Evaluation of the new dE/dx counter（newIH）prototype for the DIRAC experiment at CERN PS

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Abstract

To accept a larger intensity beam, a new dE/dx counter（IH）for the DIRAC（PS212）spectrometer was designed. First one-layer prototype with 12 strips was built and tested in the DIRAC T8 beam line in 2009. Data were taken using the DIRAC DAQ. This is the preliminary report on the data analyzed. The time resolution obtained from the prototype was 1.14 ns RMS. This mediocre time resolution is probably due to the smallness of the average number of collected photoelectrons. The mechanical design should also be reviewed.

1. Introduction

The aim of the DIRAC（PS212）experiment is to identify very rare $\pi^+\pi^-$ atomic pairs bound with the Coulomb force in a very high-intensity proton beam from the PS, and measure their decay time. The primary proton beam intensity of the T8 beam line dedicated to this experiment at CERN PS is about 10^{11}/spill, and the PS seems to be able to provide with a beam even more intense. The secondary beam emitted from the target into an angle of 5.7 degree is also intense, and that is a challenge to all the front end detectors of the DIRAC spectrometer. The updated Scifi hodoscopes have increased their granularity from 0.511 mm/chan to 0.205 mm/chan to accept a beam more intense, and also to improve the spatial resolution in the last few years. The MSGC which was limiting all the time the beam intensity is now replaced by a MicroDrift chamber which is expected to be more robust against a higher intensity beam. The performance of the current dE/dx counter（IH）produced by Protvino group, which replaced the old version prepared by CERN group has been just tangent, and will be a limiting device in case the spectrometer accepts a larger intensity beam. The main reason for the tangent performance is first its granularity. There are only 16 strips/plane, and thus the counting rate of each strip is as large as 5 x 10^5/sec. Another reason for the limited performance of IH is due to the capacity of the photomultipliers used. The update of IH was discussed inside the collaboration, and it was decided in 2008 that Protvino group prepares a new IH in collaboration with the Japanese group.

The main idea is of course to increase the granularity. If the geometrical design allows it, 32 (or 28) instead of 16 strips/plane were conceived. As the length of each strip stays as a little more than 10 cm, the strips become thin and long. The light attenuation within a strip might become a problem. Japanese group proposed a use of elastic clear optical fibers for the readout of both ends of a strip. But Protvino sticks to their design of solid lucite light guide. It was therefore decided that a prototype with solid light guides be built in 2009, and be tested the in the real beam.

The design parameters of the new dE/dx planes are as follows:

1. The counter will include 3 planes, x, y, and u which is inclined (40 strips).
2. The x and y planes consist of scintillator strips of size 1.5 mm (thick) x 4 mm (wide) x 110 mm (long) which are connected to lucite light guides of the same width, but 3 mm thick and 250 mm long.
3. About 40 photoelectrons are expected in a passage of a minimum ionizing particle.
4. For the readout, Hamamatsu H6568ModIII equipped with a ultra bialkali photocathode[1] will be used.

The prototype consists of about half a plane with 12 strips, each strip having a thickness of 1.5 mm. The prototype was installed downstream of the current IH, and the prototype was readout using the electronics (F1-TDC-ADC[2,3]) dedicated to the last plane (D) of the current IH. Data were taken in the autumn 2009, and this is the report on the analysis of the obtained data.

2. Setup

The new plane was inserted on the downstream side of the current IH. The signal from the plane was put into the DIRAC DAQ system. The trigger used was the ordinary DIRAC mixed trigger containing $\pi^+\pi^-$ events (39%), $K^+\pi^-$ events (39%), $K^-\pi^+$ events (13%), and e^+e^- events (9%). In the data, data from the Scifi plane as well as the 3 planes from the current IH planes were included. Thus one can analyze the events in coincidence with those counters. This allows to limit the data space-wise and time-wise. Fig. 1 shows the schematic display of the setup used.

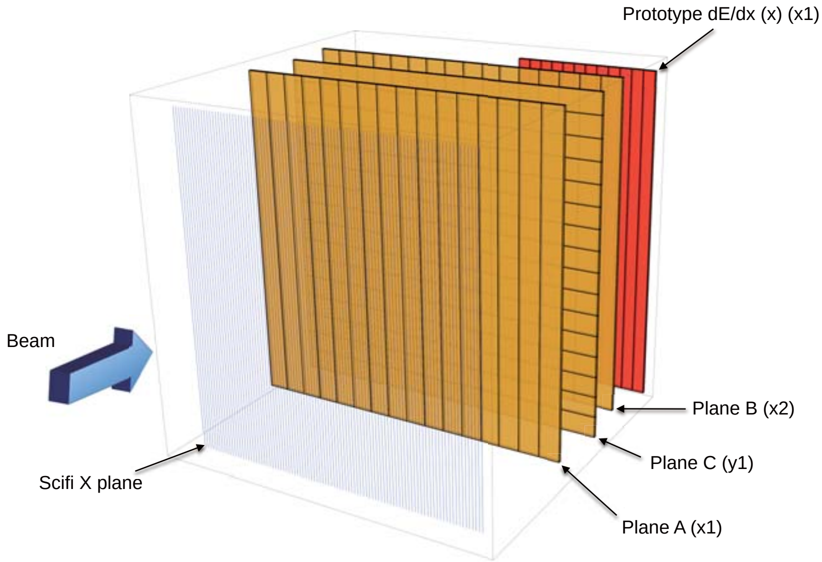


Fig. 1 Schematic view of the setup used. Electronics for the current plane D is now used by the prototype dE/dx counter (vertical).

