Scintillating Fiber Detector Efficiency Study

Daniel Goldin, Ludwig Tauscher
University of Basel

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Abstract

The scintillating fiber detector (SFD) provides information essential for momentum determination and MSGC clustering. It is crucial to assess the efficiency of this detector as the event reconstruction cannot proceed if the SFD response is inaccurate or missing. In order to accurately determine the relative momentum, we need to rely on the efficient performance of the x-plane of the detector. In what follows we assess this efficiency and analyze the detector response to single and double-track events. Lastly, we use single track event statistics to find the percentage of hits lost due to the performance ot the readout electronics or added due to the crosstalk for the case of double track events.

Introduction

For our analysis we used Spring 2001 and Summer 2000 data samples with 10 million events taken with a mixed trigger $(DNA.or.T3).and.T1_{\pi\pi copl}.or.T1_{ee}$ $.or.T_{\Lambda}.or.T_{Kaon}$. The experiment was run with different SFD thresholds during these two run periods. Since the T2 trigger was active at the time, 1999 data could not be analyzed. The results from real data are also compared to the the simulated detector response to the Coulomb pairs. The determination of the SFD efficiency makes use of the two staggered IH planes. Since only two vertical IH planes were available before 2001, only the determination of the x-plane efficiency was possible.

Procedure

At the start of our procedure, we use the hit slabs in both planes of the ionization hodoscope to localize one or two particles that have crossed the detector within a small horizontal spatial interval. Since the distance between the IH and the SFD is small (15 cm) and the amount of material between them is low, we assume the lateral displacements between the SFD and the IH due to multiple scattering in the SFD or the MSGC to be small. Moreover, we rely on the fact that the particles originate from the target area. Selected events are required to meet the following conditions:

- *Pion triggers.* Only the events with pion trigger marks are selected [2]. As an additional "clean-up measure" we eliminate events containing electrons in the Cherenkov detector (see Fig. 3) and muon tracks using the preshower and muon detectors.[1] We note that the prompt events may also contain protons ($p \geq 3.5$), which, similar to pions, are minimum ionizing.

- *Ionization hodoscope cuts:* Require ADC signals from the overlapping hit slabs in both planes of the IH as shown in Fig. 1. And in the case of:
  (a) Single ionization: Require an ADC signal in the range between 100 and 180 (Fig .4).
  (b) Double ionization: Require an simulatedADC signal above 250.

- *Timing of the hits:* We choose events with the time difference of -0.5 to 0.5 ns between the left and the right arm of the vertical hodoscope. Additionally, only the hits in the x-plane of the SFD and both planes of the ionization hodoscope which correspond to the TDC signal between 5 and 10 ns are taken. We constrain the time difference between the two planes of the ionization hodoscope to ± 2 ns. (In Fig. 2 we show timing for plane 1 of the IH; plane 2 and the SFD timing are very similar.)

- In the case of double ionization we require only one occurrence of the doubly ionized slab per event in each plane. This ensures that only one pair of particles traveling close to each other is identified.

[1] Muon tracks were eliminated using the method described in [1].

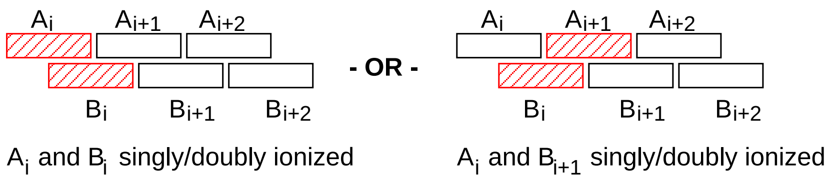

Fig. 1: Double ionization configuration in the IH.

