DEAR Technical Note IR-10

Analysis of the background measurements in the DEAR-pit

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With the 2CCD setup as described in Ref.[1] we have continued data taking in the pit up to the shut down of the DAΦNE-accelerator. On the 9th of November we have moved the 2CCD setup to a new position (Position 2) which is shifted to the direction of the incoming positron beam. Position 1 (all the measurements described in Ref. [1]) was located closer to the incoming electron beam. Position 1 and 2 are symmetric to each other with respect to the central quadrupole of the day-one DAΦNE interaction regions. The distance from the beam pipe was about 60 cm. The measurements lasted till the 24th of November. We have observed X rays (single pixel hits) and clusters (multi pixel hits) on the CCD detector. We looked especially at the behaviour of the mean cluster size and the individual cluster sizes with and without beam.

After shutdown of the accelerator we moved the setup to the floor of the pit. So the CCDs were located ~130 cm above the floor, ~100 cm away from the nearest wall, 3 days of data taking. Then we transferred the setup to the DEAR laboratory.

We compared the natural background measured in the pit and on the bottom of the pit with the one measured in the DEAR-lab with the identical setup.

1. Experimental results for "non-machine" background

We have analysed CCD-exposures of 10 minutes taken between electron and positron runs (Run# T5265 - T5270 / corresponding to 1 hour of data taking) and of 30 minutes each taken after the final shutdown of the accelerator (Run# T6366 - T6390 / 4h 10min). The CCD occupancy during these runs were around 1% or less.

1.1.a) Between beams

Run# T5265 - T5270, corresponding to only 1 hour of data-taking, therefore only poor statistics could be obtained.

- we have observed 440 ± 10 clusters/hour/half-CCD
- we have observed a ratio
  total # of clusters/ total # of X rays in the range (2-18keV) = 53 ± 9
- 2.15 ± 0.95 X rays/hour/CCD/keV in the region of interest

1.1.b) After shutdown

Run# T6366 - T6390, corresponding to 4h10min of data taking.

- we have observed 298 ± 5 clusters/hour/half-CCD
- we have observed a ratio
  total # of clusters/ total # of X rays in the range (2-18keV) = 35 ± 3

To account the total number of X rays in the region of interest, all runs (Runs # T6366 - T6417, corresponding to 8h 40min) have been analysed with the result

- 1.10 ± 0.25 X rays/hour/CCD/keV in the region of interest in Position 2.

1.1.c) Final average value of the non-machine background in DAΦNE

We can compare the value obtained in Position 2 now with the measurement done in Position 1 [1]) where 0.85 + 0.07 X rays/hour/CCD/keV were measured.
The weighted mean of the two measurements is calculated to be

0.87 ± 0.07 X rays/hour/CCD/keV in the region of interest.

1.1.d) On the bottom of the pit

We have also repeated the background measurement on the bottom of the pit. The aim of this was to see an eventual solid angle effect which might be interpreted as the existence of natural radioactivity from below. There we have observed (Run # T6470 - T6479, corresponding to 5 hours).

- 239 ± 20 clusters/ hour/ half-CCD
- a ratio total # of clusters / total # of X rays in the range (2-18keV) = 49 ± 10.

and in total (Run # T6436 - T6564, corresponding to 64.5 hours) we have seen

- 0.84 ± 0.09 X rays/hour/CCD/keV in the region of interest on the bottom of the pit.

1.2.a) In the DEAR laboratory

Finally we measured the background with the identical setup in the DEAR-laboratory - CCDs facing eastwards, approximately 2 m from the wall - (runs # T10400 - T10536/ 30 min runs / 66.5 hours). We have observed

- 458 ± 50 clusters/ hour / half-CCD
- a ratio total # of clusters / total # of X rays in the range (2-18keV) = 40 ± 10
- **2.13 ± 0.12 X rays/hour/CCD/keV.**

1.2.b) In the DEAR laboratory - rotated position

Rotating the setup in the laboratory by 90 degrees - the CCDs facing the big door, approximately 50 cm from the door - gave a small change in the x-ray rate (run # T10550-10681 / 66 hours). We have observed

- 466 ± 50 clusters/ hour / half-CCD
- a ratio total # of clusters / total # of X rays in the range (2-18keV) = 40 ± 10
- **1.89 ± 0.11 X rays/hour/CCD/keV.**

1.3 Conclusions on non-machine background measurements in the DAΦNE hall and in the DEAR laboratory

1. No position dependence has been found for the non-machine background in the DEAR interaction region, as expected.
2. In between beams, a slight activation of the accelerator materials might be the reason for higher values of clusters and X rays.
3. For X rays in the region of interest, the non-beam background measured in the pit is almost a factor of 2.5 lower than the one measured in the DEAR-laboratory. Moreover we observed 1.5 times more clusters in the laboratory than in the pit. This is most likely due to the shielding of the concrete floor and roof of the DAΦNE hall.

2. Experimental results of machine background measurements with the 2CCD setup in Position 2 (nearer to the positron beam)

2.1 X rays and clusters (for different currents and beams)

The beam conditions in this period of data taking were quite unstable and the beam lifetimes relatively short. Therefore we could not observe many clear electron or positron beam background data. For this analysis we did not use periods with colliding beams. In the following we briefly discuss the obtained "good " data.

2.1.a) Positron beam on November 15

A pure positron beam starting with ~95 mA could be observed over a period lasting for more than 4 hours (Data Run# T5282 - T5306). This was the longest "pure" beam during this period. In figure 1 we display the beam current as it is given by the DAΦNE beam monitor. Figure 2 shows the total number of clusters recorded during this period in runs of 10 minutes each. Figure 3 displays the time dependence of the total number of X rays (X rays between channel 50 and 950) and the ratio of total number of clusters versus total number of X rays in the same time period as the regarded positron beam.

As we have already seen in Ref. [1], the time dependence of the observed number of clusters reflects nicely the time dependence of the circulating beam current. This can, with less accuracy, also be reported for the total number of X rays.

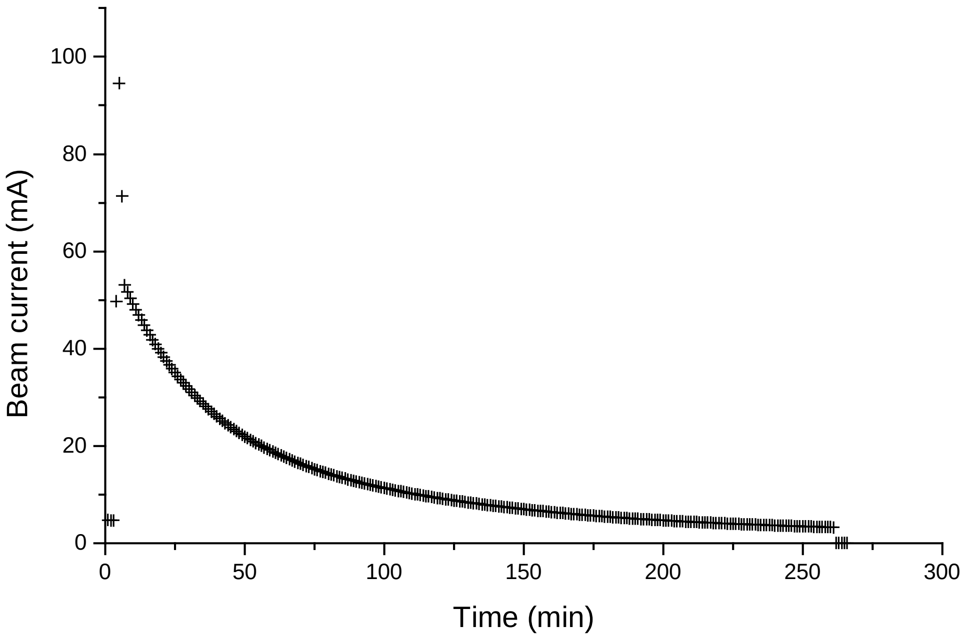


Fig.1: Time dependence of the positron beam intensity (beam current in [mA] as reported by the DAΦNE staff) on November 15, from 4:16 to 8:42 am.