3. Pulse height

A typical pulse height (PH) distribution from the prototype dE/dx plane is shown in Fig. 2a. The single photoelectron peak in this spectrum is larger than the one in the typical PH distribution from the current IH strip shown in Fig. 2b. (The spectrum shown in Fig. 2b is obtained with a preamplifier.) The width (PH spread), however, seems a little smaller in the prototype. The events displayed in Fig. 2 are both all the events accepted with the hardware threshold. The large single photoelectron peak is not due to the non-uniformity of the PH. It is probably due to the light leak from adjacent channels mapped on the 16 channel PSPM photocathode. The end of the light guide attached to the photocathode is rather large compared to the size of the photocathode (size 4 x 4 mm^2). Any misalignment can cause a light leak. To prove it, events are selected by using the Scifi X plane. The result is shown in Fig. 3. Events are selected in coincidence with the central 8 columns (width 1.64 mm) of the Scifi X plane. The single photoelectron peak is greatly reduced. This spectrum is without offline threshold applied, thus simply with the hardware threshold of the strip. Later we will see that the single photoelectron peak is again reduced when an appropriate offline threshold is applied.

The uniformity of the PH distribution among the strips is fairly good as shown in the histogram

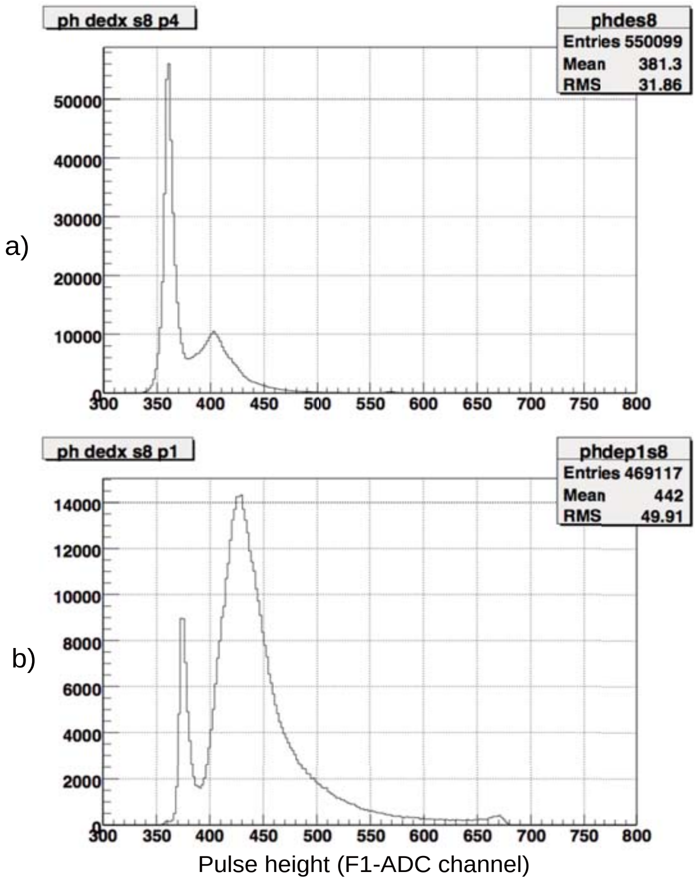


Fig. 2 a) Typical pulse height (PH) distribution from the prototype dE/dx counter (strip 8), in comparison with the current IH (plane A strip 8). b) Single photoelectron peak is larger in the prototype dE/dx counter than in the current IH. The width (PH spread), however, seems smaller.

in Fig. 4. The PH is now plotted on the vertical axis. A few strips, however, seem to have the hardware thresholds set a little too high compared to their gain as shown in Fig. 5a. Even in this case, however, the "meaningful" events seem not to be cut judged from Fig. 5b which displays only events in coincidence with Scifi X plane. The size of the single photoelectron peak is also greatly reduced.

The above-mentioned light leak causes cross talks between strips. In Fig. 6, the geometrical correlation of the strips with the Scifi X plane is shown. Fig. 6a is with the prototype counter, and Fig. 6b is with the current IH strip. The cross talk between strips is visibly larger in the prototype than in the current IH plane.

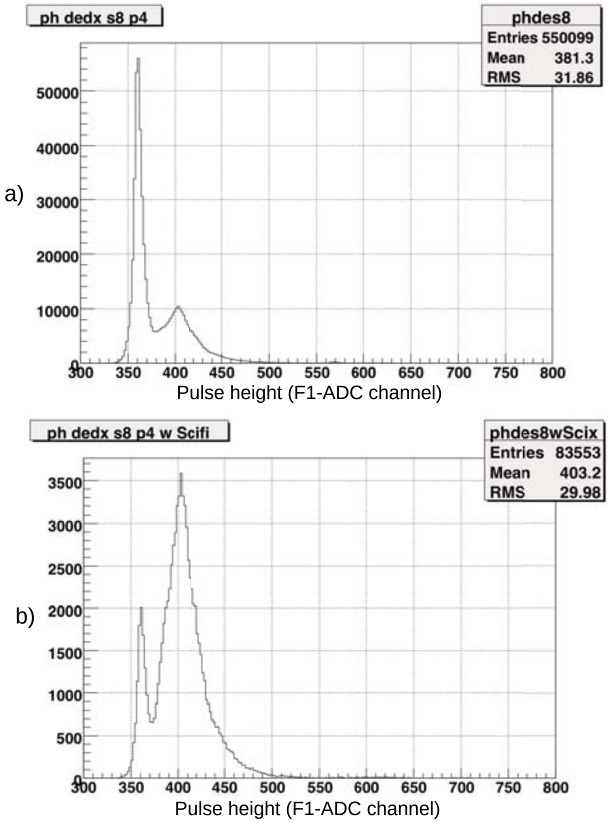


Fig. 3 Same as Fig. 2, but only events in coincidence with Scifi X (central 8 columns) are displayed.