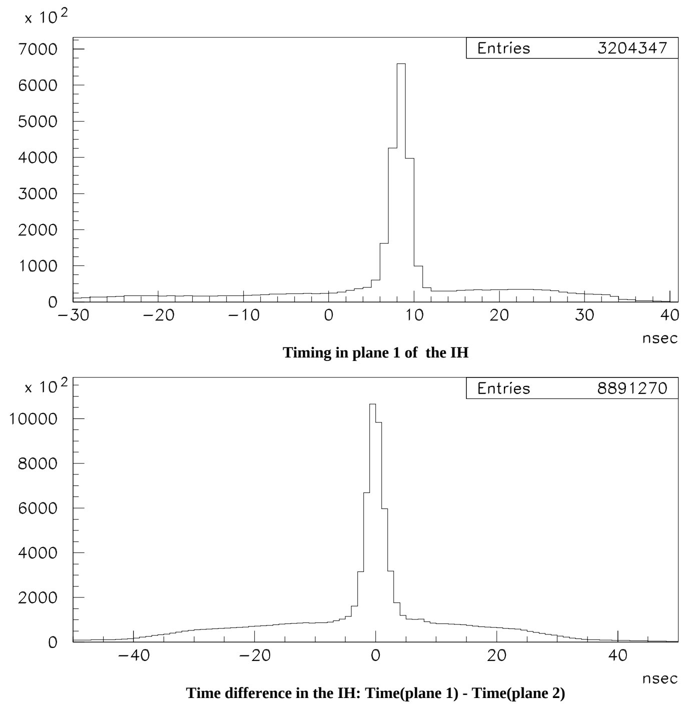

Fig. 2: Timing of prompt events. Top: timing of the first plane of the IH. Bottom: time difference between plane 1 and 2 of the IH.

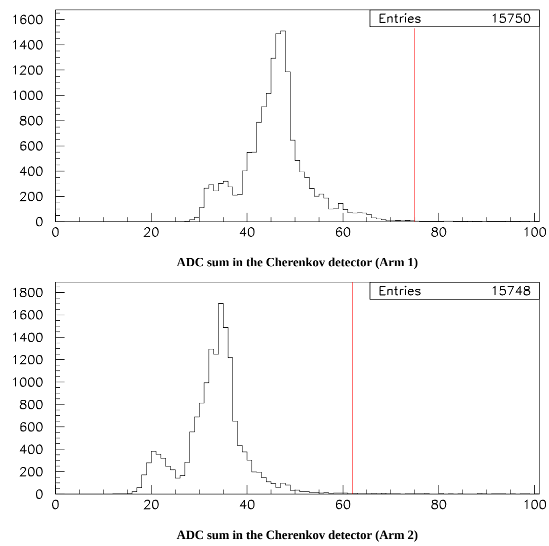

Fig. 3: ADC signal in the Cherenkov detector after the $\pi^+\pi^-$ trigger has been applied. Signals below 75 in Arm 1 and below 62 in Arm 2 (thresholds marked with the vertical line) are rejected in this analysis.

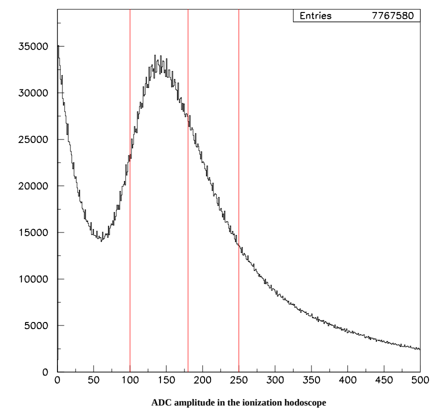

Fig. 4: ADC signal in the ionization hodoscope. Single ionization cut corresponds to the region between 100 and 180 ADC counts and and double ionization to amplitudes above 250.

Identifying “active areas” of the SFD

In the first step of our analysis we localize the “active areas” of the SFD, i. e. the regions where one should look for hits corresponding to the two slab overlap area shown in Fig. 1. In each case when the double ionization criterion in the ionization hodoscope is satisfied, we record all the hit channels in the x-plane of the SFD for this event.

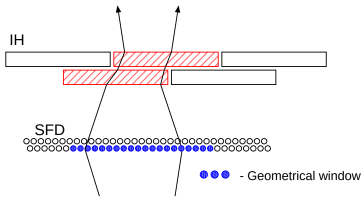

Fig. 5: Geometrical window definition.