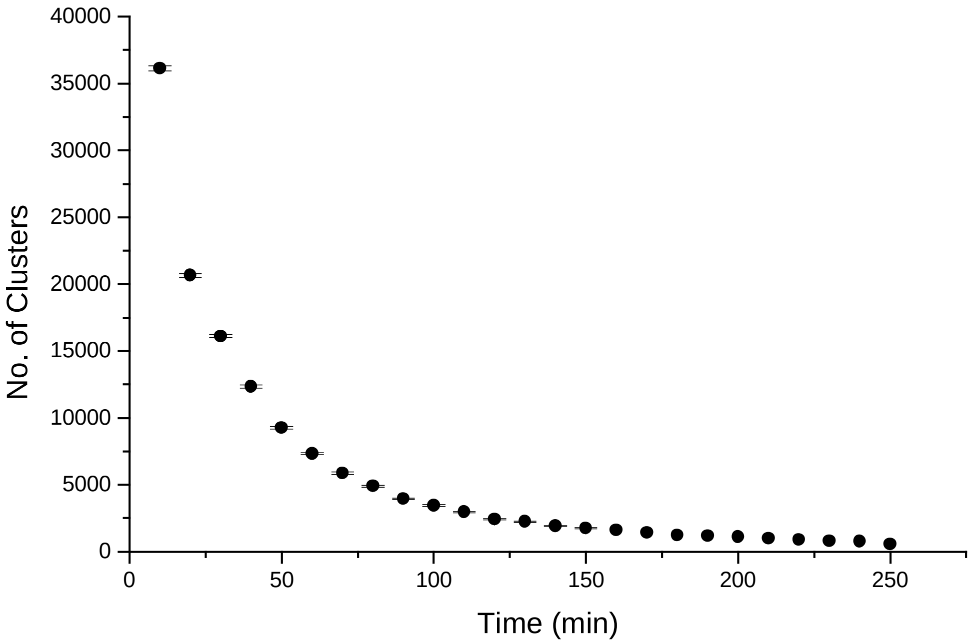


Fig.2: Time dependence of the total number of clusters recorded in runs of 10 minutes on November 15, from 4:16 to 8:42 am.

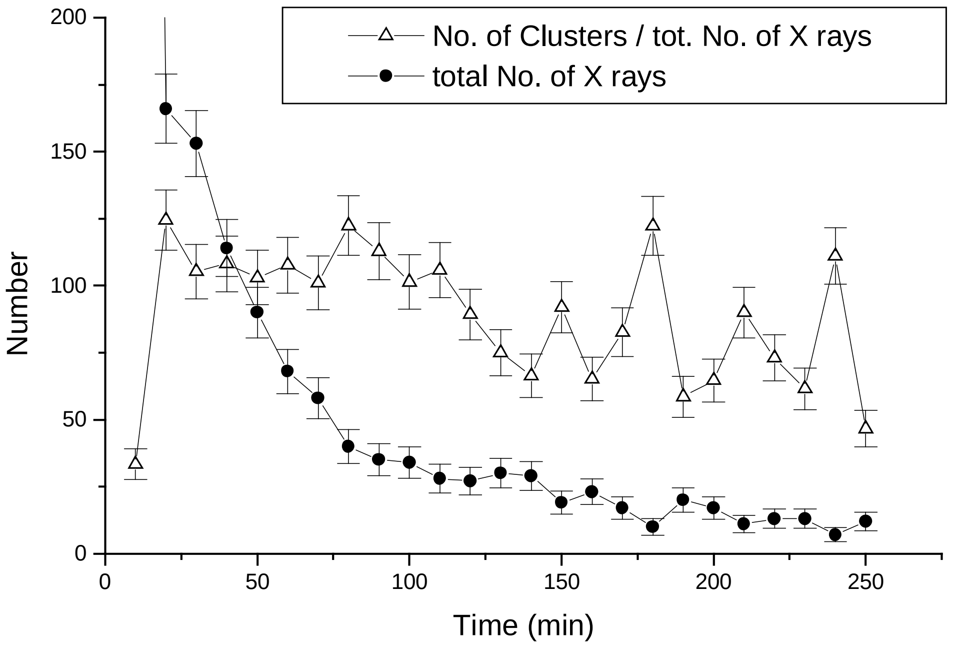


Fig.3: Time dependence of the total number of X rays (channels 50 - 950) and the ratio – number of clusters / total number of X rays in the range (2-18keV) – on November 15, from 4:16 to 8:42 am.

However, the ratio of these two numbers (No. of clusters / total No. of X rays) seems not to depend directly on the intensity of the circulating beam, although we could observe a huge number of X rays at the time of beam injection (this peak is out of scale in figure 3, its value is given as tot. No. of X rays (at t=10) = 1086). We interpret this observation as a huge loss of positrons just after beam injection.

Regarding the time after this initial peak we can give a mean value of the

- total # of clusters / total # of X rays in the range (2-18keV) = 102 ± 10.

In this period we observe an X-ray background of

- 8.5 ± 1.0 X rays/hour/CCD/keV in the region of interest.

2.1.b) Positron beam on November 20

A pure positron beam starting with ~24 mA could be observed over a period lasting for ~3 hours (Data Run# T5910 - T5925). In figure 4 we display the beam current as it is given by the DAΦNE beam monitor. Figure 5 shows the total number of clusters recorded during this period in runs of 10 minutes each.