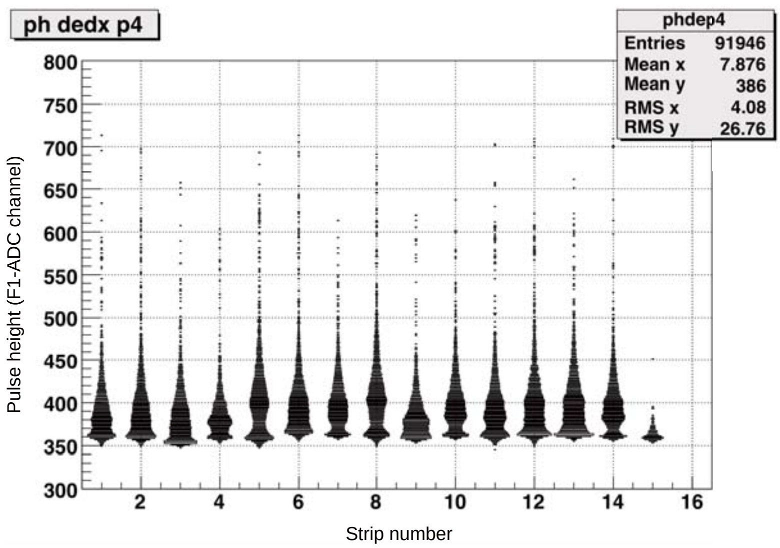


Fig. 4 The uniformity of the PH distribution among the strips of the prototype dE/dx counter

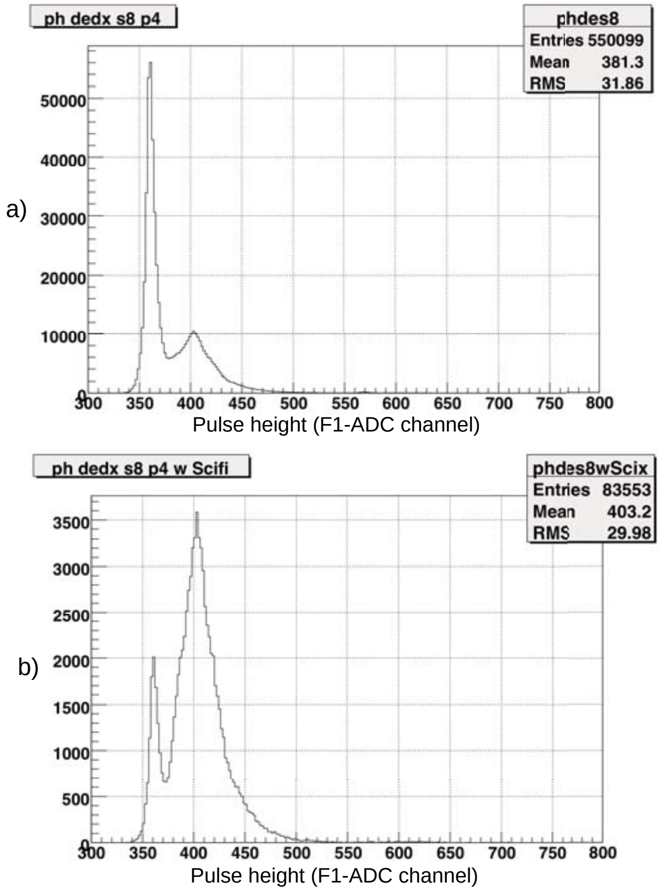


Fig. 5 a) Pulse-height distribution of the prototype dE/dx counter. b) Same, but events coincident with Scifi X (central 8 channels). Both at the minimum threshold.

The most important information needed is the average number of photoelectrons collected from the prototype. F1-TDC-ADC device does not show a pedestal peak, and thus it is difficult to evaluate the number of photoelectrons from the spectra. A separately provided information on the threshold of F1-TDC-ADC unit is not comprehensible (this gives the single photoelectron peak a negative PH), and as of now, it is not possible to deduce directly the average number of photoelectrons collected (and its variance).

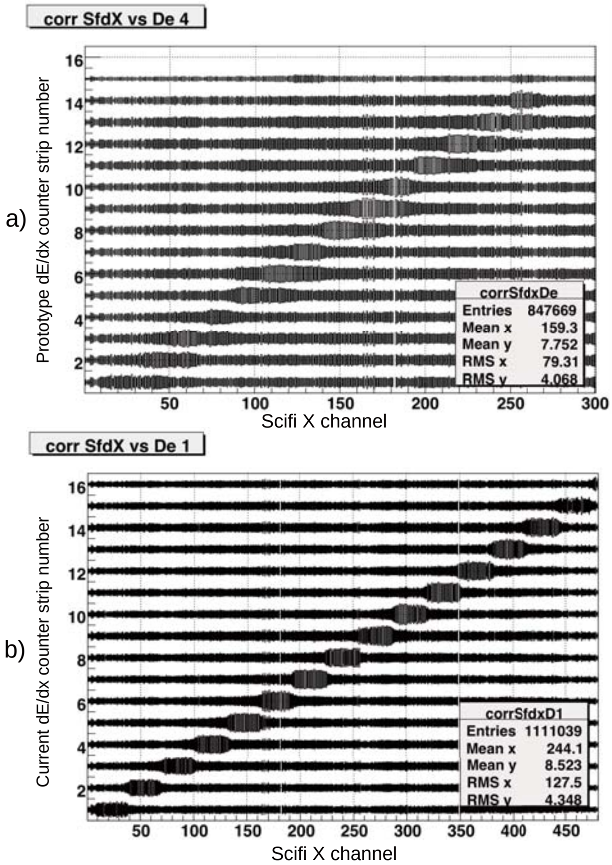


Fig. 6 a) Geometrical correlation of the prototype dE/dx counter and the Scifi X plane.
b) Geometrical correlation of the current IH and the Scifi X plane.

4. Timing

The trigger signal used accepts events at least one particle recorded in the backward DC in each arm. Further in this analysis, only events are used in which the successfully reconstructed track is only one in each arm. The trigger accepts in one event two reconstructed particles whose timings, t_{1VH} and t_{2VH} are different as much as 20 ns as shown in Fig. 7. Therefore the timings of the hits recorded by the dE/dx counter are also either those of t_{1VH} or t_{2VH}.

