Scintillating Fiber Detector Background Study and Simulation

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Abstract

We present the results of the background study in the x- and y-planes of the scintillating fiber detector (SFD) and describe the method of separating the background into correlated and uncorrelated hits. The simulation based on these results was added to the existing PSC code. Overall simulated SFD performance is compared to the experimental one.

Separating Particles and Background

We begin by considering a "geometric window" defined roughly as a projection of the overlap area of two ionization hodoscope (IH) slabs in plane 1 and plane 2 onto the x-plane of the SFD (Fig. 1). An equivalent projection of two IH slabs in plane 3 and 4 onto the y-plane of the SFD is also considered.[1] Due to multiple scattering inside and prior to the SFD the window width is slightly larger than the IH overlap area and is found to be about 10 SFD channels (around 4.4 mm).[2]

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[1] For more details on the determination of the geometrical window size see [1].

[2] The geometrical window was analyzed for the old IH slab geometry, with a narrower slab width corresponding to narrower geometrical window for plane 1 and 2 relative to 3 and 4. The application of the same width to plane 3 and 4, therefore, represents a tighter cut on the allowed SFD hits leaving the results unaffected.
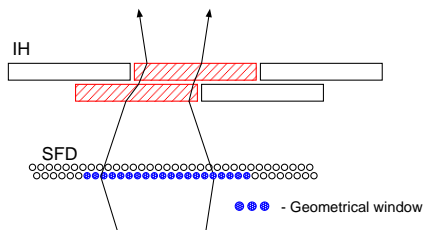
Fig. 1: Geometrical window definition.

In the first part of our analysis we look for a way to separate time-wise correlated hits from the uncorrelated ones. To this end we:

1. Select events with a singly ionized pair of overlapping IH slabs in plane 1 and 2 (plane 3 and 4).

2. Find a geometrical window in the x-plane (y-plane) of the SFD that corresponds to this overlap area.

3. Record the time differences between all the hits inside the geometrical window and each IH slab.

This analysis was performed on 2001 minimum bias ($VH1 \cdot IH$) data. Below (Fig. 2) we plot the time differences between the x-plane and planes 1 and 2 of the ionization hodoscope. The mean and the standard deviation of the Gaussian fits to the graphs give us the allowed time interval for the particle to travel between the two detectors. We call SFD hits inside the interval (set to 2σ) "time-correlated" and outside – "time-uncorrelated".

Out of the array of time-correlated (particle) hits we pick one, which we refer to as a "reference hit" (Fig. 3). (This selection is done randomly to avoid topological bias.) Subsequently, an essentially inverse procedure is performed: we look for another hit in the x-(y-)plane of the SFD, and, if one is located, IH slabs in the first (third) and the second (forth) plane directly across from it are examined. If timing in at least one of the IH slabs is within 2σ from the mean value obtained above (time-correlated signal) and the ADC signal in at least one of the IH slabs is higher than 70, the SFD hit is ascribed to a particle background. If none of the two slabs satisfy the above conditions, the hit is identified with uncorrelated background.

We are now able to plot the distances between the reference hit and the rest of the hits in the event along with the corresponding differences in time and classify them according to the background type (Fig. 4).

Qualitatively the two types of background are quite different. The uncorrelated background hit distance graph shows an approximately triangular background shape pointing to a uniform hit distribution, the conclusion
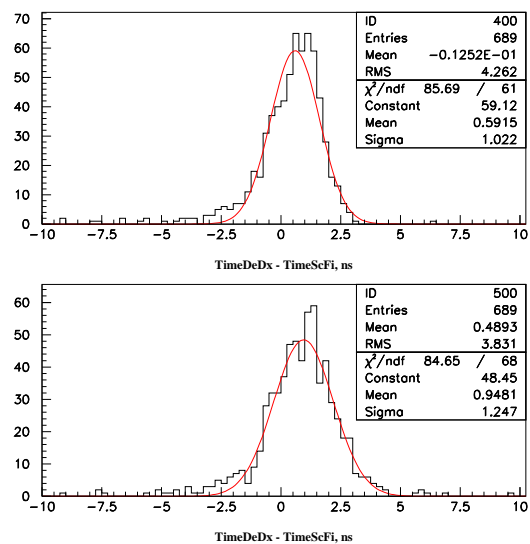
ID	400
Entries	689
Mean	−0.1252E−01
RMS	4.262
χ^2/ndf	85.69 / 61
Constant	59.12
Mean	0.5915
Sigma	1.022

TimeDeDx - TimeScFi, ns

ID	500
Entries	689
Mean	0.4893
RMS	3.831
χ^2/ndf	84.65 / 68
Constant	48.45
Mean	0.9481
Sigma	1.247

TimeDeDx - TimeScFi, ns

Fig. 2: Time correlations between x-plane of the SFD and plane 1 and 2.
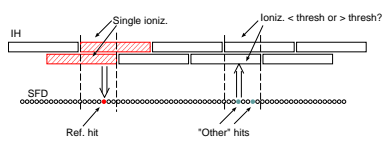

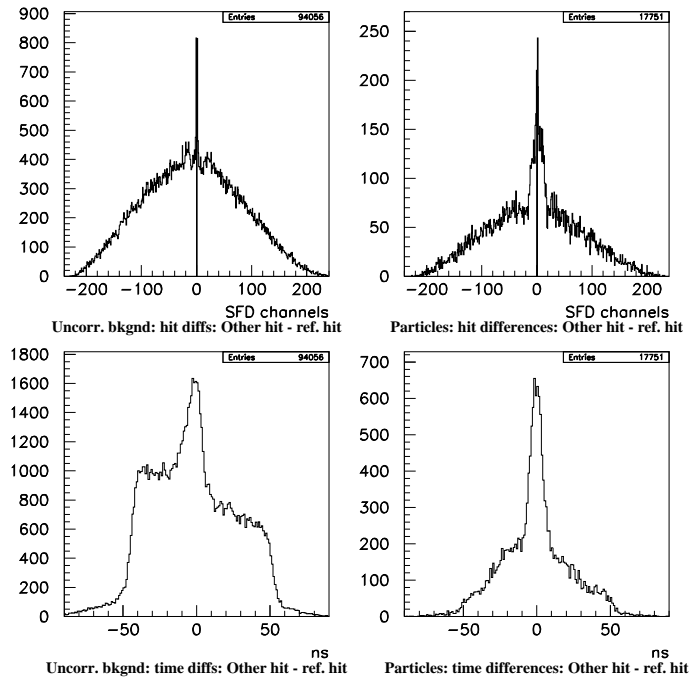Fig. 3: Separating correlated and uncorrelated background.

