BNL Experiment E949
Technical Note K-030

Efficiency of T-counters and T.2 trigger signals

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1 Introduction

In this note we report on the performance of the plastic scintillation counters with WLS fiber readout (T-counters) in the beam. These counters are installed as the innermost layer of the Range Stack (RS) to produce the trigger signal for DAQ. The counter was cut from Bicron BC404 scintillator plate of 7 mm thickness. The plastic profile is trapezoidal with a 7.5^o bevel to pack closely with its neighbours with an average gap of 0.5 mm. The counter length is 520 mm, largest width is 119.3 mm, smaller width is 117.5 mm. More detailed T-counter description can be found in the E949 technote K-013.

Our analysis is concentrated on monitoring the T-counter detection efficiency over two E949 runtime periods. We will try to understand different factors which contribute to the overall inefficiency. We have to note that the trigger signal for each RS sector (T.2) is formed as hardware coincidence of T-counter both ends with both ends of second RS layer. Therefore we also monitor the efficiency of second layer and electronic T.2 pulses.

The analysis technique developed to measure efficiencies is based on selection of individual timing signals in multi-stop TDCs. Coincidence signals are arranged by software algorithm. ADC information is used only to track the source of inefficient events.

Analyzed data were taken in fall 2001 (runs 45xxx) and spring 2002 (runs 46xxx-49xxx). Over this time a few T-counters were found to be in a broken state, probably because of broken fibers at single end. As it will be shown later the T-counter itself works, and could be effectively viewed from another end.

2 Analysis algorithm

Kbeam trigger was used to obtain the events recorded without T.2 signal. Then candidate events were selected using following steps:

- UTC track is recovered and pointed towards RS.
- RD_TRK subroutine reconstracts at least one charged track in RS. It requires hits in a few layers of a RS sector or neighboring sectors. The track must correspond to the direction drawn by UTC.
- The selected track is extrapolated backward through I-counter to the target (I-counter hit within specified region is required).
- Charged particle momentum is in a range from 200 to 250 MeV.
- Position of particle entrance point in the T-counter is a variable parameter. Additional cuts can be applied to select minimum ionizing particles going through the first two RS layers.

Pivotal data are TDC counts from each individual phototube. Coincidences between the counter ends are arranged by requiring the minimum time difference between them ("software" coincidence). Talking about efficient events in the counter we imply both ends of this counter have to coincide. All other coincidences are made in the same way.

3 Detection efficiency

Time spectra from the phototubes are rather wide because of the TDC start bounded to beam signals. To measure the detection efficiency of RS counters with good accuracy we apply the reference RS counter. Subtracting the reference counter time from the measured counter we are narrowing the time distribution, and can avoid the background inside the narrow selection time windows. We choose the 3-rd RS layer as a reference. Selected MIP for a sector must have only a single hit in both 3-rd and 4-th layer of this sector or neighboring ones. In the case of a few TDC hits in a T-counter (or 2-nd layer counter) the only one is chosen which is closest to the reference hit in a 3-d layer. The event is efficient if the hit time is inside the specified window of 20 ns width. Fig. 1 shows the time-difference spectra for the different sectors. Time difference between T-counter and 3-rd RS layer in 1-st sector is a typical case. However the PMT in 6-th T-counter spreads the spectrum. We can not call it the malfunction, it is rather the individual performance. Also the T-counter in 11-th sector shifts the difference spectrum from zero mark.

Stability of trigger signals T.2 over time can be seen from Fig. 2. One of T.2 components, second RS layer, is out of problems. T-counter broken fiber readout is responsible for the low efficiency in 6-th and 11-th sectors in 2001. Then the broken ends were bypassed in the electronic trigger layout, and the failed counters work with the single-ended readout. Some problems are observed in 7-th T-counter, presumably due to a bad cable connector after a splitter. Sector 8 also shows reduced efficiency of unknown reasons.