Fig. 8 shows the correlation of timings recorded by dE/dx counter and the time difference between t_{1VH} and t_{2VH}, namely t_{1VH} - t_{2VH}. When the hit on the dE/dx counter "belongs" to t_{1VH}, then the hits lie on the inclined straight line in this figure. On the contrary if the hit belongs to t_{2VH},

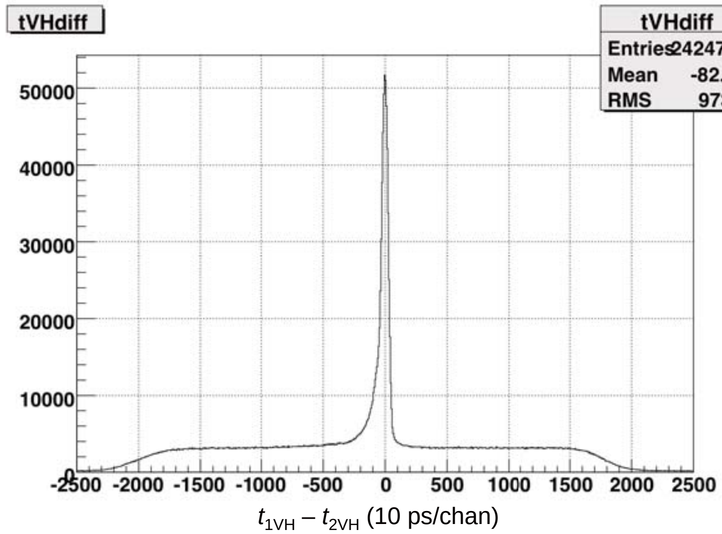


Fig. 7 The trigger accepts two reconstructed particles whose timings are different as much as 20 ns as shown in this figure. Therefore the timings of the hits recorded by the prototype dE/dx counter are either those of t_{1VH} or t_{2VH}.

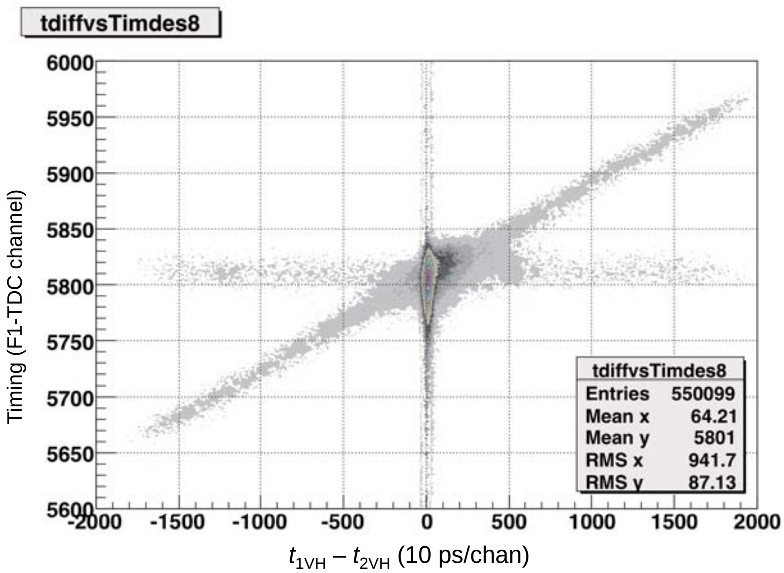
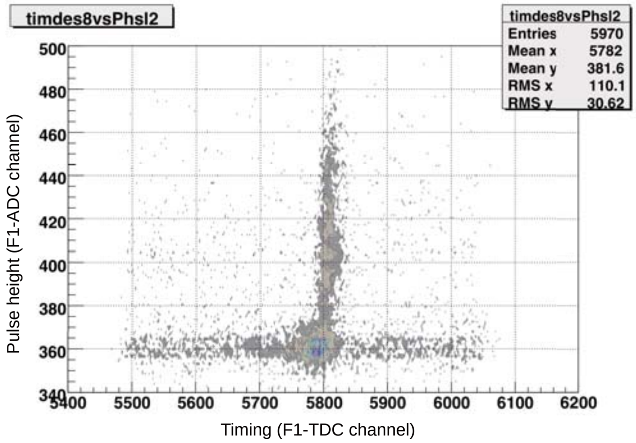


Fig. 8 Correlation of timings recorded by the prototype dE/dx counter and the time difference between t_{1VH} and t_{2VH}, namely t_{1VH} - t_{2VH}. When the hit on the prototype dE/dx counter belongs to t_{1VH}, the hits lie on the inclined straight line in this figure, whereas if the hit belongs to t_{2VH}, they are displayed on the horizontal line.

a)



b)

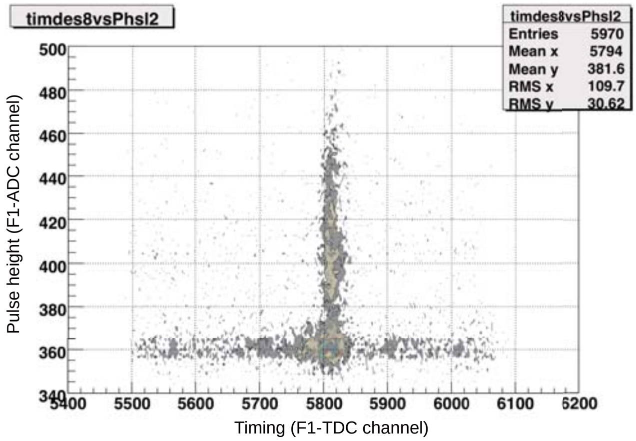


Fig. 9 Pulse-height dependence of the timing of the hits on the prototype dE/dx counter. a) There is a slight dependence of the timing on the pulse height namely the "walk effect". In b), the walk is corrected.

they are displayed on the horizontal line. To find out the timing resolution of the prototype dE/dx counter, one has to find out to which timing, the hit belongs to. This is not easy as the number of total events (statistics) is limited. Therefore in this analysis, events are selected in which t_{1VH} and t_{2VH} are very close (within ± 25 ps). We consider t_{1VH} and t_{2VH} are quasi-identical, and see the spread of the timing recorded by the prototype dE/dx counter with respect to the common t_{VH}.

