).

The sample of events evaluated to obtain the above performance contained, in each event class, the events that had at least one hit in each VH and at least one hit in each of the

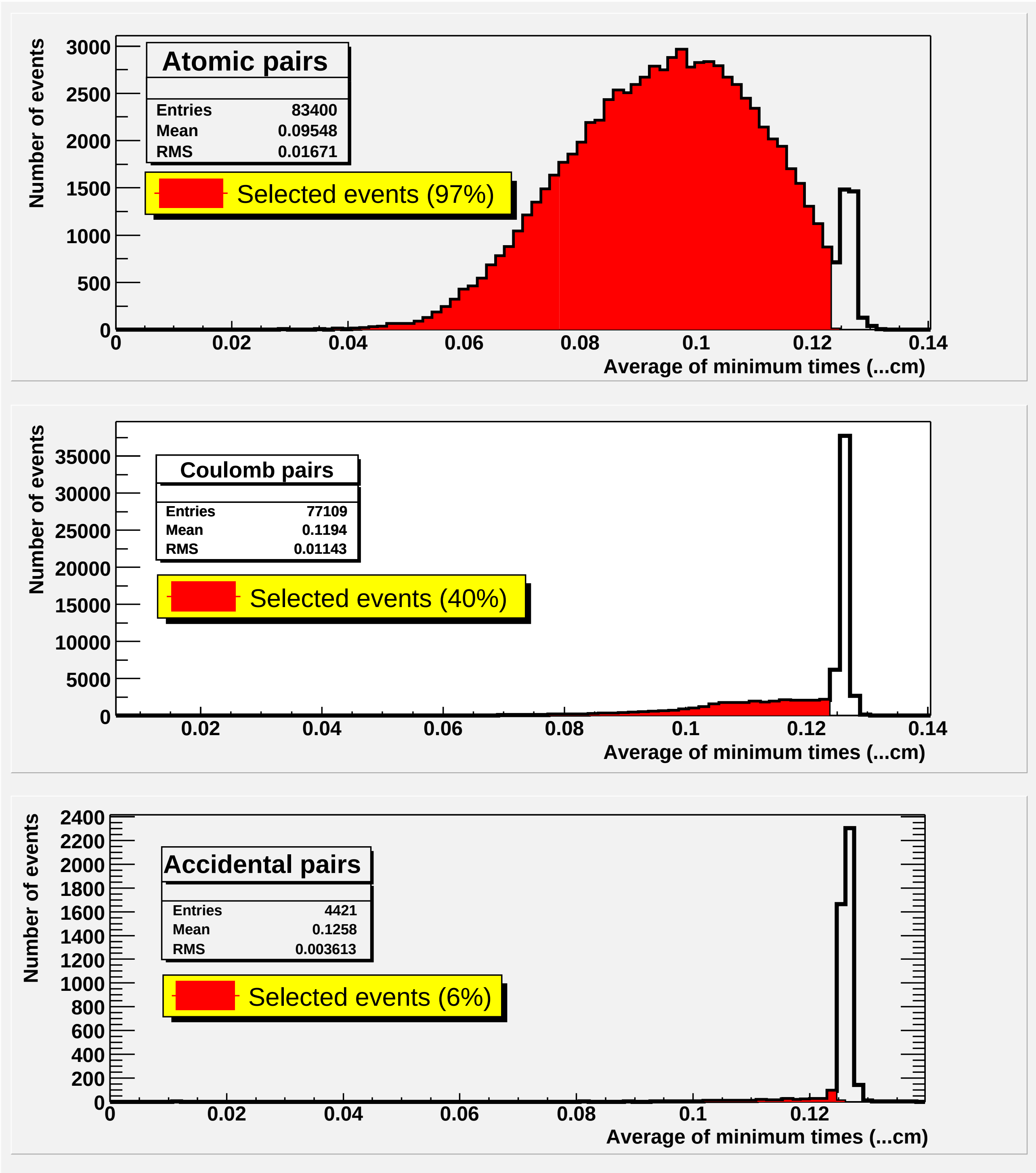

Figure 12: The average of the time minima in the 9 MDC super-planes for the three classes of events used in this study. The red areas indicate the part of the distributions remaining by selecting events with this average less than 0.124.

two x-planes of the IH detector. Again these requirements correspond well to the early DIRAC trigger stages.