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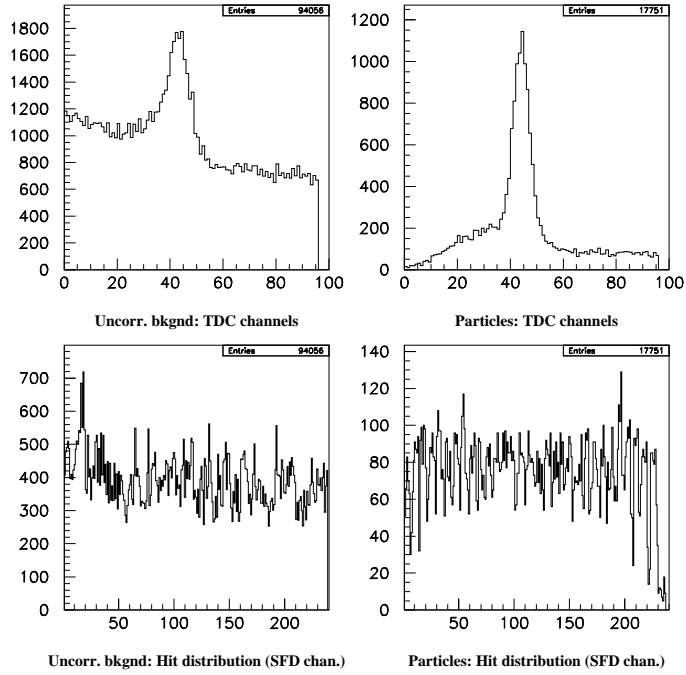Fig. 4: Time and hit differences for correlated and uncorrelated background.

Fig. 5: Time and hit distributions for correlated and uncorrelated background.

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supported by the hit map in Fig. 5. A very sharp peak on both sides of the reference hit gap for both the uncorrelated and correlated events corresponds to a single particle crossing two SFD channels, in addition to a certain amount of crosstalk. The presence of correlated particles contributes to a broad peak for the correlated events.

Simulating SFD Noise Response

The simulation takes as its input the hits corresponding to the generated particle tracks and the TDC signals provided by the output of the peak-sensing circuit (PSC) simulation. The algorithm for the simulation is outlined in the flow chart below (Fig. 6). The task of the background subroutine is to jitter the original TDC counts and provide additional background hits along with corresponding TDC signals in the x- and y-planes of the SFD based on the results above. The call to the background procedure can be turned on or off by setting BackgroundSimuMC to True or False in the FFreadInput cards (to be available in Ariane version 304_21).

Below we show an example of the typical PSC output in terms of multiplicity, hit and TDC distributions for accidental $\pi^+\pi^-$ events. If the background simulation is enabled, the subroutine begins by smearing the TDC signal based on the time jitter obtained from real data. Time jitter distribution was found by considering an SFD hit generated by a single e^+ track in the minimum bias ($VH1\cdot IH$) run (Fig. 8). It is obtained by subtracting the SFD TDC signal from the mean signal in the vertical hodoscope (taking into account VH's own jitter). The action of the simulation is to simply generate a jitter value for each hit and add it to the "unjittered" time provided by the PSC. This time is used in the subsequent background simulation.

The code is designed to detect whether the input event was generated by a single-particle or a double-particle (such as an atomic or a Coulomb pair) event. The single particle multiplicity for the x- and y-plane was found from the single (π^+) track minimum bias results. If a double track event, such as $\pi^+\pi^-$ pair, is detected, every multiplicity bin except 0, 1 and 2 are multiplied by a factor of 2. Following that, the background multiplicity (designated by M3 in Fig. 6) is generated as a result of subtraction of the PSC-generated multiplicity M1 from the overall multiplicity M2.