Fig. 2 monitors the status of RS counters. The accurate numbers for the absolute detection efficiencies in different runs are presented in Tables 1, 2, 3. The T-counter hit

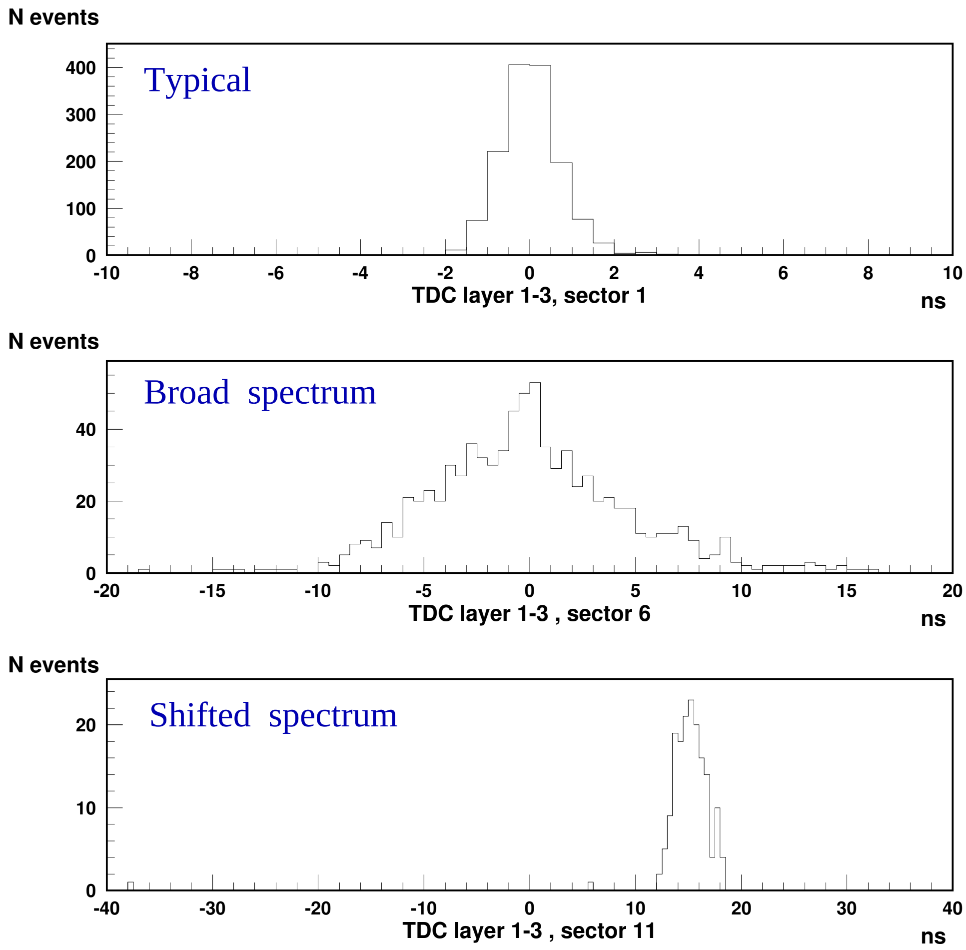

Figure 1: Time-difference spectra between T-counter and 3-rd layer for sectors 1, 6, 11. 3-rd layer is used as a reference one.

region is cut to ± 24 cm in length and ± 4.5 cm in width. Efficiencies are measured for T-counters, 2-nd layer counters, their "software" combination T.2, electronic ("hardware") signals T.2 measured independently by BM TDC and TS TDC. "Hardware" T.2 signals form the trigger and, therefore, determine the trigger efficiency, which depends on the pulses widthes, jitters and time matching. To see the average efficiency unbiased by the bad counters we exclude them from the total numbers. The sectors 6, 7, 11 are excluded in Table 1, and in other tables the sectors 6, 7, 8 are excluded.