The result can then be graphed in the form of a scatter plot and the hit distributions in the SFD per IH slab (i.e. a projection of the scatter plot onto the SFD hit axis) (Fig. 6 and 7). The SFD projection plots enable us to find the positions of the peak areas as a function of the IH slab number.

Knowing a window position, we can now obtain a precise value of its width. Due to multiple scattering we expect this width to be slightly broader than the overlap area of 3.3 mm between the slabs in the ionization hodoscope (Fig. 5). Indeed we find this to be true when we cycle over the same events plotting the distance between the center of each window and the hits closest to it. The result for the cases of single (left) and double ionization (right) is shown in Fig. 8. In the first row we plot the closest hit - window center distance in units of SFD channels, in the second the distances of 2 closest hits to the window center (closest hit - center and next-to-closest hit-center, both in the same plot) and in the third row 3 closest hits. It is evident that the width of the active areas (to which from here onward we will refer to as the “geometrical windows”) can now be fixed at 10 channels (± 5 channels centered around 0), or approximately 4.5 mm. As expected, one observes a rise in background hits as one advances from a single closest to three closest hits. The peaks correspond to the window we are looking for and the areas outside are the background hits which we can discard. The shapes of the graphs are fairly symmetrical and the maxima are centered around 0 indicating that the geometrical window was indeed found correctly.

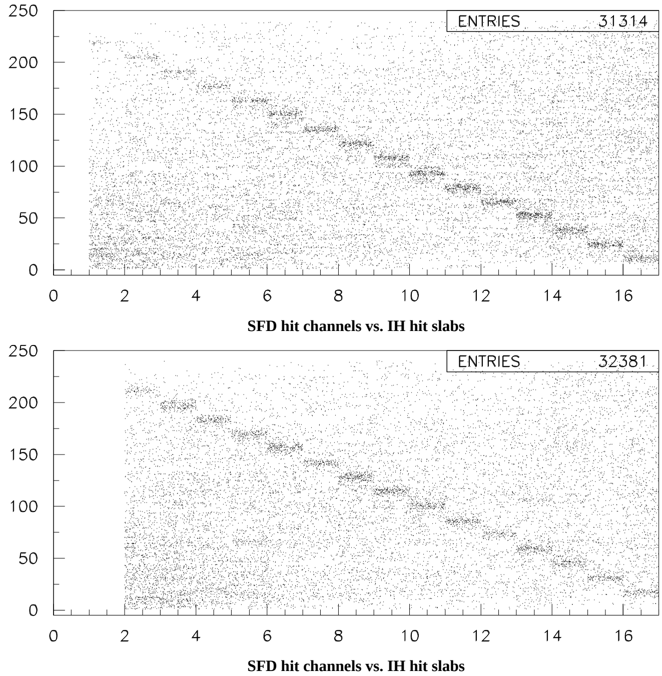

Fig. 6: Scatter plots of SFD vs. IH hits. Top graph corresponds to the left-hand side configuration in Fig. 1, bottom graph to the right-hand side.

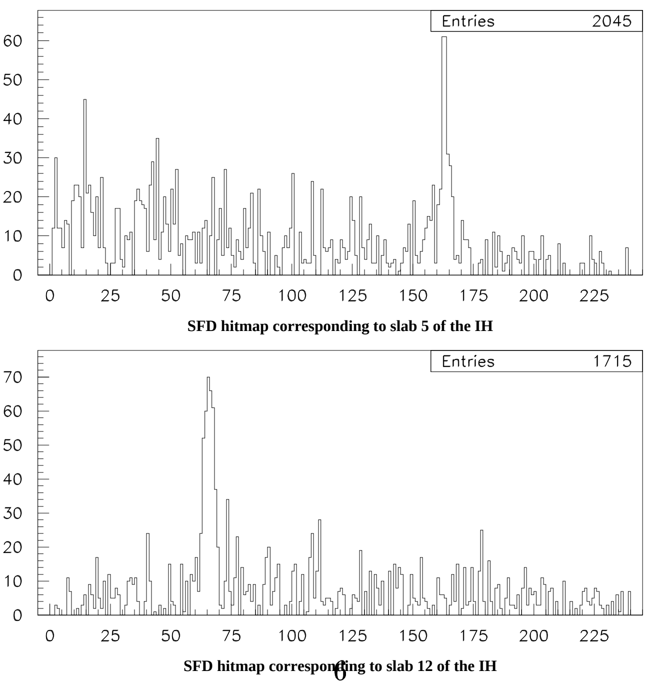

Fig. 7: SFD projections.