If M3 is less or equal to 0, the subroutine exits having executed only the time smearing. Otherwise, it proceeds to the next step of choosing whether the newly found hit is uncorrelated or correlated. The type of hit to be generated is determined by the probability ratio of uncorrelated hits to
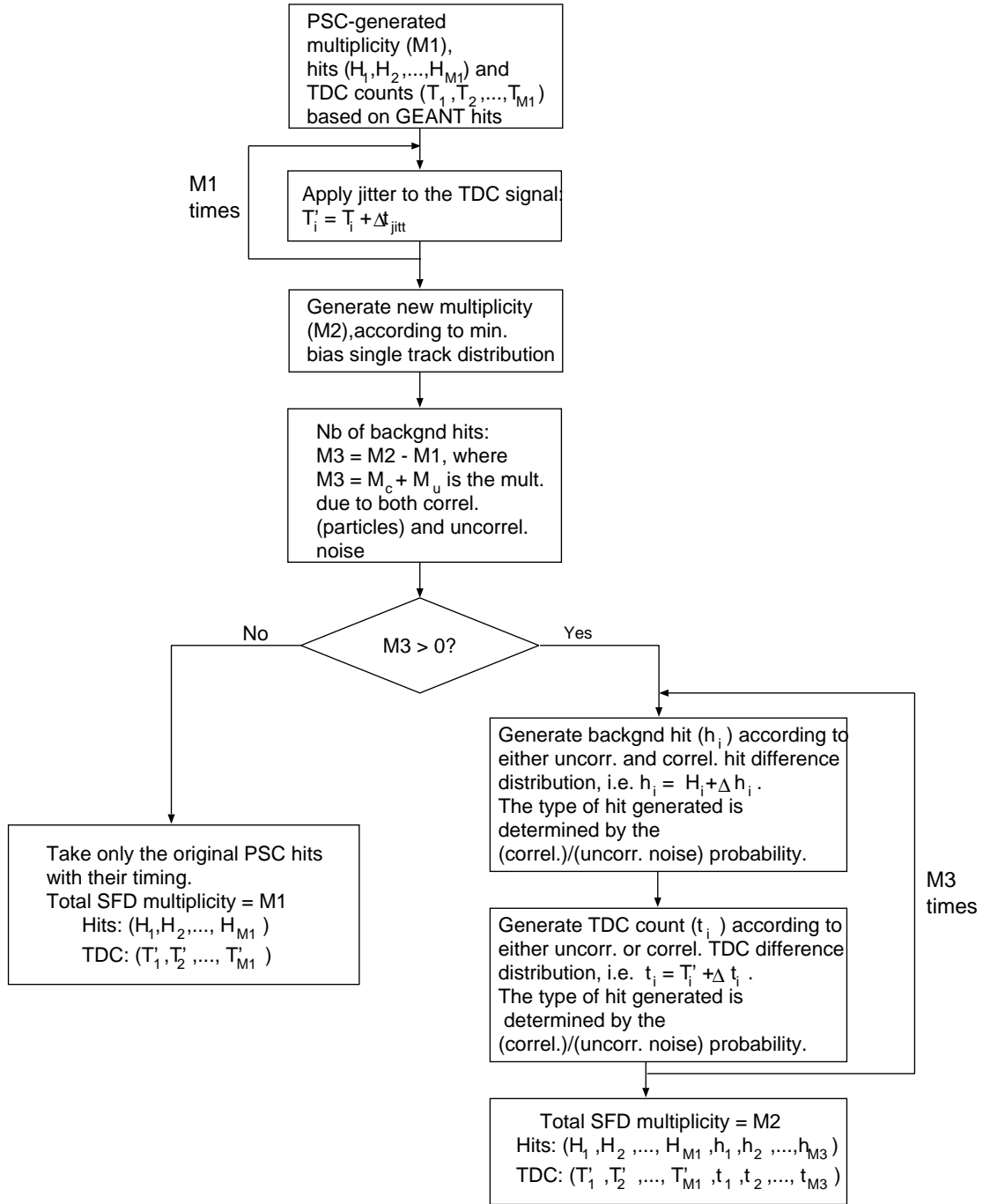
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PSC-generated
multiplicity (M1),
hits $(H_1, H_2, ..., H_{M1})$ and
TDC counts $(T_1, T_2, ..., T_{M1})$
based on GEANT hits

M1
times

Apply jitter to the TDC signal:
$T'_i = T_i + \Delta t_{jitt}$

Generate new multiplicity
(M2), according to min.
bias single track distribution

Nb of backgnd hits:
M3 = M2 - M1, where
$M3 = M_c + M_u$ is the mult.
due to both correl.
(particles) and uncorrel.
noise

M3 > 0?

No

Yes

Take only the original PSC hits
with their timing.
Total SFD multiplicity = M1
   Hits: $(H_1, H_2, ..., H_{M1})$
   TDC: $(T'_1, T'_2, ..., T'_{M1})$

Generate backgnd hit (h_i) according to
either uncorr. and correl. hit difference
distribution, i.e. $h_i = H_i + \Delta h_i$.
The type of hit generated is
determined by the
(correl.)/(uncorr. noise) probability.

Generate TDC count (t_i) according to
either uncorr. or correl. TDC difference
distribution, i.e. $t_i = T'_i + \Delta t_i$.
The type of hit generated is
 determined by the
(correl.)/(uncorr. noise) probability.

M3
times

Total SFD multiplicity = M2
   Hits: $(H_1, H_2, ..., H_{M1}, h_1, h_2, ..., h_{M3})$
   TDC: $(T'_1, T'_2, ..., T'_{M1}, t_1, t_2, ..., t_{M3})$
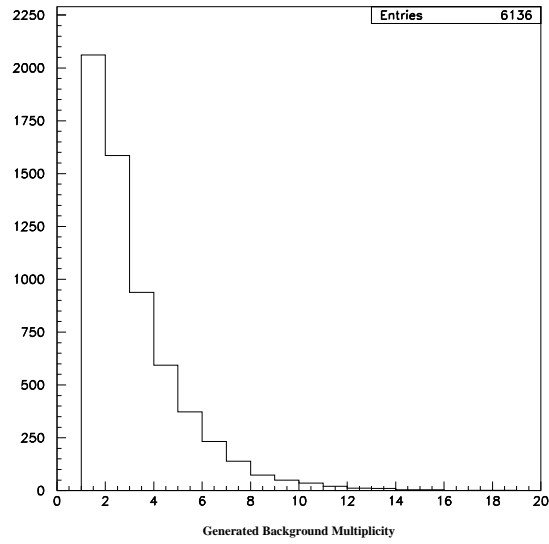
Fig. 6: SFD background simulation algorithm.