In order to be able to use the available OR-ed signals, a similar procedure as for DDT is followed. Instead of using the individual sector time measurements, one can also use the time measurements of signals originating form the available OR-ed MDC sectors (8 per MDC plane). For each such OR-ed sector the minimum time measurement found is taken as the one to be combined with the corresponding ones from the adjacent plane of the same super-plane. The DDT-2 algorithm is then followed precisely as before. Figure 13 contains the graphs of the average time measured along all the 9 MDC super-planes The selection performance obtained using such OR-ed sectors is the following:

- Acceptance for atomic pairs: 98%,
- Acceptance for coulomb pairs: 89%,
- Acceptance for accidental pairs: 22% (i.e a rate reduction of a factor of 4.5).

The two trigger stages described above are quite independent both in input data and selection algorithm. They can therefore be combined for an improved overall performance. Since the event evaluation using the OR-ed signals for both systems provides a reasonable event selection performance with minimum input data requirements (8 instead of 32 signals per MDC plane) these two algorithms were combined with a logical AND or OR function (the threshold for DDT was set at 2 and for DDT-2 at 0.123). The 'OR' combination of the two systems has the following performance:

- Acceptance for atomic pairs: 99.8%,
- Acceptance for coulomb pairs: 96.1%,
- Acceptance for accidental pairs: 40%

Nearly all atomic pairs are selected with this combination and still a rate reduction of 2.5 is obtained. The overall selection performance obtained with the 'AND' combination is (in parentheses the percentage of events preselected by DDT that was also selected by DDT-2):

- Acceptance for atomic pairs: 97% (98%),
- Acceptance for coulomb pairs: 88% (89%),
- Acceptance for accidental pairs: 12% (27%) (i.e a rate reduction of a factor of 8.5).

It has to be stressed out however that this 'AND' condition is quite restrictive as it selects virtually only events with two very close-by tracks, thus it excludes atomic or coulomb track pairs that hit adjacent or even more widely apart sectors.

The 'OR' combination seems to be the best suited for maximum acceptance of atomic pair events, whereas the DDT-2 system alone provides an excellent rate reduction in case it is needed.

8 DDT-2 hardware implementation

The DDT-2 decision should be available not more than 300 ns from the moment all the timing measurements in digital form are available. The required TDC resolution to achieved the performance presented in the previous section is of the order of 250 ps assuming a maximum drift time of 25 ns. The signal shaping takes place on the front-end electronics of the chamber These electronics format the incoming signal in 6 ns to provide differential ECL pulses for the OR of 4 adjacent cells in each plane. The digital pulses have