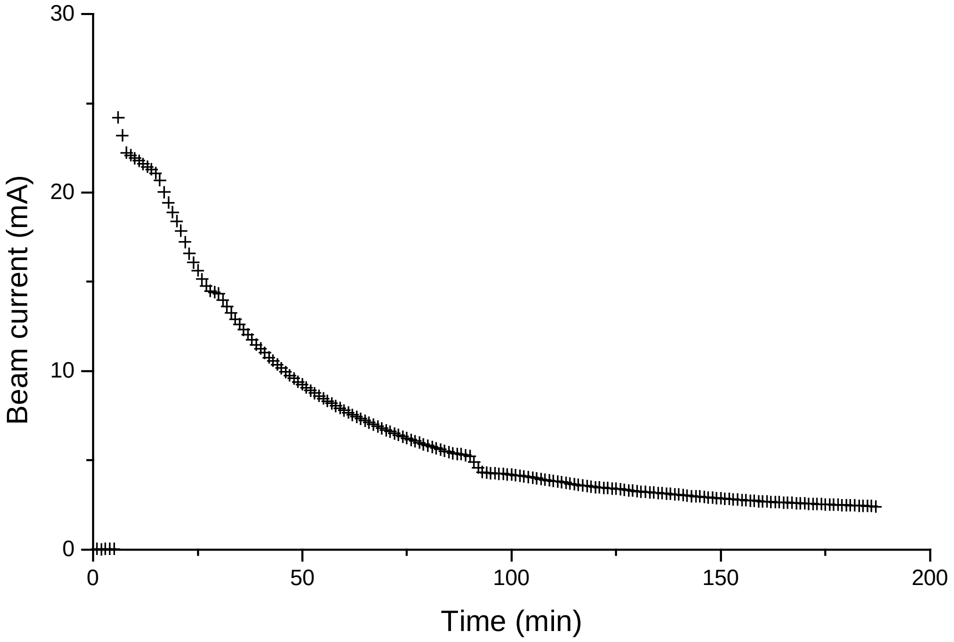


Fig.4: Time dependence of the positron beam intensity (beam current in [mA] as reported by the DAΦNE staff) on November 20, from 18:34 to 21:34.

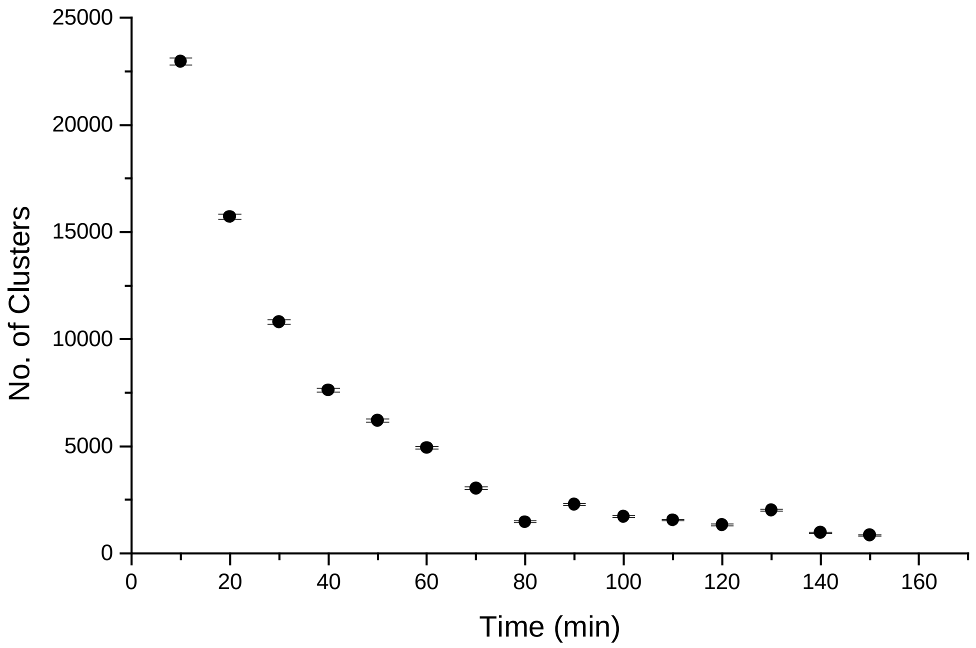


Fig.5: Time dependence of the total number of clusters recorded in runs of 10 minutes on November 20, from 18:34 to 21:34.

In this measurement we did not observe a huge initial spike, but we can see, that the slope and the "bumps" measured with the No. of clusters in figure 5 follow the corresponding changes of the initial beam current in figure 4.

We have computed the mean value of the

- total # of clusters / total # of X rays in the range (2-18keV) = 132 ± 10,

and an X-ray background of

- 7.5 ± 1.0 X rays/hour/CCD/keV in the region of interest.

2.1.c) Electron beam on November 21

A pure electron beam starting with ~12 ma could be observed over a period lasting for 60 minutes (Data Run T5949 - T5954). The shorter beam lifetime reflects the worse vacuum conditions in the electron ring with respect to the positron ring. In figure 6 we display the beam current as it is given by the DAΦNE beam monitor. Figure 7 shows the total number of clusters recorded during this period in runs of 10 minutes each.

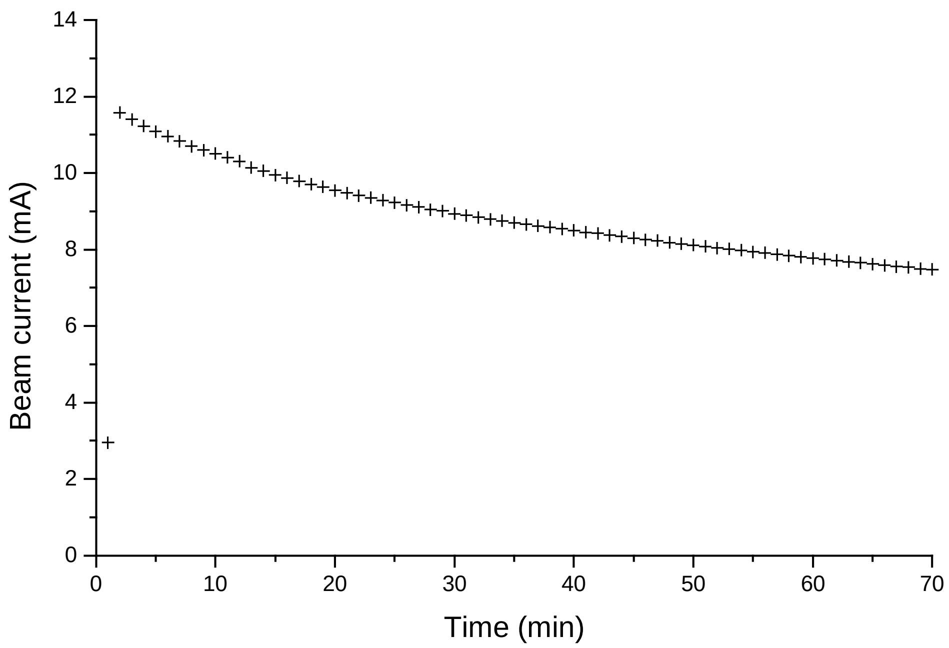


Fig.6: Time dependence of the electron beam intensity (beam current in [mA] as reported by the DAΦNE staff) on November 21, from 1:39 to 2:49.