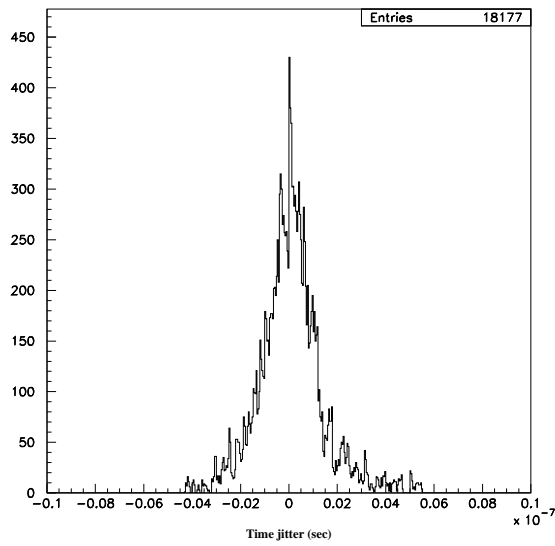Fig. 7: Generated background multiplicity.

Fig. 8: Generated jitter in SFD timing.

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particles (calculated from the ratio of the number of entries of both types). This ratio was determined to be roughly 3:2 for the x-plane and 3:4 for the y-plane of the SFD based on minimum bias data. Once the "choice is made", the subroutine produces the hit-PSC generated hit difference based on the distributions in Fig. 4. If several PSC hits are present, only one hit is selected at random.

Analogous procedure is used to find the associated TDC information. Since it is already known whether the hit comes from the correlated or uncorrelated noise, the only remaining step is to generate a relevant TDC count difference (based on Fig. 4), from which the TDC count is found.

In the final step the generated background multiplicity, hit channel numbers and the timing information are passed back to the calling subroutine.

Comparison of the simulation and experimental results

Below we compare the results of the simulated performance of the SFD for generated and real data pion pair events. Real data events came from the $T1\pi^+\pi^-$-coplanarity run with no imposed cuts. The generated events were obtained from the same run, with the input file containing lab momenta and time differences between two pion tracks. This input was run through GEANT and, finally, processed by Ariane.[3]

In Fig. 9-12 we plot multiplicities, hit maps and timing for both sets of data. These plots show a good overall agreement between both types of data. Normalized multiplicity distributions differ only by a few percent for multiplicities higher than 2 and are close to within one percent for multiplicities higher than 2. Some differences may also be observed in the shape of y-plane distributions and the timing. However, we find that the slight deviations from the real-life SFD response does not have any adverse effect on the quality of the track reconstruction.

In Fig. 13 we compare relative momentum distributions for accidental events (-15 to -5 ns VH time difference) from the $T1\pi^+\pi^-$-coplanarity run and the generated accidentals (input file contained lab momenta and timing for the accidentals in the -15 to -5 ns time interval). Evidently, we are able to reproduce the desirable flatness of the ratios of the relative momenta of the accidental pairs (except for a slight enhancement in the low Q region of the

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[3]We used 'PrshMuFinder' subroutine to reduce the muon background and thresholds of 62 ADC channels in the positive arm and 75 in the negative to reduce the e^+e^- background.

y-distribution attributable, perhaps, to the differences between artificially generated accidentals and real data).

Influence of the background on the Q reconstruction

Finally, we used our simulation to investigate the effect of background on the relative momentum reconstruction of atomic, coulomb and accidental pairs. We use generated pionium and coulomb pairs (both input files provided by Cibrán Santamarina) and accidental pairs (input file containing lab momenta and time differences between the two pion tracks was produced from the accidentals in the -15 to -5 ns time interval in the $T1\pi^+\pi^-$-coplanarity run) and compare the Q-distributions with and without background (with only PSC active) (Fig. 14-17). The ratios of the distributions are flat in the low momentum region (from -2 to 2 MeV), with background contribution evident in longer tails, which are due to mismatched track-hit assignments. We conclude that:

1. Adding background does not reduce the efficiency of the reconstruction. All the events simulated without the background are also reconstructed when the background is added.

2. As is evident from the ratios of the relative momenta with and without background, relative momenta distributions are minimally distorted by the added background. To make the difference more quantitative, one can also plot the differences per event between the Q's with and without the added background (Fig. 15). The deviations from the background-free values are all of the order of only a few tens of keV, and which, taking into account the comparable resolution of the SFD, are compatible with zero.

Conclusions

Correlated and uncorrelated background in the SFD was analyzed. The results of the analysis were used in constructing the background simulation for the SFD. With the background simulation active, we compared its output (multiplicity, hit map and timing) to the real data. Relative momenta reconstruction was tested on the accidentals for both types of data. The response of the simulation was found to be in good agreement with experimental

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results. By considering atomic pair events with and without background we found that the influence of the background on the Q reconstruction is minimal.
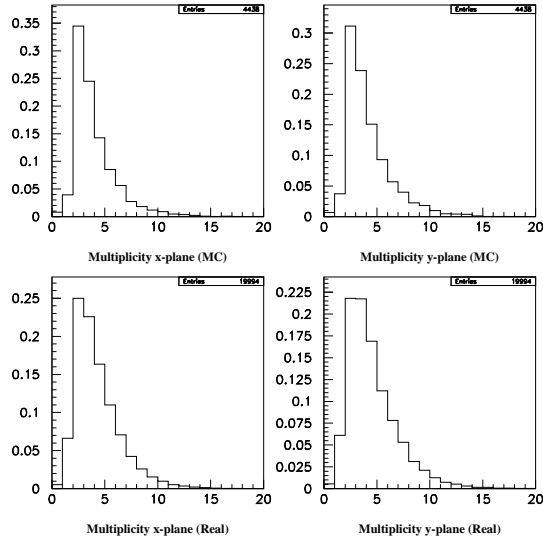
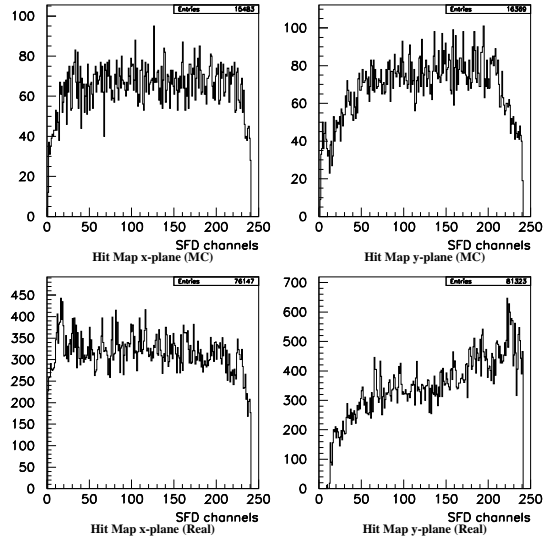Fig. 9: Multiplicities, normalized to 1 (top: Monte Carlo events, bottom: real data).