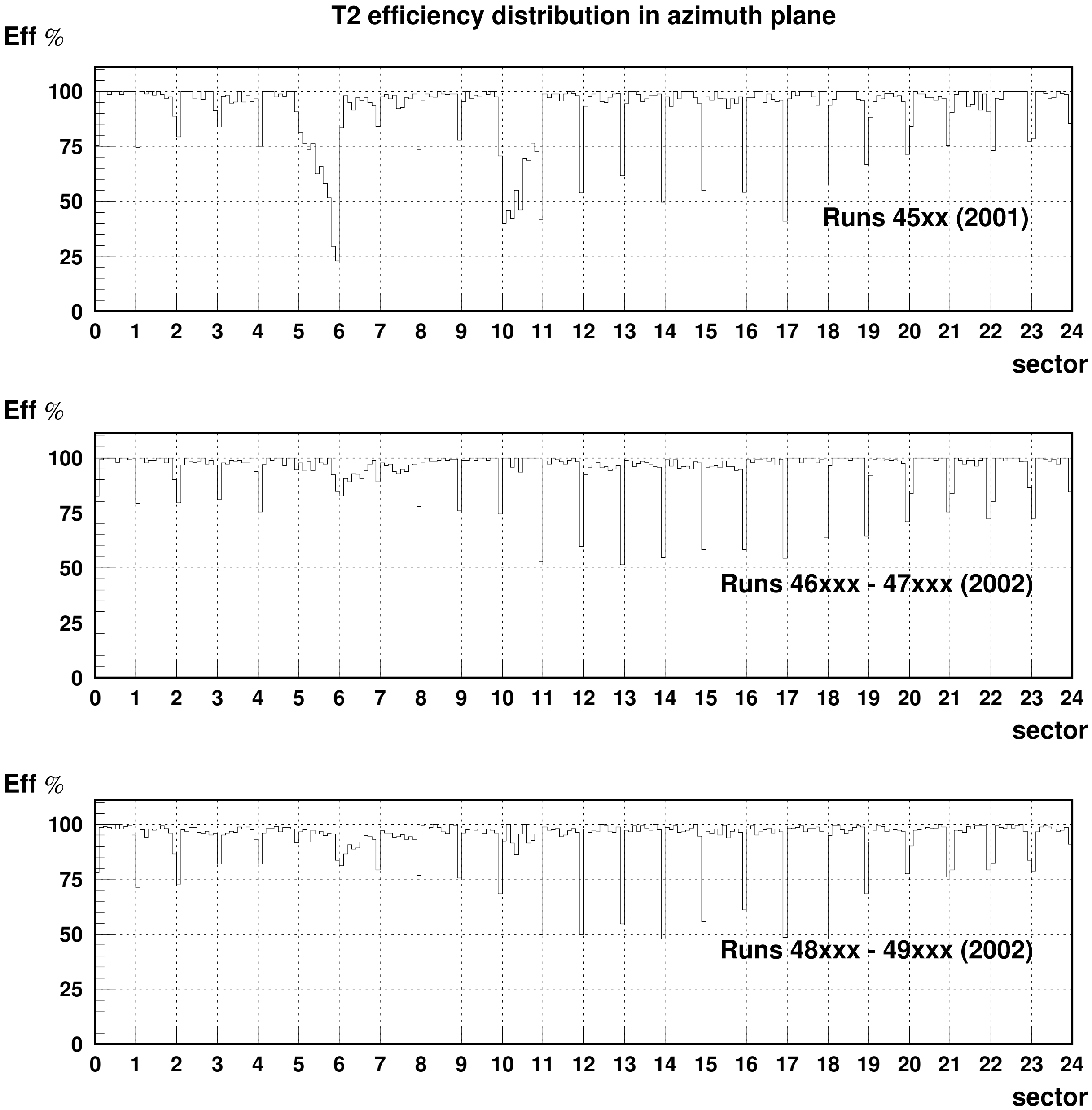

Figure 2: Efficiency of T.2 signals for all 24 RS sectors in an azimuth plane. In 2001 the two T-counters (6-th and 11-th) were found to be in a broken state at one of the ends. In 2002 runs T.2 signals were formed without broken ends.