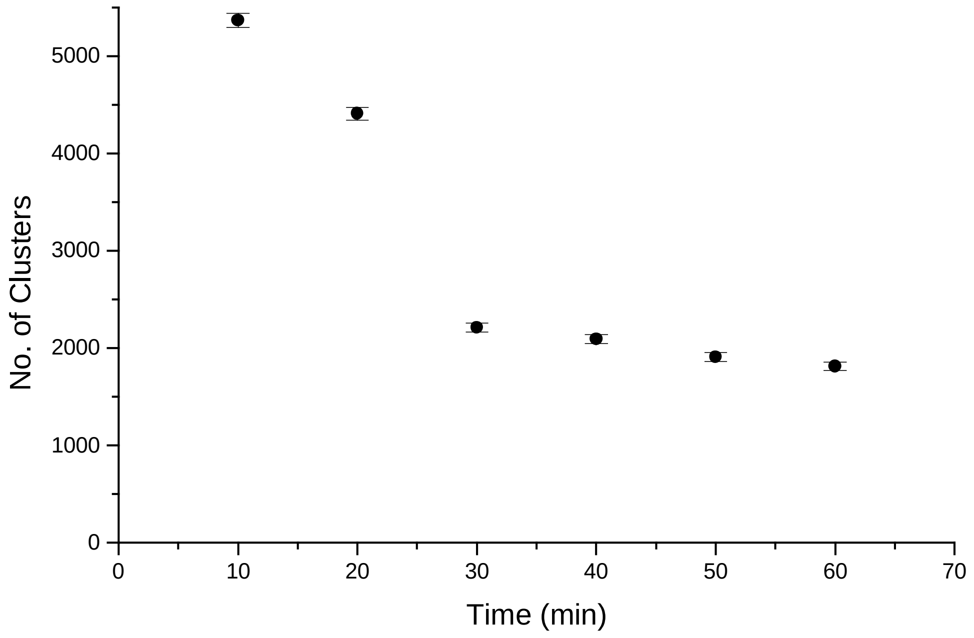


Fig.7: Time dependence of the total number of clusters recorded in runs of 10 minutes on November 21, from 1:39 to 2:49.

We have computed the mean value of the

- total # of clusters / total # of X rays in the range (2-18keV) = 102 ± 10,

and an X-ray background of

- 6.3 ± 2.0 X rays/hour/CCD/keV in the region of interest.

2.1.d) Electron beam on November 22

A pure electron beam starting with ~3.5 mA could be observed over a period lasting for 3 hours (Data Run# T6104 - T6120). In figure 8 we display the beam current as it is given by the DAΦNE beam monitor. Figure 9 shows the total number of clusters recorded during this period in runs of 10 minutes each.

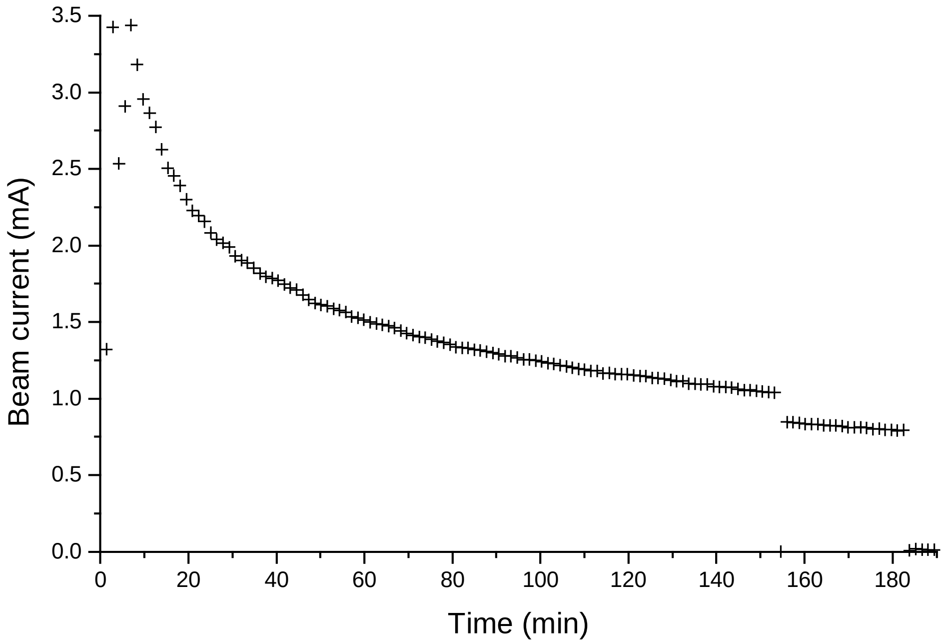


Fig.8: Time dependence of the electron beam intensity (beam current in [mA] as reported by the DAΦNE staff) on November 22, from 17:30 to 20:30.

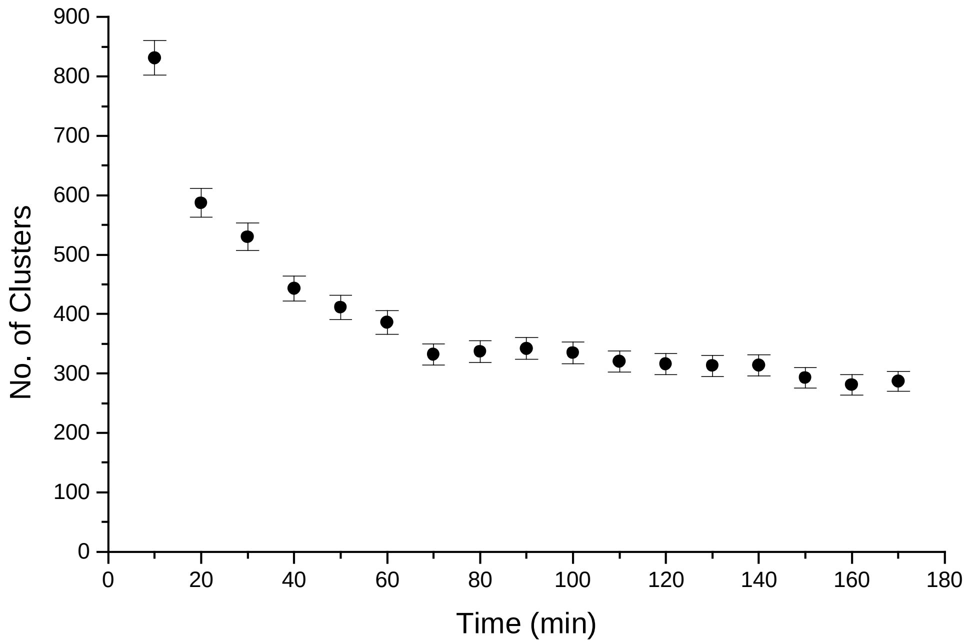


Fig.9: Time dependence of the total number of clusters recorded in runs of 10 minutes on November 22, from 17:30 to 20:30.