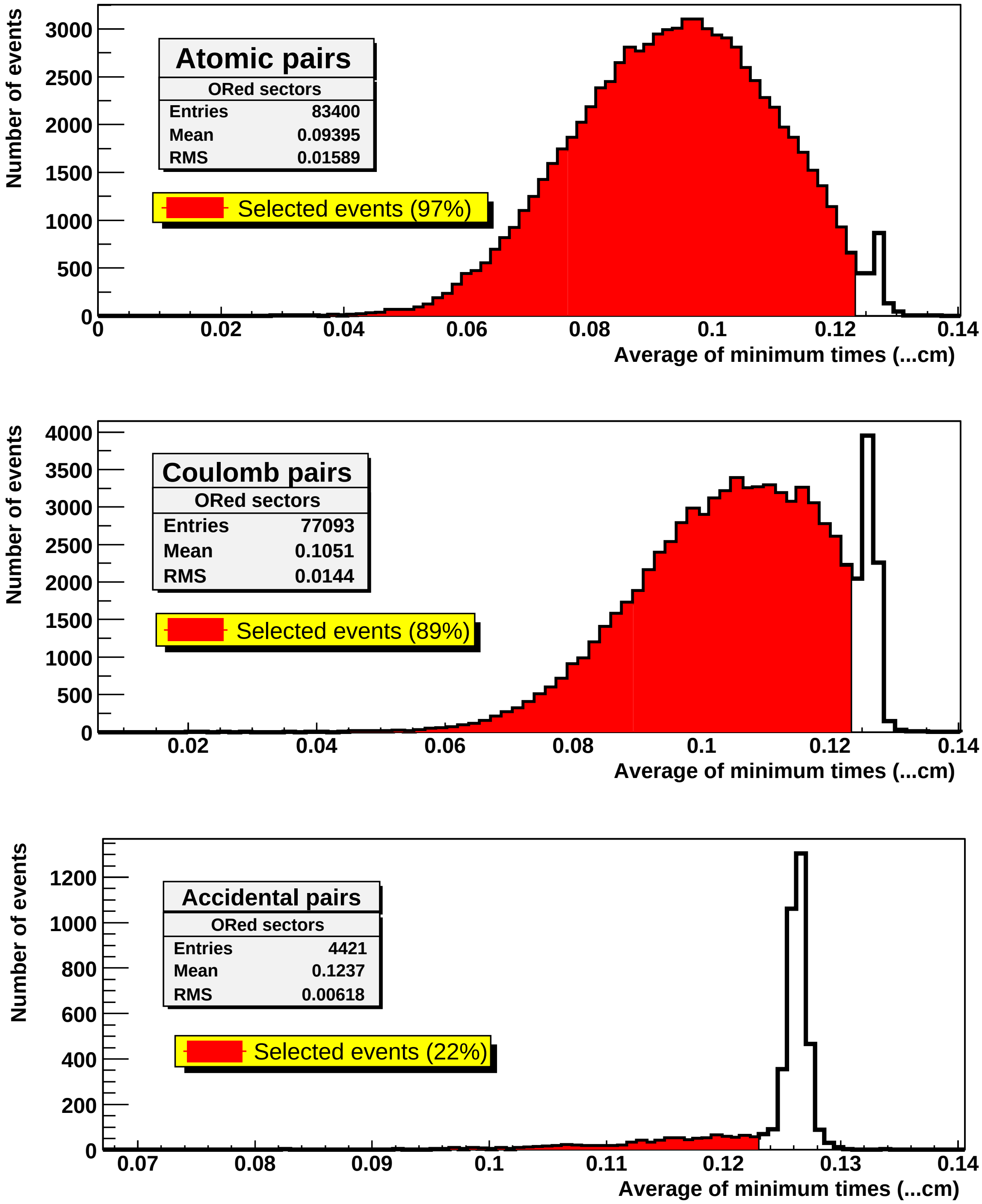

Figure 13: The average of the time minima in the 9 MDC super-planes for the three classes of events used in this study. The red areas indicate the part of the distributions remaining by selecting events with this average less than 0.123. The present plots are obtained when using the OR-ed MDC signals which provide 8 signals per MDC plane

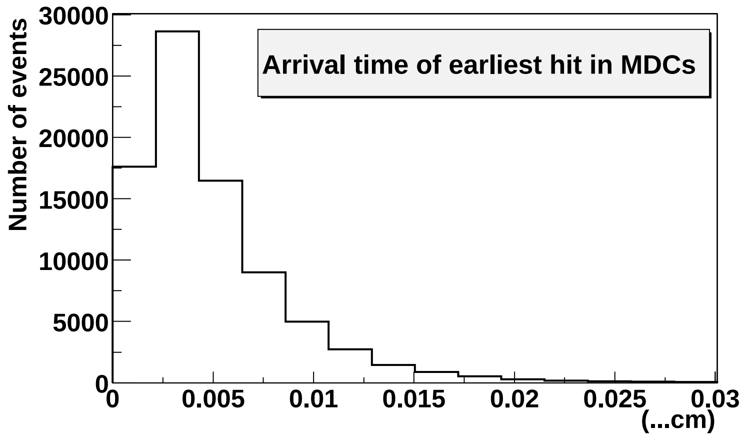

Figure 14: The drift time of the OR of all the MDC signals. The plot is obtained using atomic pairs but it is identical for all other event classes. Note once more the units in cm, which assume a linear relation between drift-time and distance from the anode wire.