Table 1: RS counters efficiency obtained with RS layers 3 and 4 for **Runs 45xxx.**
BM and TS are hardware T.2 signals measured in corresponding TDCs.
T-counter width cut : -4.5 $\leq$ X $\leq$ 4.5 cm
T-counter length cut : -24 $\leq$ Z $\leq$ 24 cm

Sectors	N_{events}	Eff $_{T-counter}$, %	Eff $_{layer2}$, %	Eff $_{T.2}$, %	Eff $_{T.2}$, (BM) %	Eff $_{T.2}$, (TS) %
1	508	99.8	100.0	99.8	97.6	96.9
2	492	99.4	99.6	99.0	95.7	95.7
3	324	99.4	99.4	99.1	97.2	96.9
4	404	98.0	99.3	97.3	94.8	94.3
5	607	99.5	99.7	99.2	95.2	95.4
6	291	64.3	99.7	63.9	61.9	61.5
7*	423	95.5	99.8	95.3	91.5	91.3
8	549	96.7	99.3	96.4	94.5	94.4
9	614	99.0	99.8	98.9	95.1	95.1
10	442	98.6	99.8	98.6	95.0	94.8
11	673	73.8	82.6	59.9	57.8	58.5
12	642	98.8	99.7	98.6	93.6	93.8
13	695	99.4	98.7	98.1	96.0	95.7
14	446	99.6	98.9	98.4	96.6	96.4
15	549	99.1	98.5	98.0	97.3	96.7
16	691	99.6	96.5	96.2	96.1	96.1
17	507	98.6	99.4	98.2	91.9	91.7
18	355	98.9	99.7	98.6	93.8	94.4
19	411	99.8	99.0	99.0	97.1	96.8
20	733	99.2	98.1	97.3	93.9	93.5
21	598	99.0	98.7	98.5	93.1	93.1
22	510	97.8	99.0	97.3	91.6	92.4
23	287	99.3	100.0	99.3	93.4	92.7
24	707	98.7	99.7	98.7	92.5	92.4
Total	12458	96.7	98.2	95.3	91.9	91.8
Total[1]	**11071**	**99.0**	**99.1**	**98.2**	**94.8**	**94.7**

*Bad cable connector
[1]Sectors 6, 7, 11 are excluded.

Table 2: RS counters efficiency obtained with RS layers 3 and 4 for 46xxx-47xxx.
BM and TS are hardware T.2 signals measured in corresponding TDCs.
T-counter width cut : -4.5 $\leq$ X $\leq$ 4.5 cm
T-counter length cut : -24 $\leq$ Z $\leq$ 24 cm

Sectors	N_{events}	Eff $_{T-counter}$, %	Eff $_{layer2}$, %	Eff $_{T.2}$, %	Eff $_{T.2}$, (BM) %	Eff $_{T.2}$, (TS) %
1	985	99.6	99.9	99.7	86.6	90.9
2	715	99.2	99.7	99.2	87.1	92.7
3	497	98.4	99.8	98.6	84.5	89.9
4	638	98.6	99.7	98.4	86.2	92.5
5	807	99.5	99.5	99.3	91.9	97.1
6*	402	90.3	100.0	90.3	81.3	86.8
7**	590	93.4	100.0	93.4	86.8	91.0
8	762	95.0	99.6	95.1	87.3	92.4
9	916	99.2	99.8	99.1	91.8	95.9
10	620	99.7	99.8	99.5	90.8	96.0
11*	600	99.7	99.7	99.3	89.8	94.0
12	861	98.7	99.8	98.8	89.8	94.9
13	1044	98.7	97.2	96.0	90.8	96.6
14	668	99.1	98.1	97.2	89.7	96.6
15	844	99.3	97.6	96.9	88.6	96.4
16	1040	99.2	96.6	96.1	91.4	96.4
17	840	98.8	100.0	98.8	88.5	95.1
18	736	99.9	99.9	99.7	90.1	94.8
19	662	100.0	100.0	100.0	88.7	95.3
20	1127	98.8	99.8	99.1	88.6	94.7
21	837	99.9	100.0	99.9	89.1	93.1
22	664	99.1	99.8	99.1	86.4	93.8
23	461	99.6	100.0	99.6	89.6	93.9
24	1006	99.4	99.6	99.3	88.8	93.3
Total	18322	98.7	99.3	98.2	88.8	94.2
Total[1]	**16568**	**99.2**	**99.3**	**98.7**	**89.1**	**94.6**

*Single end logic
**Bad cable connector
[1]Sectors 6, 7, 8 are excluded.