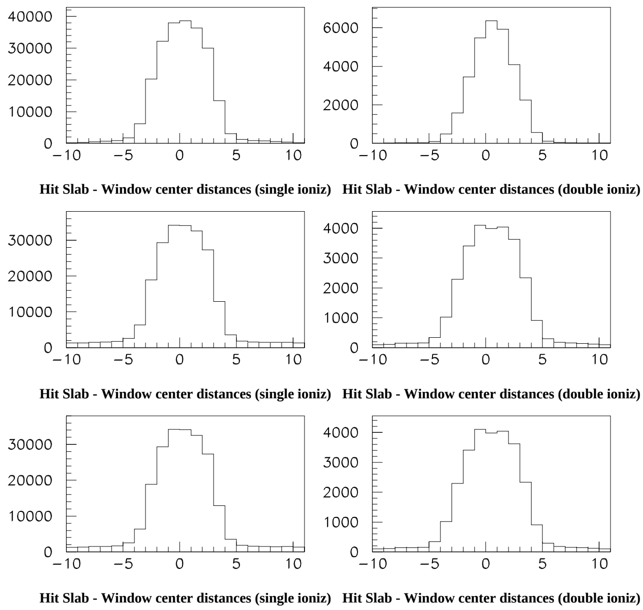

Fig. 8: Hit slab - window center distances in units of SFD channels. Top: closest hit, center: 2 closest hits, bottom 3 closest hits to window center distances:

Efficiencies

By counting hits inside and outside a geometrical window whenever two overlapping singly (doubly) ionized signals in the IH are registered, we find the combined window multiplicity (Fig. 9). In Table 1 we show these results in numerical form.

For the single ionization case the imposed cuts reduce the original sample of 10 million events by a factor of 1.2×10^{-3} both for the year 2000 and 2001. The number of events with no signal when one was expected is registered in 13% of the events in 2001 and in 19% of the events in 2000. We also note that the single hit events dominate the statistics as expected and that only about 2.3% of the events in 2001 (1.4% in 2000) have two or more hits within the geometrical window.

For the case of double ionization the reduction factor is 3.3×10^{-3} for 2001 runs and about 3.5×10^{-3} for the year 2000. We observe events with no signal when one was expected in 7.6% of the cases in 2001 and in 30% in 2000. As expected, most of the remaining cases have one or two hits within the geometrical window. There is a sharp increase in the number of double hits in 2001 with respect to 2000 (25% in 2001 compared to only 9% in 2000).