a width of 10 ns , with a rise time of 1 ns. The stability of these signals with respect to the arrival time of the analog detector signal is better than 10 ps and hence they can easily be used for on-line timing purposes. Given these signal characteristics it is not advisable to transmit them over a long distance, for example to the DIRAC experimental barraque. Hence DDT will be installed in the DIRAC experimental hall, as close as possible to the MDC detector.

8.1 First possible implementation

For timing measurements one needs to measure the time difference between two signals. In a typical TDC application measuring the time STOP-START, START signal must be well correlated with the initial physical interaction that produces the detected particles. It must also have very small jitter in order to allow for a precise time measurement of the STOP signal. For the case of DDT the usual approach of using the general trigger decision is not possible, as this is only available 700 ns after the proton-target interaction. Hence a specific DDT-2-trigger has to be used. Two options are possible: Either make/modify a scintilator detector with very good timing characteristics to be used as a fast external trigger, or use an internally generated trigger by combining the OR of all the input signals. This OR will presumably be constant between events (since there are a few tracks per events and 18 MDC planes, which makes approximately 30–35 hits per event, equally distributed in drift-time). A Monte-Carlo simulation has provided the distribution in figure 14 for the drift time or this global OR signal. Using the drift-time vs distance dependence from [1], the mean of this distribution is about 0.5 ns. However it has quite a long tail towards longer drift-times. Using this global OR as the DDT-2-trigger which starts all time measurements, the distributions in figure 15 are obtained. The selection performance obtained using the OR-ed sectors and time measurements with respect to the DDT-2-trigger is the following when events with an average minimum time less than 0.11 (...cm) are selected (in parentheses the overall performance when combining in OR this event selection with DDT at a threshold of 2):