Fig. 10: Hit maps (top: Monte Carlo events, bottom: real data).

References

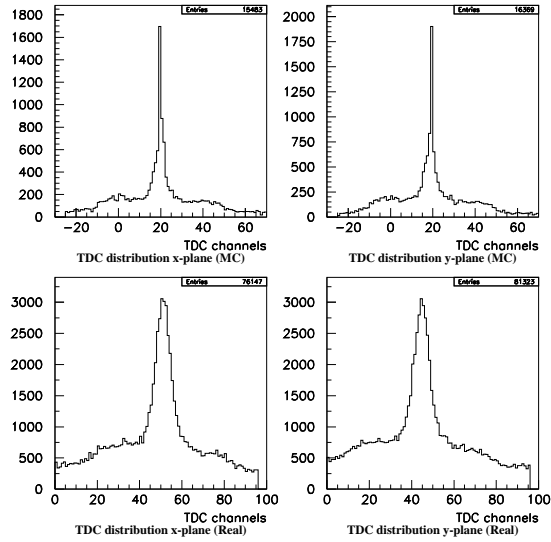[1] *DIRAC NOTE-03-02*: Scintillating Fiber Detector Efficiency Study, D.Goldin [Basel], L.Tauscher [Basel]

Fig. 11: TDC signals (top: Monte Carlo events, bottom: real data). Note that the real data signals are