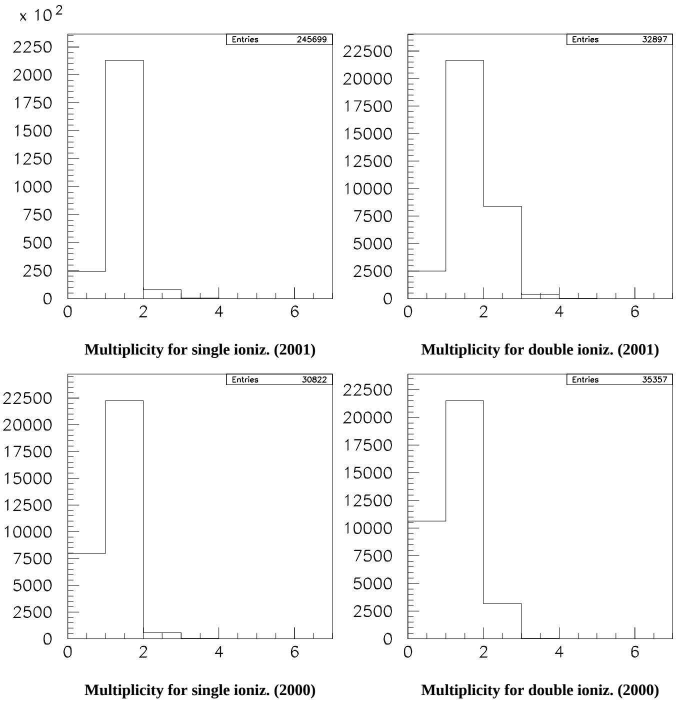

Fig. 9: Multiplicity inside geometrical windows.

Run	Total	**Mult. 0 (%)**	Mult. 1 (%)	Mult. 2 (%)	Mult. > 2 (%)
2001	100%	**13.3±0.3**	84.4±0.8	2.12±0.13	0.147±0.035
(evts)	12285				
2000	100%	**19.1±0.4**	79.4±0.8	1.37±0.11	0.067±0.023
(evts)	11970				

Run	Total	**Mult. 0 (%)**	Mult. 1 (%)	Mult. 2 (%)	Mult. > 2 (%)
2001	100%	**7.62±0.15**	65.8±0.4	25.4±0.3	1.10±0.06
(evts)	32897				
2000	100%	**30.1±0.3**	60.9±0.4	8.96±0.16	0.127±0.018
(evts)	35357				

Table 1: Window multiplicities with statistical errors for single ionization (top) and double ionization events (bottom).

Efficiencies with Tracking

The results in the tables above could be refined further if for every single ionization event in the overlapping IH slabs one also requires the presence of a zeroth-order track and, in the case of of double ionization, two tracks upstream of the magnet.[2] The region of the SFD where each track is "allowed" to pass is determined by multiple scattering downstream. Its width, set to 2σ, is found to be $1.6/P_{tot}$ cm, where P_{tot} is the total lab momentum of the zeroth-order track. The center of this new window, which we will call the "track window", is the midpoint of the overlap region of two singly (doubly) ionized IH slabs (Fig. 10). The track window width can be shown to vary from 9 SFD channels, which is close to the the geometrical window size of 10 channels, to about 30 channels (4.5 mm to 13.5 mm range) (Fig. 11).[3] In addition, to make sure that only the hits corresponding to tracks

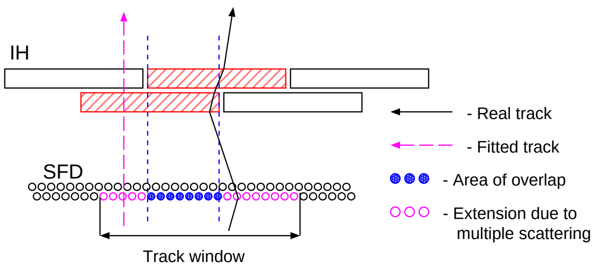

Fig. 10: Track window definition.

are selected we restrict our sample even further by applying the same sized track window to the y-plane of the SFD[4] and require the single and double track events to have at least one hit inside and the timing of the hits to be between 5 and 10 ns.

Whenever a track passes through the track window in the single ionization case (for double ionization we require two tracks to pass through their respective track windows), the y-plane spatial restrictions, and the initial time constraints imposed on the ionization hodoscope and the x-plane of

[2] At this stage of tracking the drift chamber fit extended upstream and connected by a straight line to the target (assumed at the origin).

[3] If one compares and plots position and width of the track window with that of the geometrical window, one finds that the geometrical window is entirely contained within the track window in 97% of the selected events.

[4] Multiple scattering downstream of the magnet is approximately the same in the x and y direction.