- Acceptance for atomic pairs: 95% (99.7%),

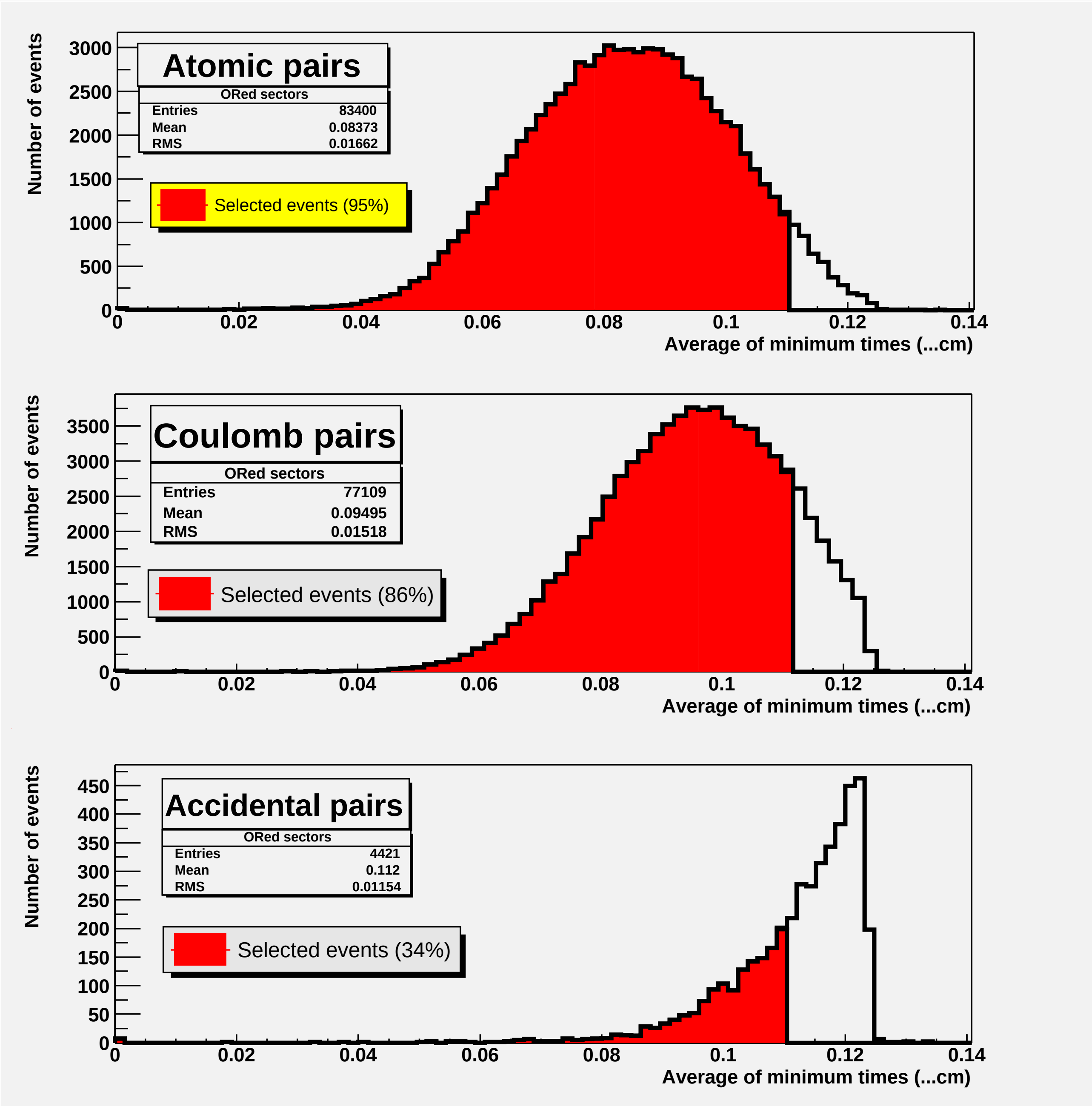

Figure 15: The average of the time minima in the 9 MDC super-planes for the three classes of events used in this study. The OR-ed MDC signals are used and all times are measured with respect to the DDT-trigger (the OR of all the incoming MDC signals per event). The red areas indicate the part of the distributions remaining by selecting events with this average less than 0.11.