shifted relative to the simulation due to delays in electronics.
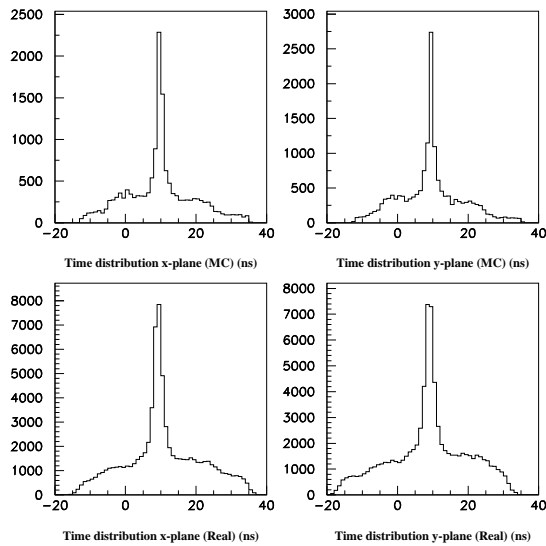
Fig. 12: Timing (top: Monte Carlo events, bottom: real data).
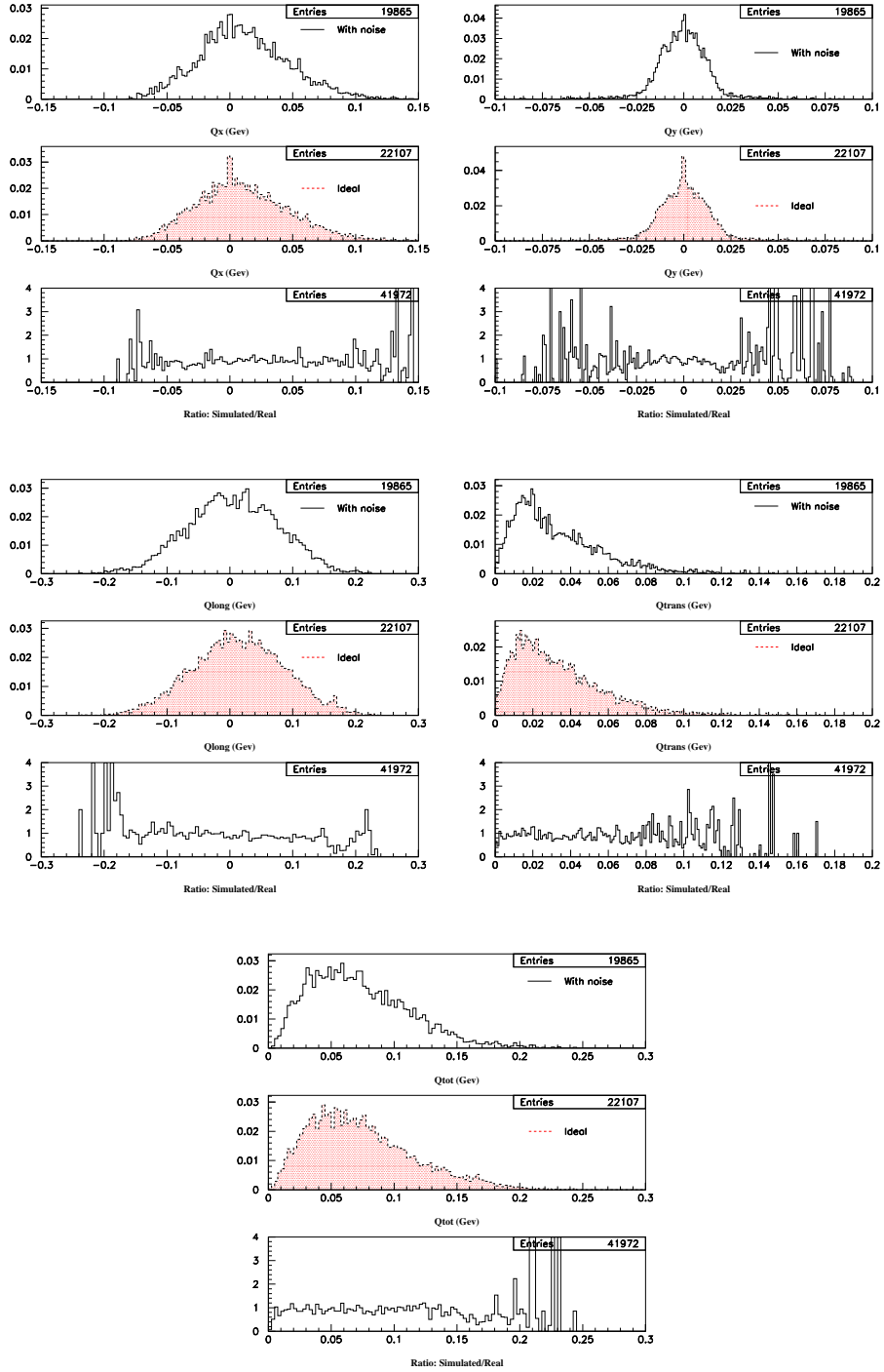
Fig. 13: Relative momenta for simulated and real accidental $\pi^+\pi^-$ pairs with their corresponding ratios. The flatness of