For those events, the correlation between the timing of the dE/dx counter and the PH is displayed in Fig. 9a. There is a slight dependence of the timing on the pulse height namely the "walk effect". By taking advantage of the F1-TDC-ADC unit, this walk has been corrected by using the PH information of each hit as shown in Fig. 9b. The resulting time resolution is shown in Fig. 10. The timing resolution deduced from this figure by fitting the peak with a gaussian is 1.14 ns

RMS. By dropping events with small PH, the time resolution found becomes 1.12 ns. The time resolution found of the Scifi X plane was 522 ps. The number of photoelectrons collected in the Scifi X plane was about 12 in average (effective thickness is 1.9 mm). Thus if this time resolution of the prototype dE/dx counter is purely a statistical effect, then the average number of photoelectrons is ≃ 8.12. However, the time resolution of the Scifi X suffers from the non-uniformity of the effective thickness, (and also the absolute timing of the channels of Scifi X is not yet aligned), while the dE/dx strips are flat, and the thickness is constant. That means the number of photoelectrons collected in the prototype dE/dx counter is even smaller than 8.12. One has to take into account the fact that the quantum efficiency of the PSPM used in the prototype dE/dx counter is nearly 2 times larger than those used for the Scifi counters [1]. Therefore the design of the dE/dx counter should be reviewed so as to increase the number of photoelectrons collected.

Just as a reference, the time resolutions of the current dE/dx counter planes are also evaluated with the same method. It was 1.10 ns RMS for typical strip of the plane 1 (and 951 ps RMS when small PH events are dropped), thus was slightly better than the prototype.

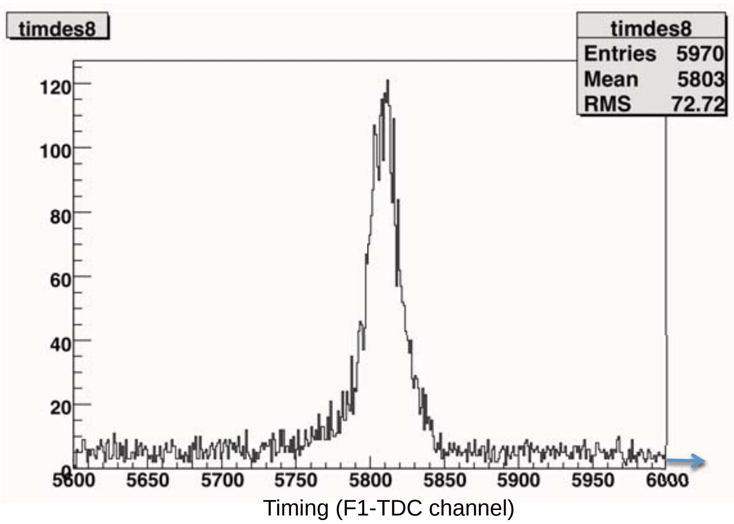


Fig. 10 By taking advantage of the F1-TDC-ADC unit, the "walk effect" has been corrected by using the PH information as shown in Fig. 9. The timing resolution deduced from this figure by fitting the peak with a gaussian is 1.14 ns RMS (112 ps/chan assumed). By dropping events with small PH, the time resolution found becomes 1.12 ns.

5. Efficiency

One has to go through a very sophisticated procedure to evaluate the absolute efficiency of the prototype counter, using other counters. It must be easier when the MicroDC starts working correctly. Thus, for the time being, we assume that the existence of the plateau in the counting rate as a function of the PH in a well defined area on a strip is interpreted as 100% efficiency.

To define the area on a strip, hit information from the Scifi X, Y and U planes are used. The timing of the hits on the prototype dE/dx counter and the Scifi planes are very well correlated, as shown in Fig. 11. Fig. 12 shows the geometrical correlation between hits on Scifi X plane and the prototype dE/dx strips. This histogram is therefore similar to the one shown in Fig. 6a, but in this display, the timing correlation between the prototype dE/dx and 3 planes of Scifi counter is also

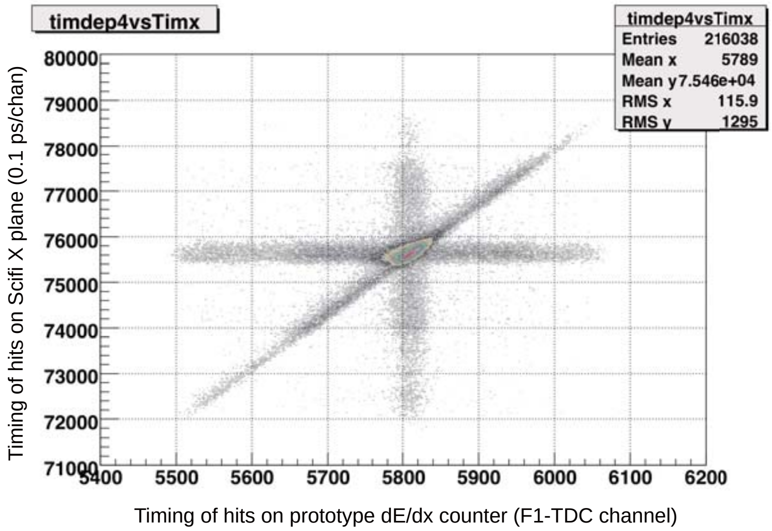


Fig. 11 Timing of hits on the prototype dE/dx counter vs. timing of hits on Scifi X plane. They are strongly correlated.

checked. We already discussed the cross talk (overlap) between the strips in conjunction with the light leak at the level of the photocathode. This seems to be reduced by the check of the timing correlation with Scifi X plane. But the cross talk effect can also be caused by the misalignment of the strips (obliqueness of the slabs). Fig. 13a shows the image made with Scifi X, Y and U planes of the strip 8 of the prototype dE/dx counter. In Fig. 13b, events with PH smaller than 380 (appropriate offline threshold - later shown) are dropped. The strip might be slightly oblique, but not much.