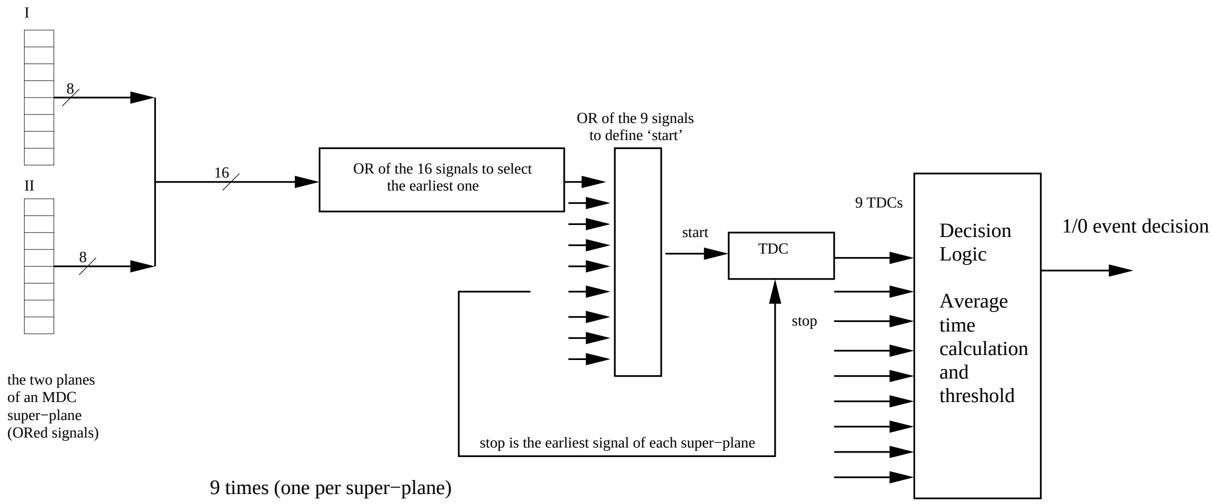

Figure 16: A block diagram of the DDT-2 implementation using an OR to define the overall earliest signal per event, to be used to start all time measurements. Only the part concerning one super-plane is shown for clarity.

- Acceptance for coulomb pairs: 86% (93%),
- Acceptance for accidental pairs: 34% (i.e a rate reduction of a factor of 2.9) (47%).

Figure 16 shows a block diagram of the proposed hardware implementation.

8.2 Second possible implementation

The main problem the previous implementation faces is a considerable performance reduction due to an inherent uncertainty of the ‘start’ signal for any time measurement. Since DDT-2 tries to be an independent trigger system, no signals from other detectors should be used. Therefore instead of a precise external stable in time trigger to be used for timing measurements, the OR of all the observed signal in the detector was used. Due to the relatively low track multiplicity this produced ‘start’ has still a jitter and measurements based on it are not as precise as they could.

In this section a different approach is followed. Here the proposed implementation is based on a set of meantimer modules, which provide signals with much better timing quality than above. A meantimer is is normally used with long scintillators to provide the mean time of the detection of a passing particle (when the scintillator is equipped with a photomultiplier in each end). The resulting signal is produced at the same time (with a resolution of about 200 ps) irrespective of the impact point of the particle on the detector (and hence its distance from the photomultipliers). A typical meantimer implementation can be seen in figure 17

The basic idea in this section is to use as inputs in meantimers the detected signals in corresponding sectors of superimposed planes. Hence for each sector whenever a single particle passes through a signal is generated at a precise time moment. The earliest arriving signal from all the sectors and from all the super-planes constitutes the ‘start’ signal with respect to which all other times are measured. Per super-plane the earliest signal is used and its arrival time is measured. With the resulting maximum nine measured times their mean value is calculated to provide the discriminant variable for the DDT-2 trigger. Figure 18 shows the distribution of this mean time for the various event classes under

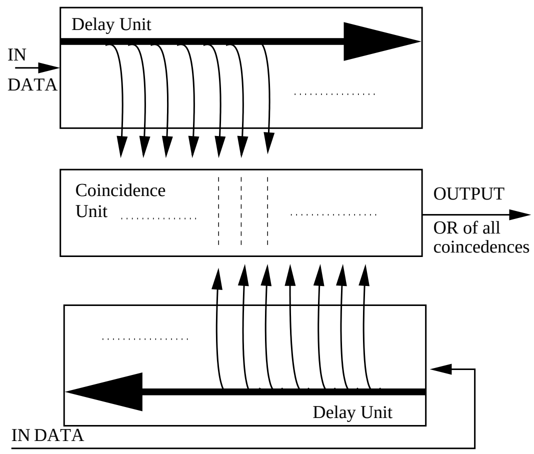

Figure 17: A block diagram of a typical meantimer implementation with discrete digital electronics. The delay unit delays its input for a finite number of fixed times. For each of these steps the signal is also send out to be combined with the corresponding signal form the second delay unit in a simple coincidence (AND function). The OR of all these pairwise coincidences is the final output of the circuit. The meantimer function is achieved by having the two delay units 'face to face' and the coincidence taking place between signals that in total have had a constant delay.

study. It should be noted here that for calculation convenience all (maximum nine) times measured are used for the calculation of the mean. If in the hardware implementation only the non-zero values are used (i.e. excluding the signal used as 'start') the expected performance of the system shall be identical as only one signal in the whole MDC chamber system will have a value 0.0. A detailed simulation of the hardware implementation confirmed this statement.