Table 3: RS counters efficiency obtained with RS layers 3 and 4 for **Runs 48xxx-49xxx**.
BM and TS are hardware T.2 signals measured in corresponding TDCs.
T-counter width cut : -4.5 $\leq$ X $\leq$ 4.5 cm
T-counter length cut : -24 $\leq$ Z $\leq$ 24 cm

Sectors	N_{events}	Eff $_{T-counter}$, %	Eff $_{layer2}$, %	Eff $_{T.2}$, %	Eff $_{T.2}$, (BM) %	Eff $_{T.2}$, (TS) %
1	1441	99.2	99.9	99.2	95.7	96.0
2	1252	98.5	99.0	97.6	95.2	95.4
3	1001	98.4	98.2	97.0	94.0	94.5
4	1260	97.8	99.2	97.3	93.8	93.9
5	1045	98.9	99.4	98.4	95.3	95.5
6*	848	96.9	98.8	95.8	92.0	92.5
7**	1145	92.0	98.8	91.3	87.8	87.9
8	1084	94.8	99.4	94.6	91.0	91.0
9	1036	99.2	99.0	98.5	93.9	94.7
10	732	97.5	99.5	97.7	91.0	92.3
11*	785	98.3	99.0	97.6	93.5	94.0
12	1098	97.4	99.3	97.1	91.7	92.3
13	1219	98.4	99.4	97.9	93.1	93.6
14	1100	98.9	99.2	98.4	94.3	94.6
15	1281	98.2	99.0	97.6	93.4	94.1
16	1215	98.7	98.2	97.2	94.6	95.1
17	1251	98.2	99.5	97.9	92.6	92.9
18	1085	99.2	99.1	98.6	93.6	93.8
19	1199	99.1	99.2	98.3	93.5	94.2
20	1408	98.7	99.1	98.1	93.3	94.0
21	1165	99.3	98.9	98.5	93.2	93.9
22	939	98.7	99.4	98.3	91.8	92.0
23	893	99.4	99.2	98.8	91.3	90.9
24	1180	98.7	99.4	98.2	91.8	92.4
Total	26662	98.1	99.1	97.5	93.1	93.5
Total[1]	**23585**	**98.6**	**99.2**	**98.0**	**93.5**	**93.9**

*Single end logic
**Bad cable connector
[1]Sectors 6, 7, 8 are excluded.

4 Effect of gaps between RS sectors

To see the inefficient events caused by the gaps between RS counters the I-counter was used as a reference, i.e. we analyze the timing spectra of difference between the I-counter hits and RS counters. No any additional cuts in RS were applied to keep alive the events entering the gap region. Such an algorithm did not provide the very good selection of MIPs and the absolute accuracy of the efficiency measurement. However it allow us to compare the counter center with the edge regions. UTC determines the RS sector and track coordinate at T-counter level. Then the angle coordinate for this sector is calculated. Azimuth angular size of a single RS counter is ± 0.1309 rad if to ignore the gaps. Our approximation is ± 0.13 rad. Fig. 3 shows the average efficiency scan for all T-counters in the azimuth plane versus the angle under which the counter hit position is viewed from the target. Efficiency is flat at 106 mm width (at least) while the full T-counter width is about 118 mm. To measure the size of the cross-sector gap between the counters we need a larger statistics and more complicated analysis because of the track accuracy at UTC and geometrical position uncertainity of T-counters.

The efficiency distribution in an azimuth angular plane for all sectors is shown in Fig. 4 for runs 48xxx-49xxx. Each sector is measured in 10 bins. A single bin width is 0.026 rad, which corresponds to about 1.18 cm of linear width for T-counters and 1.20 cm for 2-nd layer. 6-th, 7-th and 8-th T-counters form a low efficiency cluster. Efficiency drop for the 6-th counter is inconsistent with data presented in Fig. 2, where the different MIP selection algorithm was used.