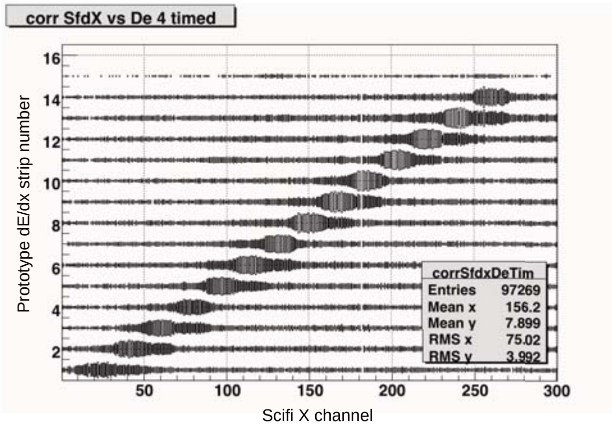


Fig. 12 Geometrical correlation between hits on Scifi X plane and the prototype dE/dx strips. The overlap between strips seems rather large. Only well-reconstructed hits are used in Scifi X（triplets）. The dE/dx events are with their hardware threshold.

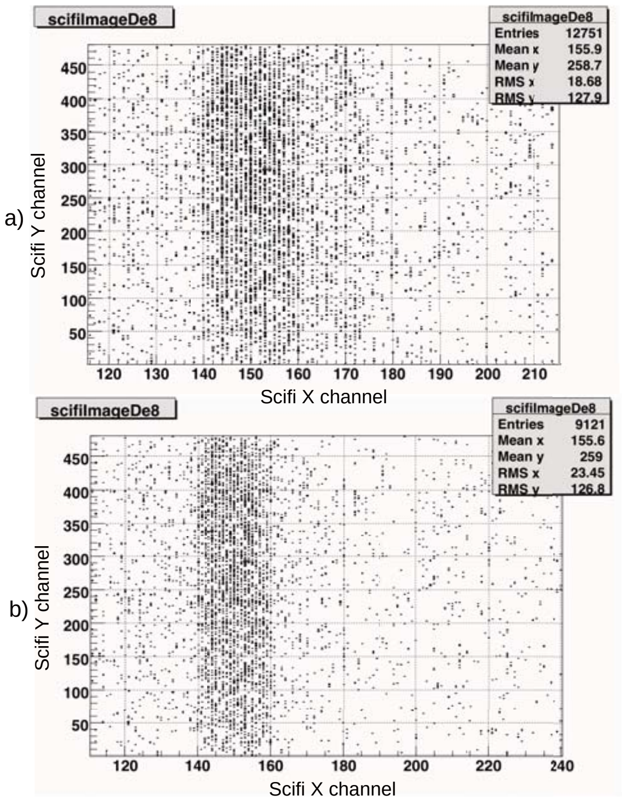


Fig. 13 a）Image of the typical dE/dx counter strip（strip 8）reconstructed with Scifi X, Y, and U planes. b）Events with PH of the prototype dE/dx counter smaller than 380 are dropped.

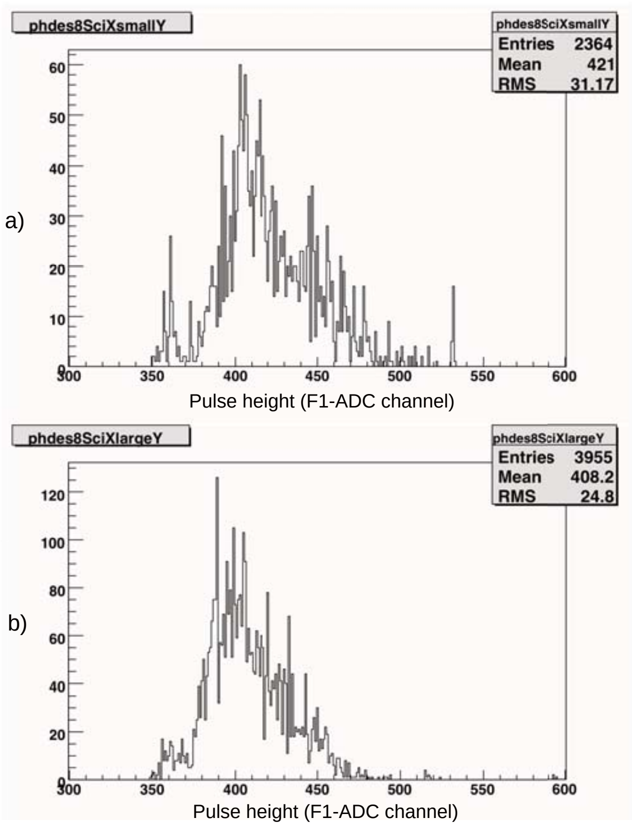


Fig. 14 Light attenuation effects in the prototype dE/dx strip（Y position dependence of PH）. a）PH distribution of the hits close to the PSPM（Chan 49-146 in Scifi Y）. b）PH distribution of the hits far from the PSPM（Chan 334-431 in Scifi Y）. The events have been selected using Scifi X, Y and U planes.