The selection performance obtained using the OR-ed sectors and time measurements as described before is the following when events with an average minimum time more than 0.005 (...cm) are selected (in parentheses the overall performance when combining in OR this event selection with DDT at a threshold of 2):

- Acceptance for atomic pairs: 97% (99.8%),
- Acceptance for coulomb pairs: 92% (97%),
- Acceptance for accidental pairs: 24% (i.e a rate reduction of a factor of 4.2) (44%).

Figure 19 shows a block diagram of the DDT-2 implementation proposed in this section. The meantimes may either be commercially available 16 channel modules or custom-made devices implemented in the DDT-2 layout.

9 Conclusions

A very simple discriminant variable is proposed for DDT, to select close lying tracks by using only the new MDC detector in DIRAC. This trigger may well be combined with the standard DIRAC triggers to increase acceptance for good events and reduce background. It may also be used as an independent trigger which would allow more detailed studies of acceptance for the on-line as well as the off-line selection methods.

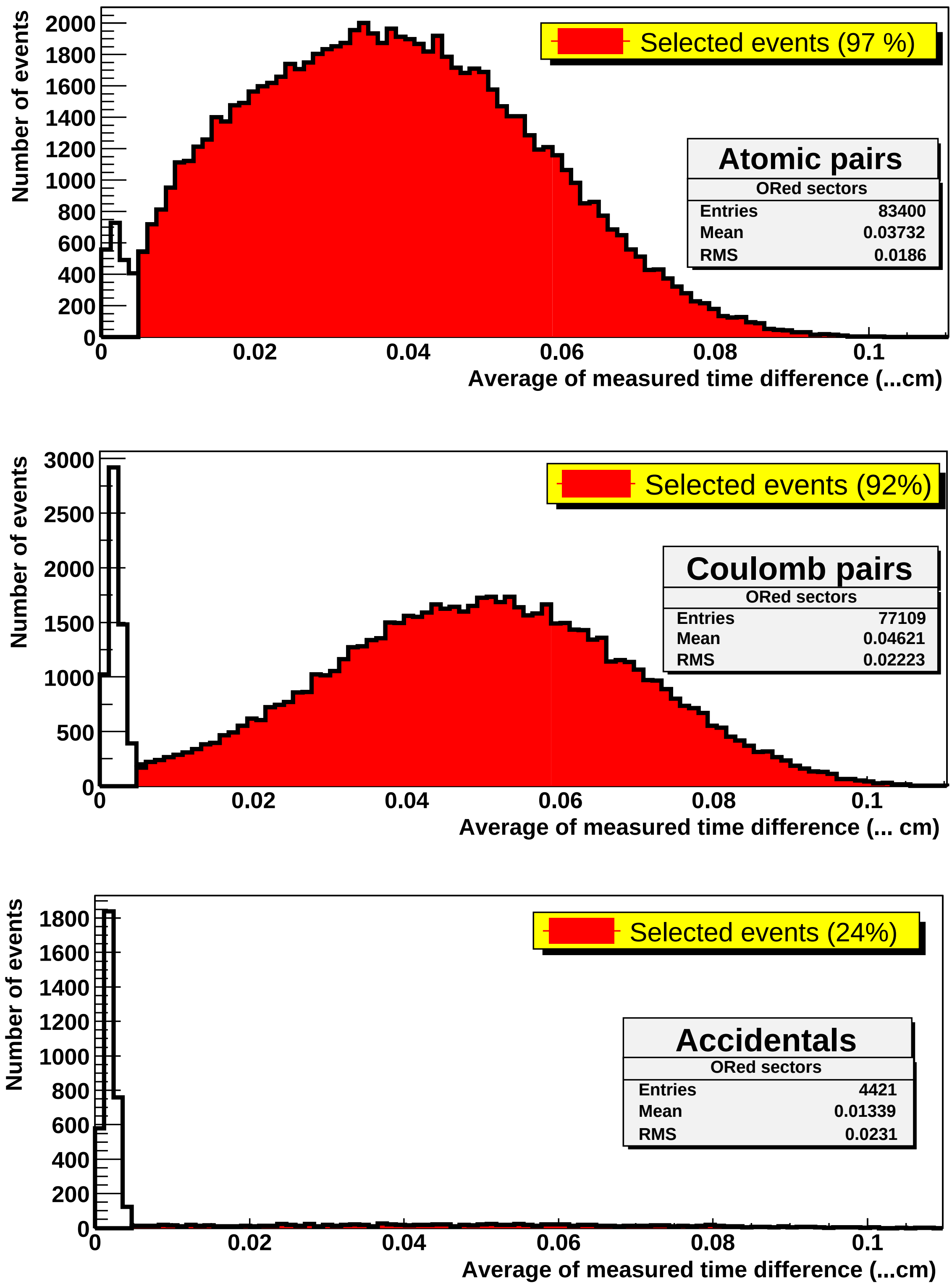