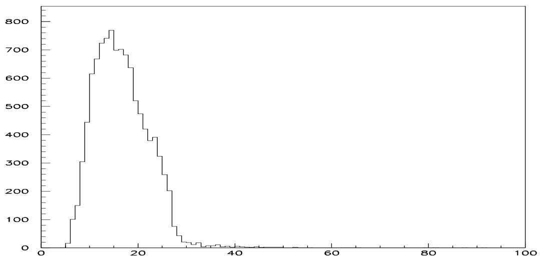

Fig. 11: Track window width distribution.

the SFD are satisfied, we record the appropriate hits in the x-plane. One of the effects of these restrictions is a reduction in the background outside the geometrical window. In Fig. 12 (2001 data) we compare distances of the hits closest to the window center - the position of the window center with and without the track requirement for the case of double ionization. The percentage of hits outside the $\pm$ 5 channel window is around 4% in the latter case, and about 1% in the former. For the single ionization the decrease in background hits is smaller and is around 1%.

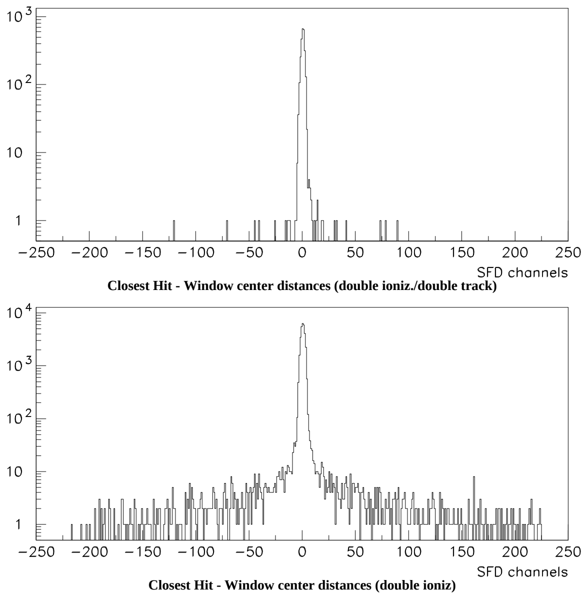

Fig. 12: Double ionization: closest slab - window center distributions for events with (top) and without (bottom) the track requirement. The bottom plot is the expanded version of Fig 8.

For comparison with Fig. 8 we also plot closest hit - window center distances for different locations of the tracks relative to the track windows (throughout this part of the analysis we do require the presence of at least one downstream track for the events with single ionization and at least 2 tracks for the events with double ionization) (Fig. 13, 14).

One can now plot multiplicities inside the geometrical window (Fig. 15) and construct a table similar to Table 1 (Table 2).

To summarize the rest of the results, the single track requirement reduces the statistics in Table 1 by a factor of 1.3 in 2001 and by a factor of 1.4 in 2000. For the double ionization events this factor is around 3 in 2001 and 4.6 in 2000. The track constraint contributed to a signifcant drop in inefficiency (multiplicity 0): from 13% to 9.6% (2001) and 19% to 13% (2000) for single ionization, and from 7.6% to 2.8% (2001) and 30% to 22% (2000) for double ionization. The effect of decreased SFD thresholds in 2001 can be observed through a relationship between the number of double hits relative to the number of single hits: with the track requirement the number of double hits exceeds that of the singles for 2001 data whereas the opposite is true for the previous year (the time correlated neighboring hit channels were merged into a single hit or not registered at all due to higher threshold values in the peak sensing circuit [3] used in the SFD readout). Lastly, another effect of lower SFD thresholds, which becomes more evident with the track constraint, is the increase in the number of double ionization events with multiplicity higher than 2. Such events were registered in 2.08±0.14% of the cases in 2001 as compared to 0.206±0.051% in 2000.