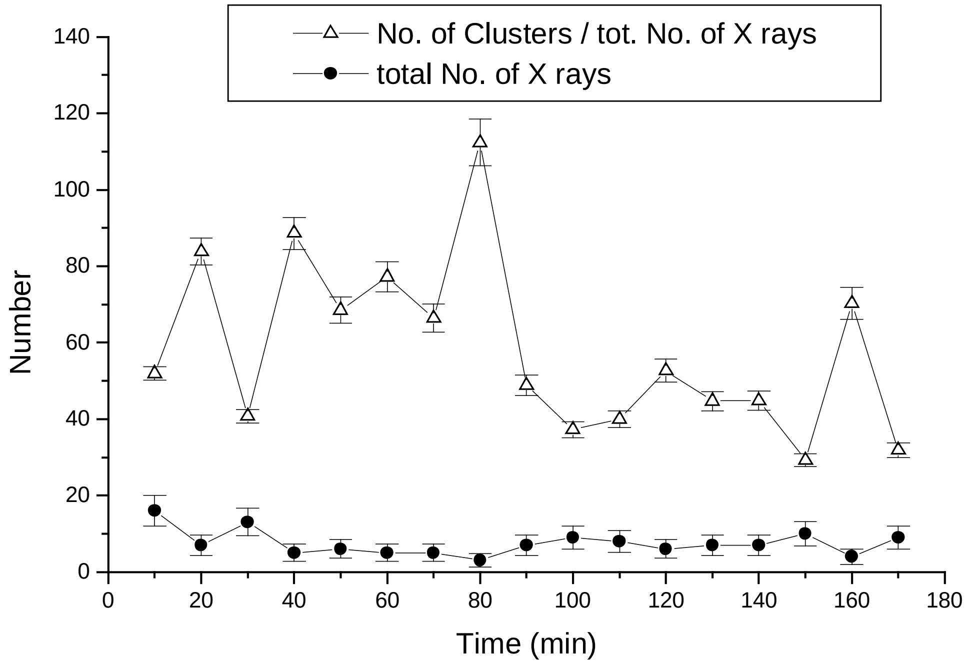


Fig.10: Time dependence of the total number of X rays (channels 50 - 950) and the ratio – number of clusters / total number of X rays in the range (2-18keV) – on November 22, from 17:30 to 20:30.

Figure 10 displays the time dependence of the total number of X rays (X rays between channel 50 and 950) and the ratio of total number of clusters versus total number of X rays in the same time period as the regarded electron beam.

We have computed the mean value of the

- total # of clusters / total # of X rays in the range (2-18keV) = 53 ± 5,

and an X-ray background of

- 2.0 ± 0.5 X rays/hour/CCD/keV in the region of interest.

Here we see, that the total number of X rays remains almost constant. Again, the ratio total number of clusters versus total number of X rays does not follow the time dependence of the beam current. Moreover, its absolute value reflects the values obtained in the no-beam measurements. We explain this observed low number by the low beam current and little beam losses.

2.2 The x-ray energy spectrum

2.2.a) The measurements

We have observed x-ray energy spectra at different beam conditions: electron beams, positron beams and colliding beams, with circulating beam current starting from 0.1 mA up to 100 mA. We have observed x-ray energy spectra which agree well with each other. Therefore we have added up all "good" exposures - the ones which were not totally overexposed, due to intense background caused by quick beam loss - to give a final spectrum shown in figure 11 and figure 12.

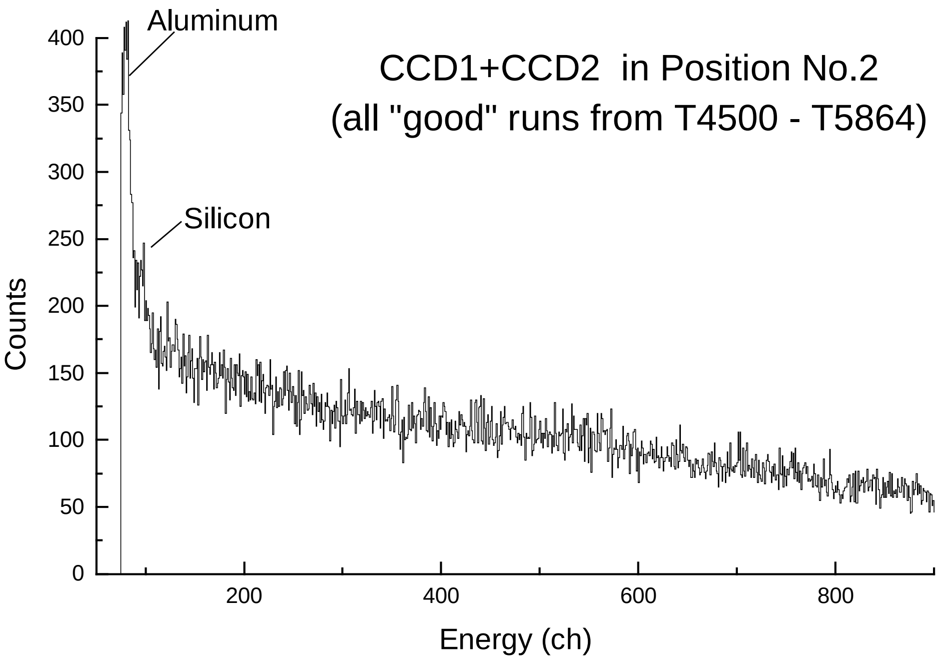


Fig.11: Energy spectrum for positron, electron runs. One can see the aluminum peak at ~1.49 keV and the Si-peak at ~1.74 keV.

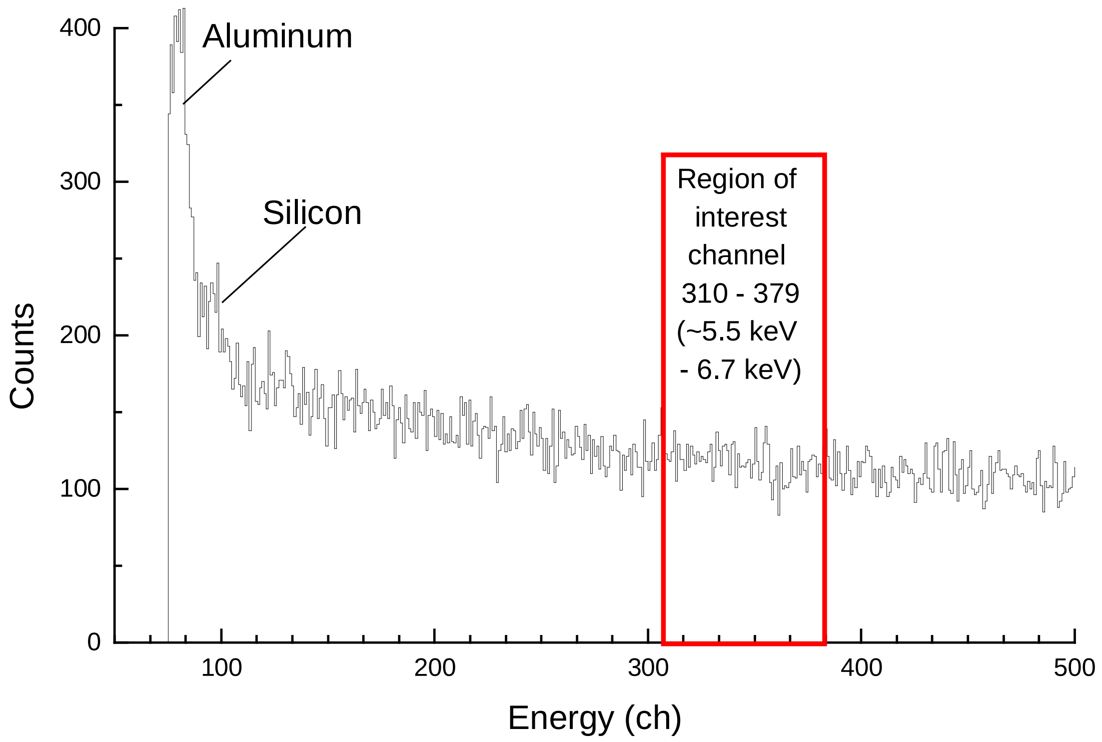


Fig.12: Same spectrum as in Fig.11, but enlarged and the "region of interest" is displayed. No structure can be seen in this region.