Figure 18: The arrival time average of the earliest signal from each MDC super-plane (coming out from the meantimers and measured with respect to the overall earliest signal arrived for the event) for the three classes of events used in this study. The OR-ed MDC signals are used. The red areas indicate the part of the distributions remaining by selecting events with this average more than 0.005 (...cm).

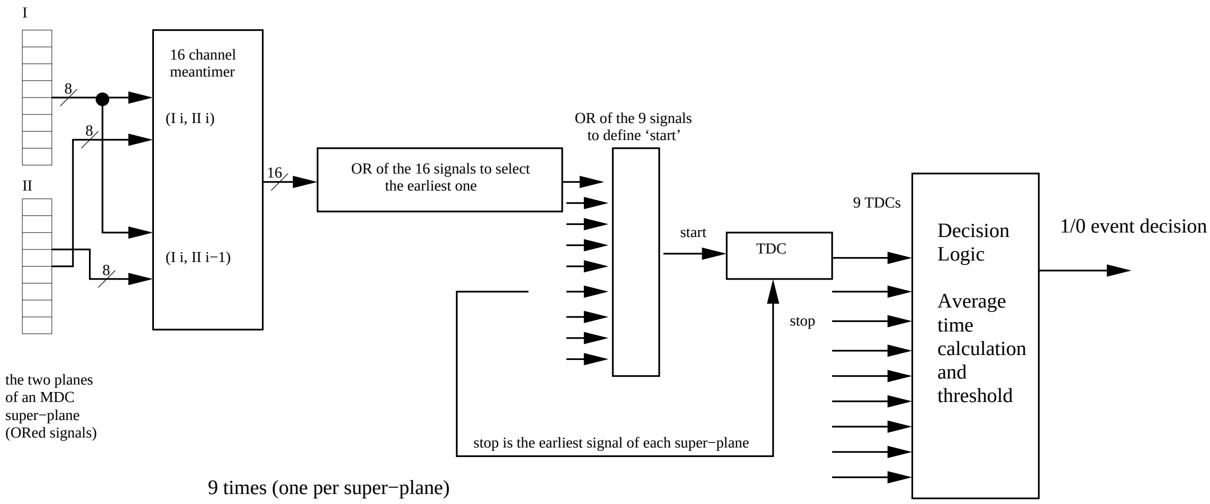

Figure 19: A block diagram of the DDT-2 implementation using meantimers to shape MDC input signals. Only the part concerning one super-plane is shown for clarity. One 16 channel meantimer is used per super-plane. The 8 signals from plane I are used twice. Once with the corresponding sectors of plane II and once with the sectors in plane II shifted by 1 sector, to accommodate the overlap of half a sector between the two planes.

The second layer of the DDT trigger (DDT-2) can effectively isolate atomic pionic pairs from background with very high efficiency. The use of timing information makes the event classification decision longer but much more powerful. A hardware implementation of this system will certainly be a big step towards a multitude of independent triggers for an efficient, redundant trigger system without any unknown systematic effects.

References

[1] The DIRAC Micro Drift Chamber Project, V. Kruglov and L. Tauscher, DIRAC internal note.