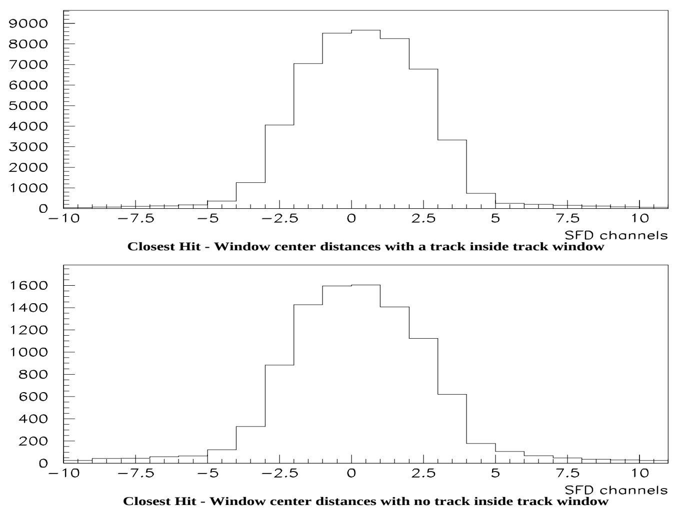

Fig. 13: Single ionization: closest slab - window center distributions.

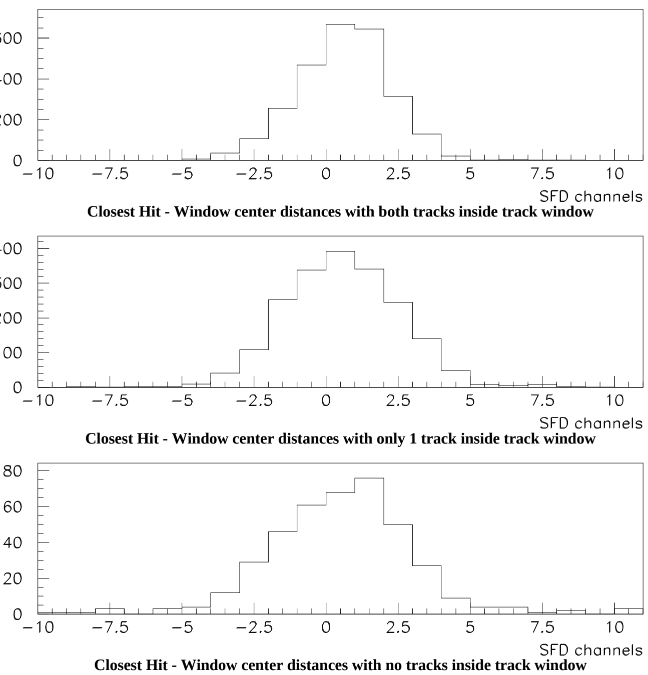

Fig. 14: Double ionization: closest slab - window center distributions (2001 data).

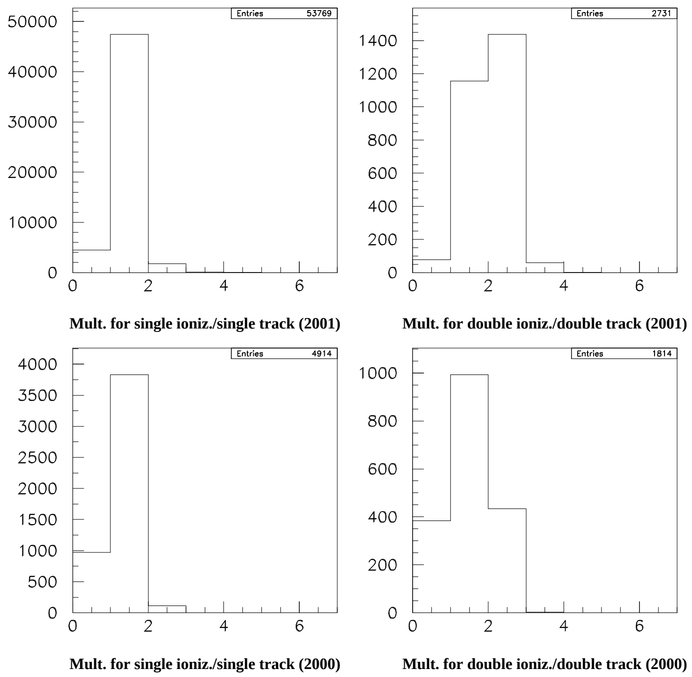

Fig. 15: Multiplicity inside geometrical windows with the track requirement.