Due to the fact that the CCDs were positioned about 60 cm away from the beam pipe, all the observed X rays are induced by secondary particles, created in the machine pipe (2mm stainless steel) by the particles lost from circulating beams, in the aluminum cap of the CCDs. Therefore one can only observe electronic aluminum X rays from the cap material and fluorescent X rays from the CCDs silicon material. The main part of the observed energy region displays a smooth background distributions which can easily be approximated and does not represent a problem for the actual measurement.

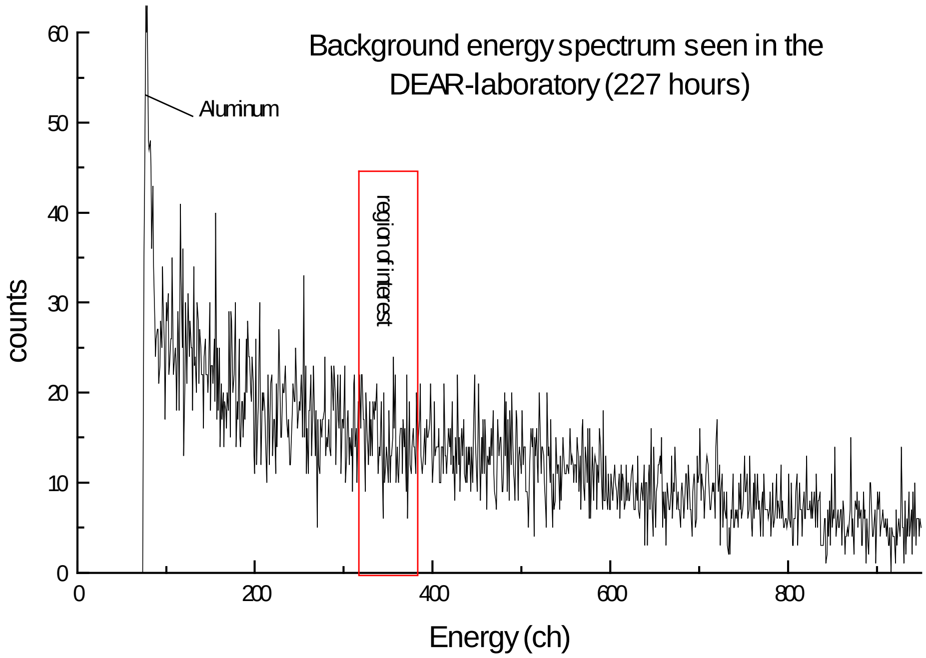


Fig.13: The x-ray background energy spectrum as seen in the DEAR-laboratory (no-beam background) in 227 hours of data taking with the identical 2CCD-setup.

In figure 13 we show the x-ray energy spectrum obtained in the DEAR-laboratory in 227 hours of data taking with the identical 2CCD-setup. The observed energy spectrum does not significantly differ from the one measured with beam in the region of interest. However, the silicon fluorescence peak could not be observed. The similarity of the x-ray energy spectra is not surprising, as the origin of most of the observed X rays lies for both, the measurements in the pit and the one in the DEAR-lab, in the aluminum cap of the detector.

2.2.b) Conclusions

- The displayed x-ray background energy spectra, measured with electrons/positrons circulating beams, show only an induced fluorescent aluminum and silicon x-ray peak.
- The observed energy spectrum does not have a significant structure in the region of interest. This is understandable, because the X rays observed in these measurements originate mainly from interactions within the aluminum cap or the CCD materials.

2.3 Distributions of " mean value of cluster size "

2.3.a) Experimental observations

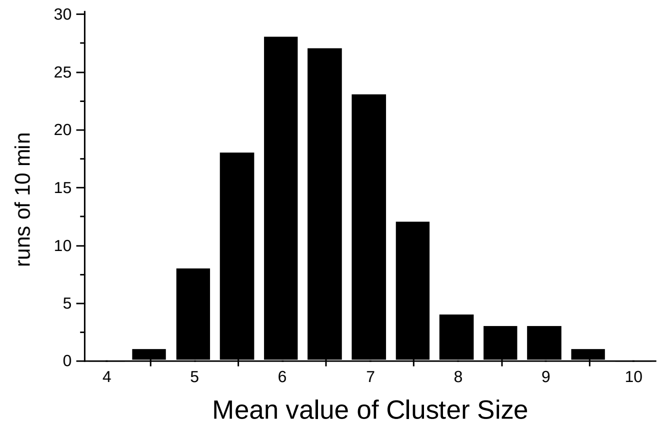
Using the program CCD-VIEW, one can analyze each "CCD image" (half a chip) concerning the following quantities:
How many clusters (with one or more than one hit pixel) are in one CCD image ? What is the size (number of pixel hits) of these clusters ?
We can determine the distribution of the occurring cluster sizes. We can also determine a mean size of these clusters, called " mean value of cluster size ", by adding up the number of pixel hits and dividing this number by the number of clusters.

We compared the observed mean value distributions for electron, positron and no-beam measurements. We are using the following data (10 minute runs) which have in common a CCD occupancy of less than 2 % (98 % of all pixels show no hits):

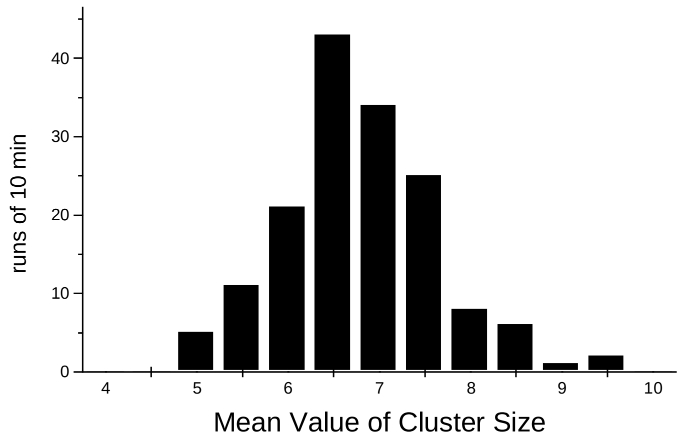
No beam: run # T5264-T5270, T6366-T6390 (5h20min)
Electron beam: run # T5949-T5954, T6104-6120, T6208-6215 (4h50min)
Positron beam: run # T5273-T5306, T6342-T6350 (5h30min)