The efficiencies for each sector are listed in Table 4. These numbers are obtained for the angle cut $-0.13 \leq \theta \leq 0.13$ rad, i.e. the full sector width including the gaps was selected. Data presented in Table 5 were obtained with the angle cut $-0.11 \leq \theta \leq 0.11$ rad, which corresponds to ± 5 cm at the T-counter width. Comparing both tables we can see the effect of cross-sector gaps for detection efficiency. The gaps reduce the T-counter efficiency by 2.2%, and 2-nd layer loses 2.7%. The T.2 signal efficiency is reduced by 3.7%. It seems as the gaps in 1-st and 2-nd layers are not overlapped. We have to note that there is some uncertainty caused by the accuracy of the track reconstruction in UTC. The real detection efficiency can be higher in the gap area where some tracks can be pointed by UTC in the wrong neighboring sector. More complicated analysis could find such events.

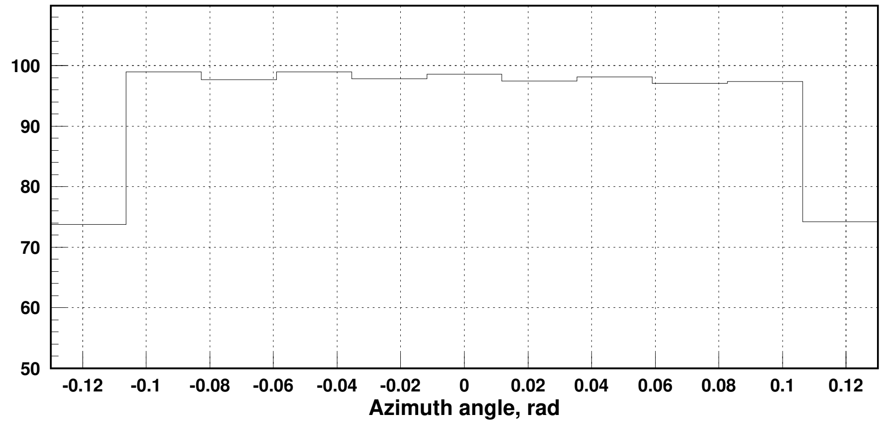

Figure 3: The average efficiency across a T-counter in azimuth plane versus the azimuth angle. Azimuth angular size of a RS counter is ± 0.1309 rad (including gaps).