Run	Total	**Mult. 0 (%)**	Mult. 1 (%)	Mult. 2 (%)	Mult. > 2 (%)
2001	100%	**9.61±0.33**	88.0±1.0	2.22±0.16	0.190±0.46
(evts)	8968				
2000	100%	**12.7±0.4**	85.7±1.0	1.48±0.13	0.096±0.034
(evts)	8365				

Run	Total	**Mult. 0 (%)**	Mult. 1 (%)	Mult. 2 (%)	Mult. > 2 (%)
2001	100%	**2.88±0.16**	45.6±0.6	49.4±0.7	2.08±0.14
(evts)	10906				
2000	100%	**21.5±0.5**	55.5±0.8	22.8±0.5	0.206±0.051
(evts)	7761				

Table 2: Window multiplicities with statistical errors for single ionization with 1 track in a track window (top) and double ionization events with 2 tracks in a track window (bottom).

SFD Efficiency with Coulomb Pair Events

Finally, we consider the response of the simulated SFD to Coulomb pair and single track events and compare them with the real data efficiencies above. In both cases we used 30,000 2-pion event input file[5], taking away one track to generate single track events. This file was processed by GEANT resulting in an output file which contained detector hit and time of flight information. Subsequently, the same subroutine (linked with Ariane 304_23) was run over the GEANT-processed output, while the same constraints as in the beginning of the article were kept. This yields the following geometrical window multiplicities:

Run	Total	**Mult. 0 (%)**	Mult. 1 (%)	Mult. 2 (%)	Mult. > 2 (%)
2001	100%	9.26±1.11	88.4±3.4	2.38±0.56	0.
(events)	756				
2000	100%	22.6±1.7	71.6±3.0	5.60±0.83	0.124±0.124
(events)	804				

Run	Total	**Mult. 0 (%)**	Mult. 1 (%)	Mult. 2 (%)	Mult. > 2 (%)
2001	100%	1.13±0.29	42.6±1.8	53.8±2.0	2.49±0.43
(events)	1327				
2000	100%	17.3±1.1	56.1±2.0	26.5±1.4	0.073±0.073
(events)	1365				

Table 3: MC-generated window multiplicities for the single (top) and double ionization events (bottom).

Overall, the Monte Carlo generated window multiplicities are found to be in good agreement with the experimental data (Table 1 and 2), with mean multiplicities differing by at most 1 σ. Since the Monte Carlo SFD thresholds have been tuned based on the Table 1, one observes a closer agreement between these results than with the a track window case (Table 2). Conversely, since for the Coulomb sample the background is virtually non-existent, MC double track multiplicities show a better agreement with Table 2 than with results in Table 1.

Conclusions

Since the goal of the experiment is to detect a pair of charged particles, we will summarize the efficiencies obtained with double ionization. By examining prompt events within allowed hit ranges in the SFD satisfying a

[5]Input file was provided by Cibrán Santamarina.

double ionization requirement in the ionization hodoscope we find the efficiency to detect at least one particle in 2001 run to be about 92% with no track requirement, 97% with one. For double ionization events with 2 track requirement the efficiency of detecting one or two hits with the active area of the SFD is 91% with no track constraints and 95% with the track constraint. The crosstalk (i.e. double hits in SFD with the singly ionized slab in the IH) is observed in 2.2% of the events (with the track requirement on). For the year 2000 the two particle detection efficiency was 70% with and 79% without the track constraint. Crosstalk was close to 0, consistent with higher threshold settings. These results were, finally, compared to the simulated one, with the good agreement found between the two, with average multiplicities deviating no more than one σ from each other.

Acknowledgements

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References

[1] *DIRAC NOTE-01-02*: Muon identification in the DIRAC experiment, V. Brekhovskikh [Protvino], M.V. Gallas [CERN]

[2] L. Afanasyev *et al.*, "The multilevel trigger system of the DIRAC experiment," Nucl. Instrum. Meth. A **491**, 376 (2002)

[3] A. Gorin *et al.*, "Peak-sensing discriminator for multichannel detectors with cross-talk," Nucl. Instrum. Meth. A **452**, 280 (2000)