Figure 14 compares the distribution of the "Mean Value of Cluster Size" as observed with different beam conditions. The measurement with the positron beam shows a significant lower mean value (see also Table 1) as the other two measurements. This is just the **opposite behaviour as seen in our measurement in Position 1**. It is a puzzling experimental observation, that the "Mean Value of Cluster Size" is observed smaller by a CCD detector on the positron beam side for a positron beam and vice versa on the electron beam side.

a) No beam



b) Electron beam



c) Positron beam

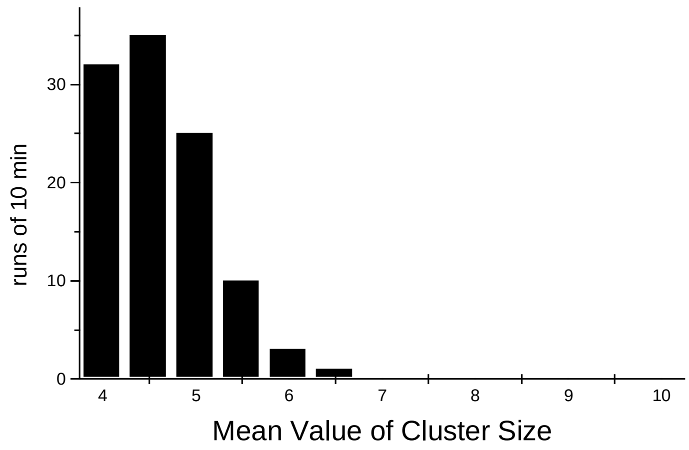


Fig.14: "Mean Value of Cluster Size": Distributions for a) no beam , b) electron beam c) positron beam measurements.

"Mean Value of Cluster Size"	Electron beam	Positron beam
Position 1 (Ref. [1])	6.28	6.60
Position 2	6.69	4.87

Tab.1: Calculated "Mean Value of Cluster Size" for Position 1 (closer to the electron beam / Ref. [1]) and Position 2 (closer to the positron beam / this measurement).

This experimental observation can be likely explained by a simple geometric effect which is shown in figure 15. There we see a schematically drawing of the CCD-detector in Position 1 and Position 2, of the quadrupole magnets and of the DAΦNE-beam pipe.

We assume, that for background particles induced by a positron beam the main amount of particles, which hit the CCDs and create clusters there, have their origin in the area closer to the positron beam (encircled area B-Po). For the background particles induced by an electron beam the situation is symmetric and we assume that they mainly come from the area closer to the electron beam (encircled area B-El).

The effect of this on the CCDs in Position 2 is the following: The angle between the CCD detector plane and the average path of the background particles is α if the background is induced by a positron beam, and is β if the background is induced by an electron beam. It is clearly visible, that in Position 2 the average angle α is larger than the average angle β. The smaller the angle with respect to the CCD plane is, the larger is the number of pixels which can be hit by the same particle; therefore, the larger is the cluster size seen by the CCDs. This is just the effect observed in our test measurements.

A broader area of background production can broaden the cluster distribution.

Additionally, shading and degrading of the background particles at the central quadrupole can contribute to this position dependence.

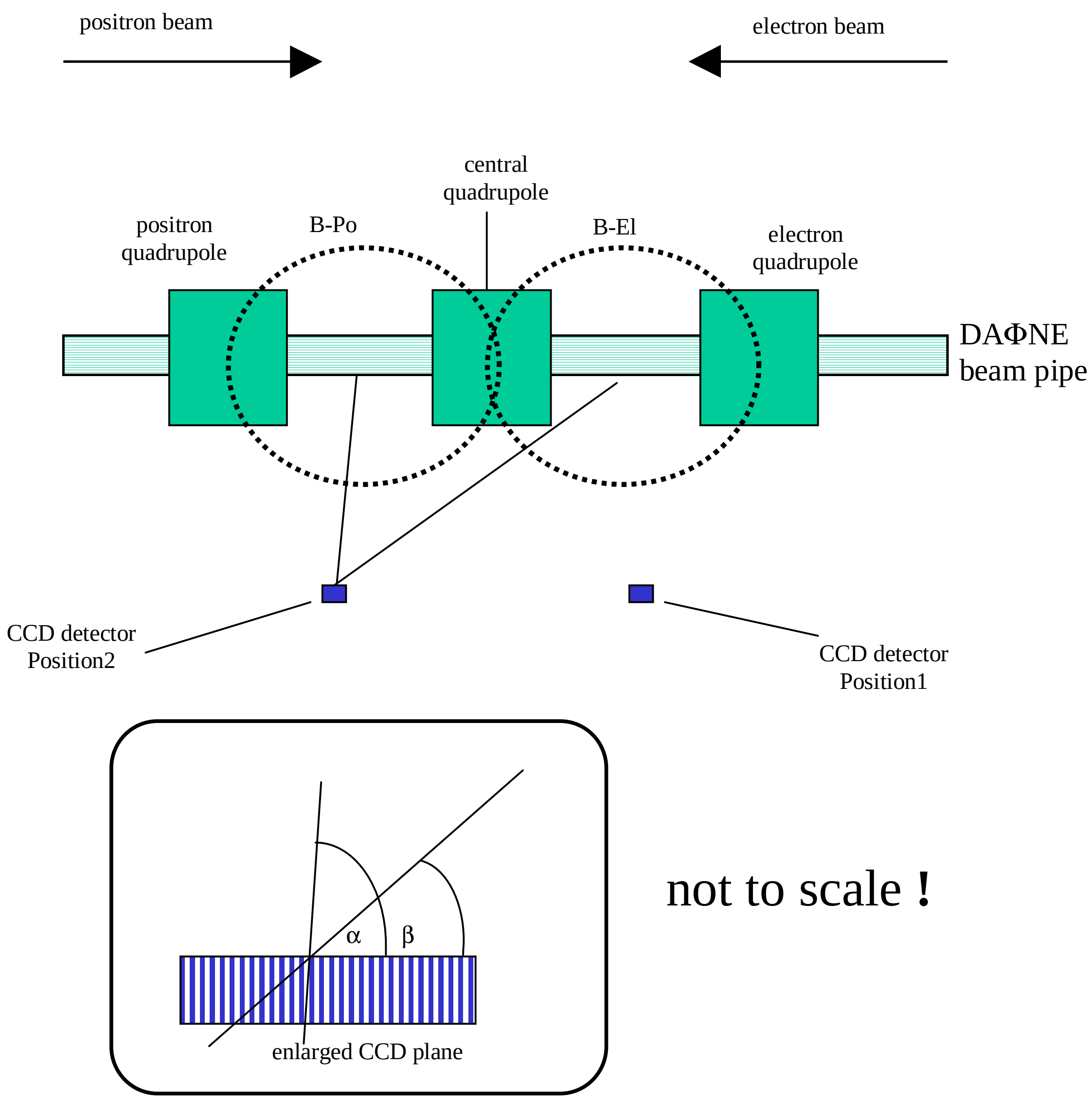


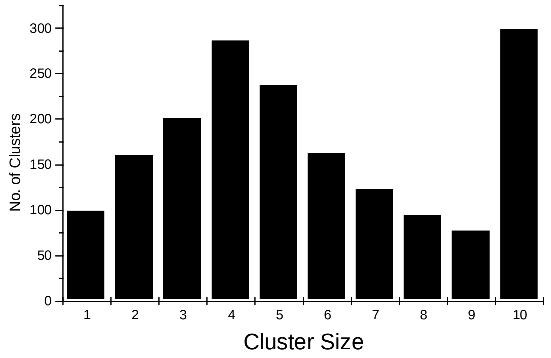
Fig.15: Schematic drawing of the 2CCD setup in the pit. The three quadrupole magnets, the DAΦNE-beam pipe and the CCD detector in Position 1 and Position 2 are shown. The enlarged area display possible particle paths with respect to the CCD plane. The parallel lines should schematically represent the CCD pixels. The different number of hit pixels is obvious.