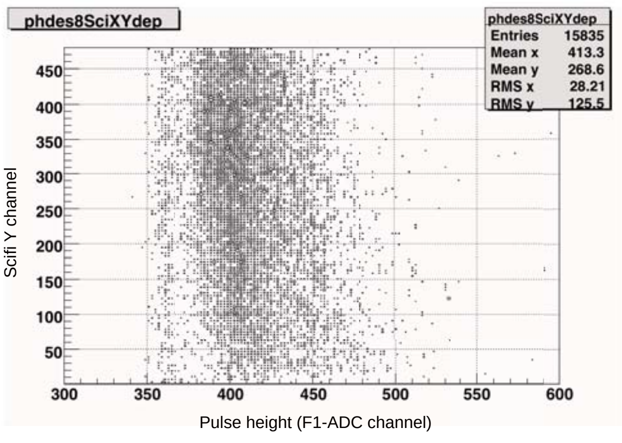


Fig. 15 Dependence of PH distribution in the prototype dE/dx counter on the Y position（Scifi Y channel）showing the light attenuation.

The efficiency is also influenced by the attenuation of the light within a strip along the length. If this is large, then it is impossible to apply an appropriate threshold to guarantee a good efficiency and to reject background. Fig. 14a is a PH distribution of the hits close to the PSPM. The events have been selected using Scifi X, Y and U planes. Fig. 14b is the same spectrum, but from the hits at the far end of the strip. It is clear that the attenuation is fairly large. Fig. 15 shows the same effect, but this time the PH distribution is plotted as a function of the hit position along the Y axis. Although the thickness of the light guide is nearly the same near the joint to the scintillator strip, a large end effect is visible.

Now the efficiency of the strips of the prototype dE/dx is evaluated on the area defined by the Scifi planes. The timing cut is also applied to the dE/dx events, but this time, a fairly broad time window such as from -2.5 to 1 ns on the difference t_{1VH} - t_{2VH} was applied. The number of hits in this geometrical area as a function of offline threshold is shown in Fig. 16. The red curve shows the variation of number of hits in the whole area. The blue and green curves are for the quarter in height of the strip near the light guide and far from it. In all three curves, a relatively clear plateau is observed at about 365 of PH. The three curves are normalized at this point, since the number of hits varies along the Y axis. From these curves, one should be able to temporarily conclude that

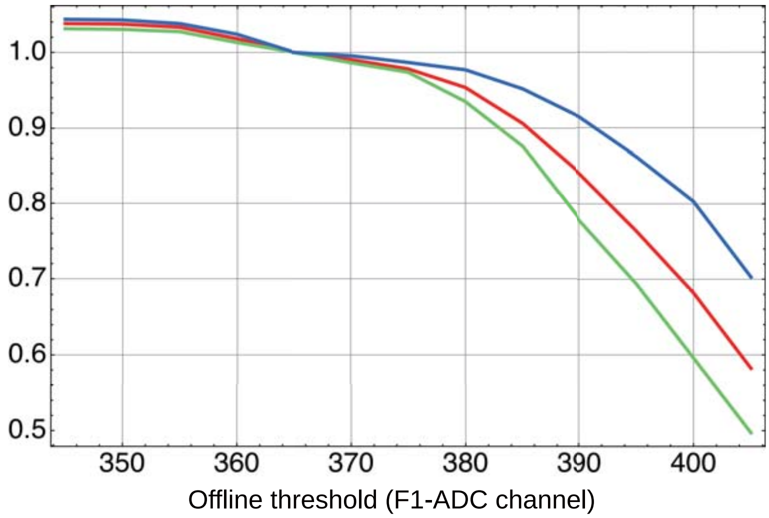


Fig. 16 The number of hits in a fixed area defined by Scifi X, Y, and U planes are shown as a function of offline threshold applied. The red curve shows the variation of number of hits in the whole area. The blue and green curves are for the 1/4 of the strip near the light guide and far from it. In all three curves, a relatively clear plateau is observed at about 365 of PH. As the number of tracks passing through the areas are different, the number of events are normalized at this PH. Events with timings –2.5 ns < t_{1VH} - t_{2VH} < 1 ns and correlated with the Scifi timing are chosen. Blue: Scifi Y channel 50 – 145, Red: 50 – 430, and Green: 335 - 430.

the efficiency is nearly 100% regardless of the Y position of the hits. Below Ph = 365, number of background events increases.

Once one knows the Y position of a hit, one can make a correction of the PH from the information either from other detectors, or a dE/dx counter strips running in the other direction. But when there are 2 hits apart, then this correction is no more possible. And especially the dE/dx counter is used for the distinction between single hit and double hits, it is desirable that the light attenuation be reduced more.

6. Construction

Figure 17 shows the number of hits recorded by the prototype dE/dx counter as a function of the column number of Scifi X plane, between column 200 and 300 of Scifi Y plane, vertically. The aim of this display is to see how much “gaps” we have between the strips. The reason why the events are selected with Scifi Y plane is that if the dE/dx strips are oblique, then the effect can be smeared out. Fig. 17 shows that the gaps are just visible for the first 10 strips, but for the last strips, the gap is very large. This demonstrates the difficulty in construction of the design. Fig. 18 shows the projection of the dE/dx strips to the Scifi plane. The obliqueness is not very visible. Many background events are probably due to the background tracks which are not parallel to the Z axis.