the ratios indicate that the SFD simulation is working correctly.
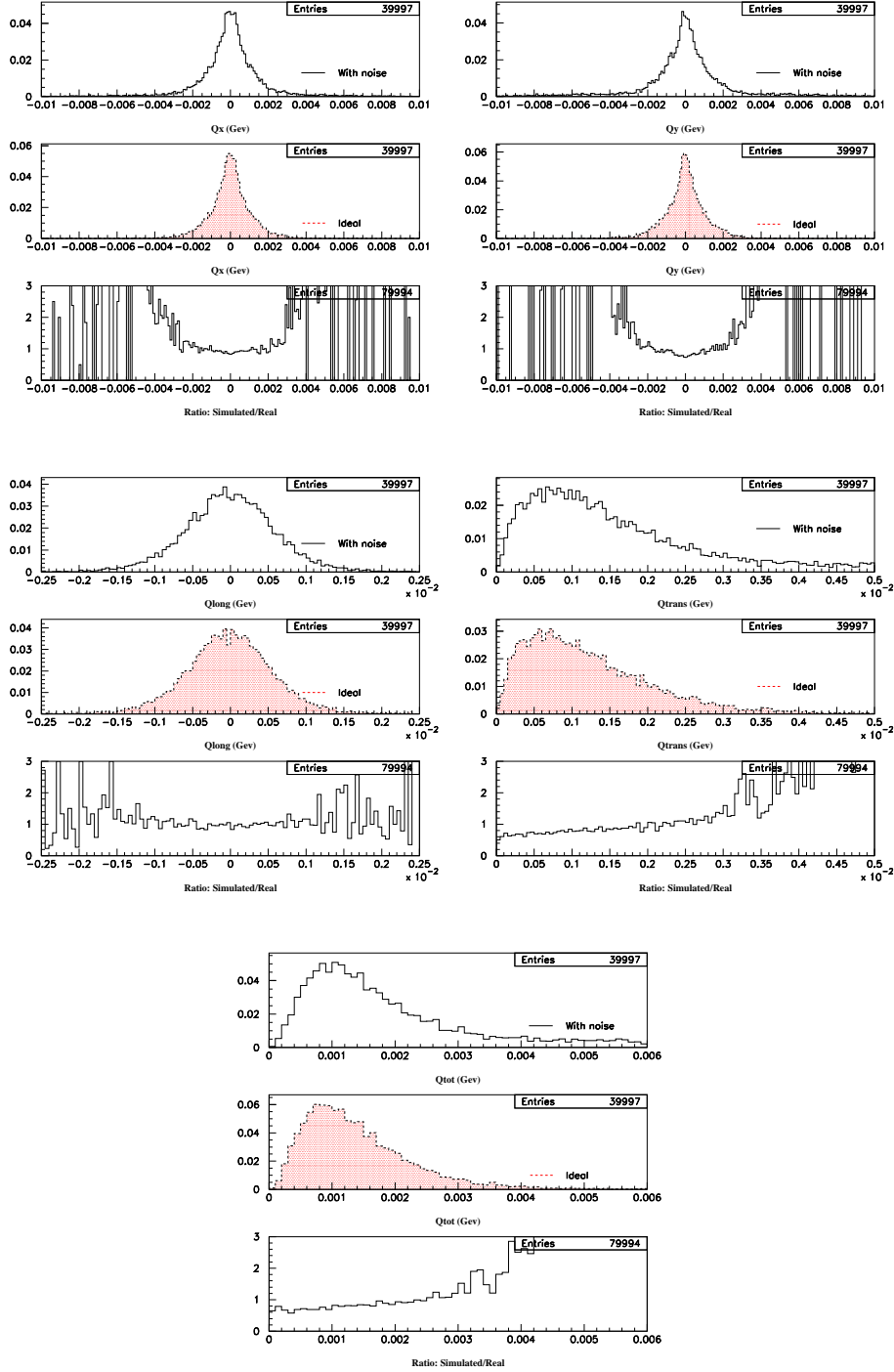
Fig. 14: Relative momenta of atomic pairs and ratios with and without the SFD background. The ratios are flat and the original number of events is preserved with the background on.
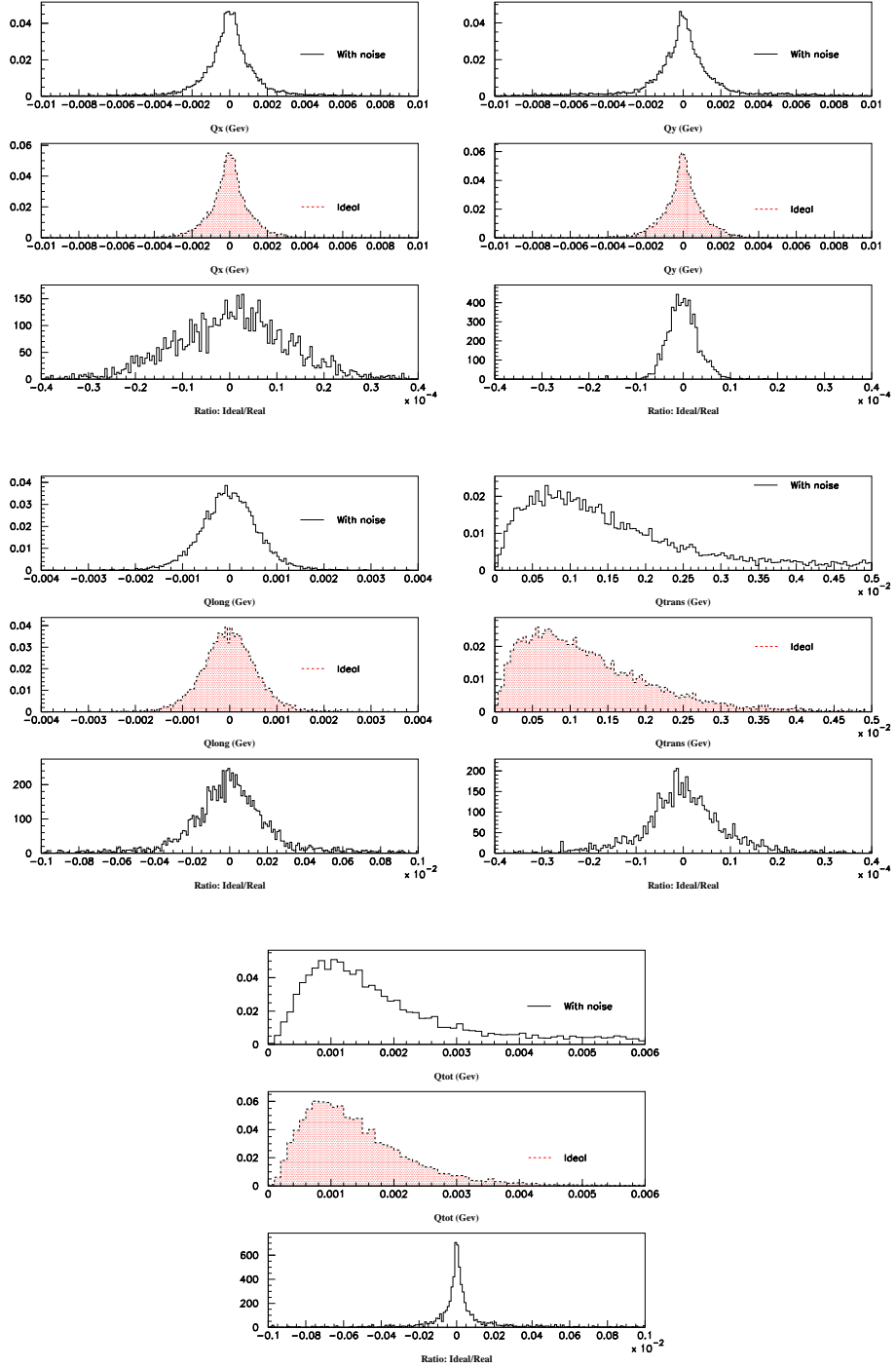