2.3.b) Conclusions

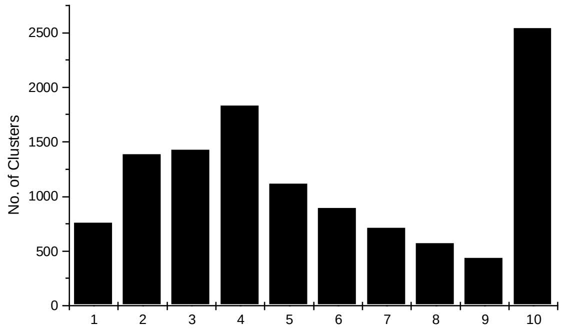
- The mean values of the cluster sizes are different, as it occurred with the setup in Position 1. The values for the measurements with electron beams are higher than the positron beam data, when the setup is in Position 2 nearer to the positron beam.
- The mean values behave just opposite to the measurements in Position 1. A general behaviour "nearer to the beam, smaller the cluster size" can be extracted.
- A likely explanation of this behaviour as geometric effect is given in figure 15.

2.4 Distributions of the cluster size versus beam configurations

a) no beam



b) electron beam



c) positron beam

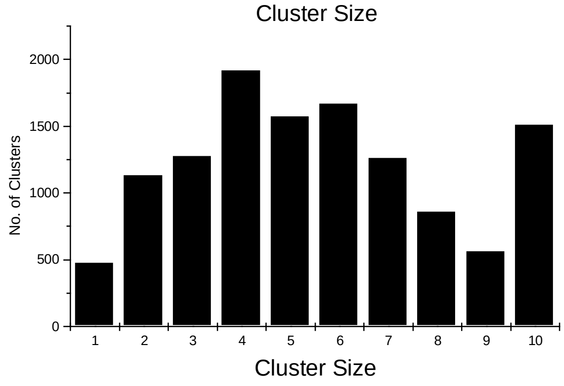


Fig.16: Cluster sizes observed with different beam modes in Position 2; a) no beam, b) electron beam, c) positron beam. Bin 10 denotes all sizes larger than 9.

In this chapter we analyze the relationship between the cluster sizes and the beam modes. As already explained in chapter 2.3.a, one can extract for each half-CCD the number of hits of a certain size. Using these, we can determine the distribution of these number of cluster sizes; with one restriction, all sizes larger than 9 are not separated and occur in bin 10. In figure 16 our results are displayed for the different beam modes. We have used the runs with no beam (run # T5264-T5270), electron beam (run # T5490-T5499) and positron beam (run # T5282-T5307). All these runs have approximately an equal occupancy of ~ 2 %. In figure 17 the individual distributions have been normalized to their highest peak with cluster size smaller than 9. For all beam modes this happens to be bin 4.

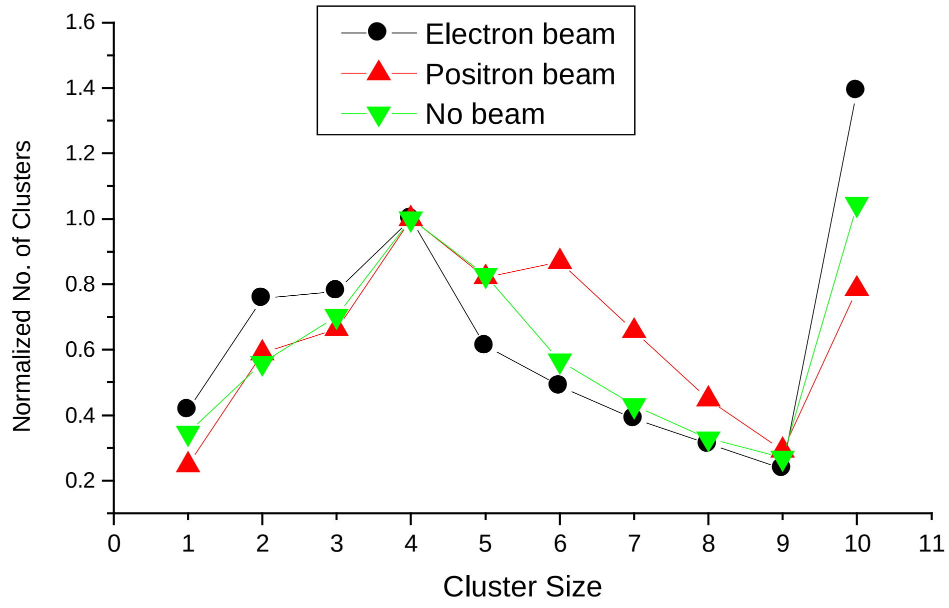


Fig.17: The distribution of the cluster sizes for different beam modes. 10 denotes all sizes larger than 9. All distributions are normalized to bin 4.

From figure 16 and 17 we can conclude, that:

1. In Position 2, nearer to the positron beam, pixel sizes larger than 9 are clearly more frequent for the electron beam than for the positron beam. This corroborates the result "larger mean value of cluster size for the electron beam background" in Position 2.
2. Disregarding bin 10, all the distributions are peaked in bin 4.
3. The width of the cluster size distribution is broader for the positron beam than for the electron beam measurements.
4. Compared with the no beam data, the electron beam and positron beam distributions behave oppositely.

Point 1 and 4 can have the explanation shown in figure 15; point 3 is likely due to a broader area of background production. Point 2 is not yet explained.

3. Results and conclusions:

1. We proved, that we are able to run a CCD-measurement in the DEAR/FINUDA pit for 1½ months without problems. The JUMBO2 system was very stable during this data taking.
2. In the pit the natural background without beam was measured to be almost a factor of 2.5 lower than in the DEAR laboratory. There is no position dependence within the pit.
3. The energy spectra show no significant pattern in the region of interest. The aluminum and silicon electronic x-ray peaks can clearly be identified.
4. The difference of the mean values of cluster size measurements can be attributed to the locations of their production. If these are different they cause different angles of the background particle path with respect to the CCDs surface.
5. The cluster sizes seems to depend on the position of the setup with respect to the entrance beam: for instance, if the setup is near to the electron beam pipe, then the mean value of cluster size is smaller when electrons are circulating with respect to when positrons are circulating, and viceversa. This is the difference between the measurements in Position 1 (Ref. [1]) and Position 2. An explanation for this behaviour is given in figure 15.

References:

[1] M.Augsburger et al., DEAR Technical Note IR-9, DEAR - first beam test at DAΦNE with a simplified 2 CCD setup.