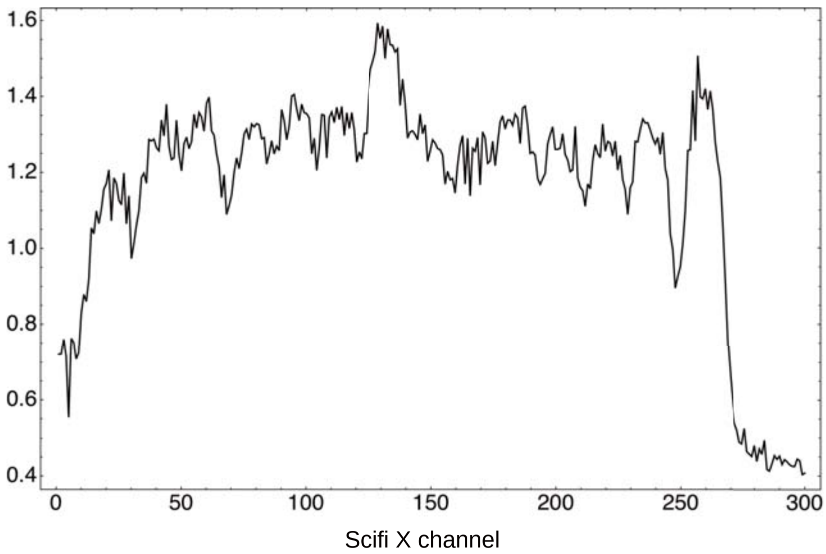


Fig. 17 To check if the gaps between strips of the prototype dE/dx counter are visible, number of hits recorded by the prototype dE/dx counter are displayed as a function of the column number of Scifi X plane. To be free from the obliqueness effect which might smear out the distribution, events are selected vertically using Scifi Y plane (channels between 200 and 300).

7. Conclusions

Pulse height

1. F1-TDC-ADC readout seems to give a correct PH information. It would be necessary to apply a little larger HV.
2. All meaningful hits produce PH larger than single photoelectron.
3. As the pedestal information is missing, it is difficult to evaluate the number of photoelectrons. A separately given information about the threshold does not give a right information.
4. The average number of photoelectrons is at most 8, deduced from the comparison with the time resolution of Scifi planes.

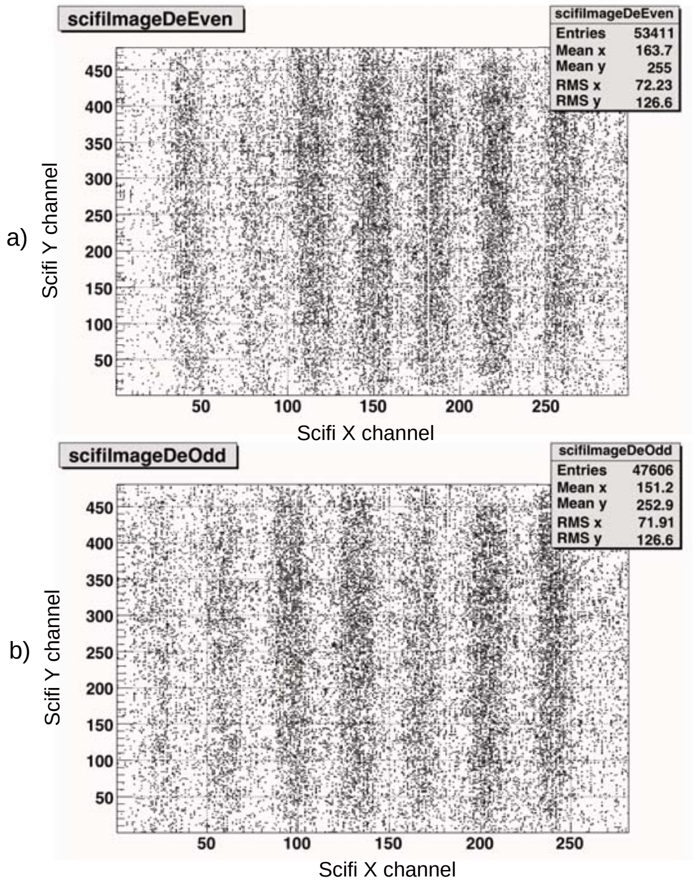


Fig. 18 Image of the prototype dE/dx strips projected to Scifi X, Y and U planes. The obliqueness is not very visible. Many background events are probably due to the background tracks which are not parallel to the Z axis. a) Even-number strips (1, 3, 5, etc.) b) Odd-number strips

5. The spread of the PH is slightly smaller than in current IH planes.
6. Near the hardware threshold, a lot of background events cause the inter-strip correlation. This might be the cross talk at the level of the photocathode of the PSPM. The mapping of the light guide might need a more careful adjustment.
7. A light attenuation along the strip is visible. It is large near the joint to the light guide. The design should be improved. Although it seems that the attenuation does not make the application of an offline threshold unique to a strip, it is desirable that this effect be improved for the specific application to the DIRAC experiment, where the distinction between single and double hits is important.

Timing

1. The timings of the hits on dE/dx and those on Scifi X are tightly correlated.
2. Using two-hit events whose VH timings are very close（tight cut）the time distribution peak was identified.
3. It is slightly PH dependent（walk effect）and it can be corrected using the PH information.
4. The timing obtained is 1.14 ns RMS in slab 8（typical）of the prototype dE/dx counter, not good.
5. The timing resolution of the current IH plane was 1.117 ns.
6. Compared to Scifi X whose timing resolution is 522 ps, the timing of dE/dx counter is not good. The reason is unclear.

Efficiency

1. The image of the prototype dE/dx strip can be clearly reconstructed using triplet hits on Scifi X, Y, U.
2. The light attenuation within a slab is noticeable.
3. Number of counts on the prototype dE/dx plane in a window defined by Scifi X, Y and U planes is calculated as a function of the PH.
4. It shows a kink at PH = 365, and also a plateau.
5. Efficiency is probably 100% at threshold = 365.
6. The threshold dependence of the counts is Y position dependent.

Construction

1. Gaps between strips of the prototype dE/dx plane are visible.
2. The distance between strips is 3.753 mm（at Z position of Scifi）.
3. The gaps are larger on the right-side strips.

4. Cross talk between strips seems fairly large.
5. This can be partially due to particles not perpendicular to the plane.
6. Obliqueness of the strips does not seem to be very large.

The largest open question is, how much beam intensity the new dE/dx plane can stand? We could not answer to this question in this study.

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