Fig. 15: The deviations of the relative momenta per event with background included relative to the background-free values are small ($A_{2\pi}$ sample).
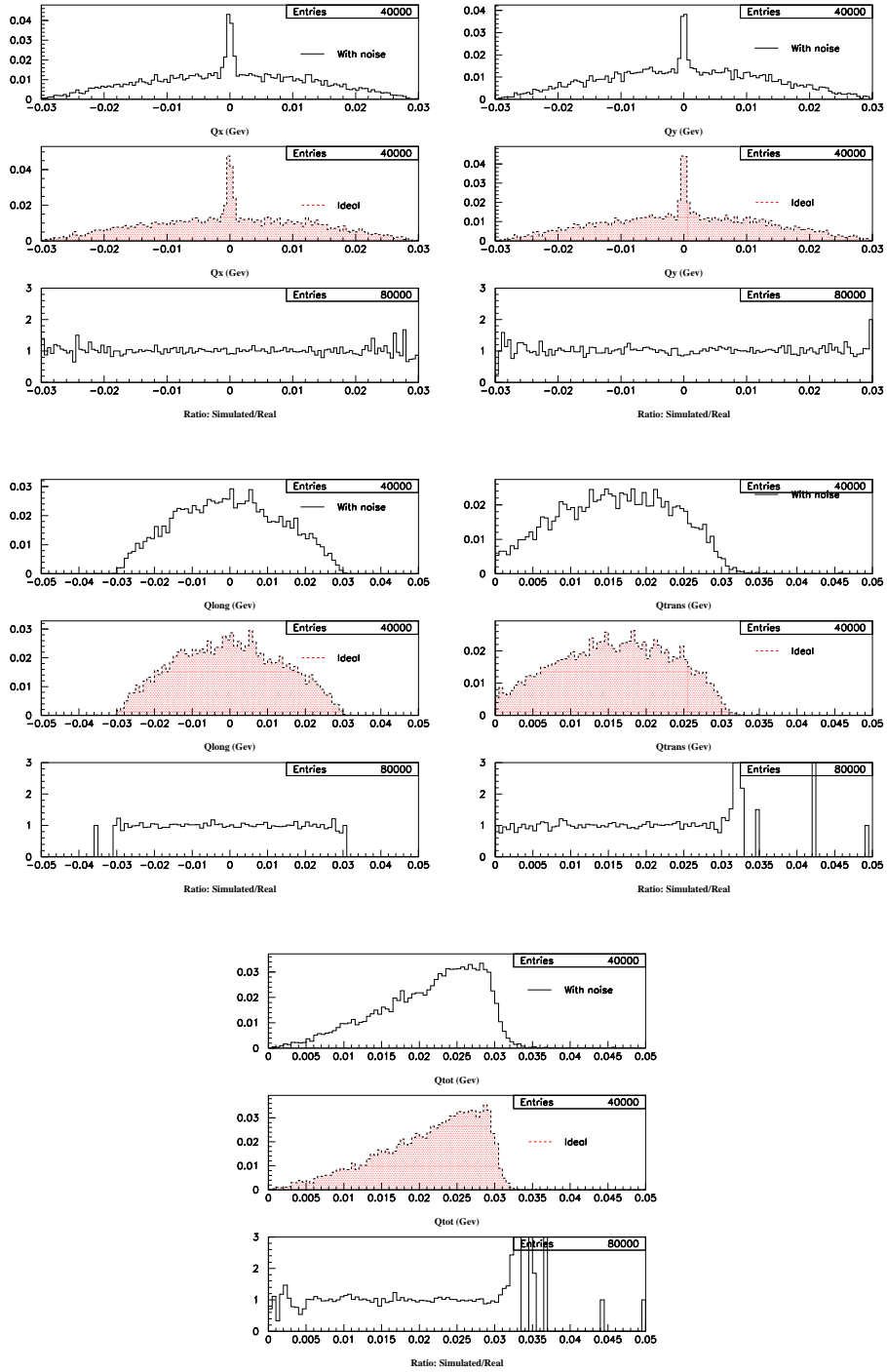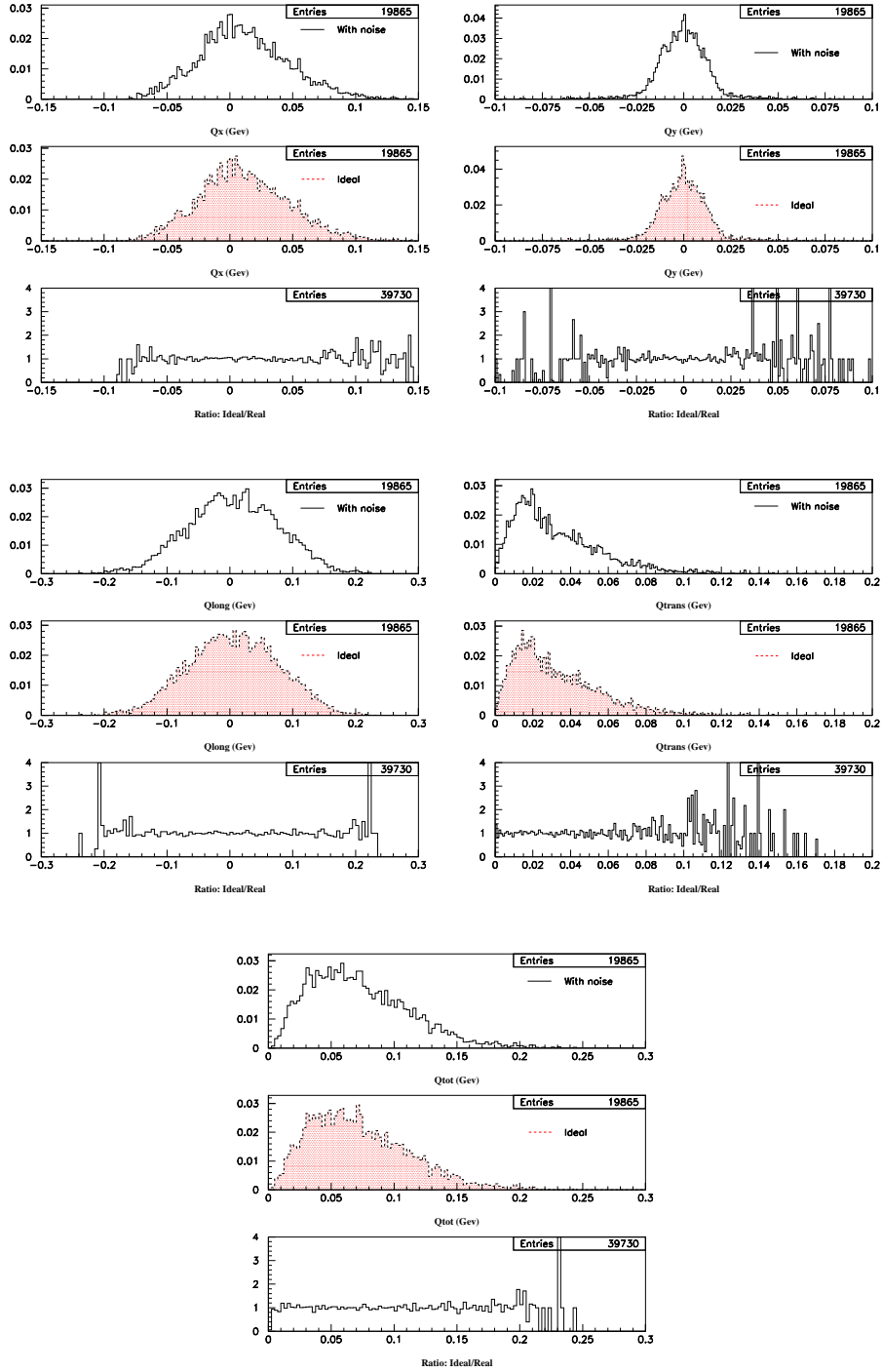
Fig. 16: Coulomb pairs with and without background.

Fig. 17: Accidentals with and without background.