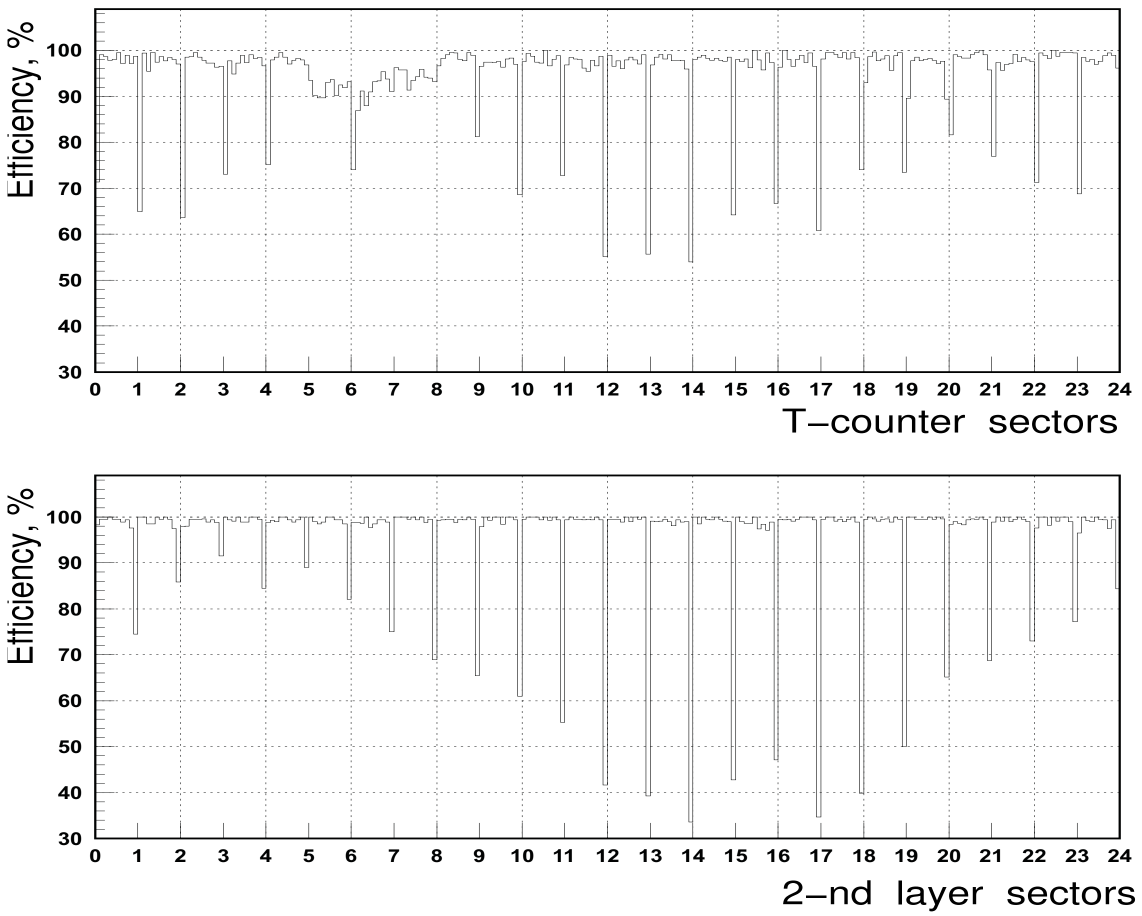

Figure 4: The efficiency distribution in an azimuth angular plane for all sectors (runs 48xxx-49xxx). Basic MIP selection: track in UTC, hit in I-counter, a few hits in the corresponding RS sector (or neighboring sectors).

Table 4: RS counters efficiency obtained with IC counters for Runs 48xxx-49xxx.
T-counter width cut : full width including gaps
T-counter length cut : -25 $\leq$ Z $\leq$ 25 cm

Sectors	N_{events}	Eff $_{T-counters}$, %	Eff $_{layer2}$, %	Eff $_{T.2}$, %
1	1943	96.1	97.5	94.2
2	1793	95.8	98.4	94.5
3	1878	94.5	98.9	93.9
4	1787	95.6	98.7	94.6
5	1686	96.0	98.6	95.1
6*	1636	91.7	98.3	90.3
7**	1769	90.1	97.3	88.1
8	1663	94.5	97.7	92.6
9	1737	97.5	97.1	96.0
10	1586	95.5	97.0	94.6
11*	1617	96.7	96.8	95.3
12	1765	94.5	95.7	93.4
13	1890	94.9	95.4	93.5
14	1938	95.0	94.4	93.0
15	1937	95.7	95.1	93.2
16	1925	95.5	94.8	93.0
17	1912	94.8	94.0	92.2
18	2036	97.3	94.9	94.2
19	2027	96.4	95.8	94.1
20	2025	96.7	97.6	95.0
21	2009	97.5	97.0	95.0
22	1940	95.7	97.5	93.5
23	1854	97.2	97.7	95.2
24	1832	95.5	98.5	94.6
All sectors	**44185**	**95.5**	**96.8**	**93.7**
All sectors[1]	**39117**	**95.9**	**96.7**	**94.2**

*Single end logic
**Bad cable connector
[1]Sectors 6, 7, 8 are excluded.

Table 5: RS counters efficiency obtained with IC counters for Runs 48xxx-49xxx.
T-counter width cut : -5.0 $\leq$ X $\leq$ 5.0 cm
T-counter length cut : -25 $\leq$ Z $\leq$ 25 cm

Sectors	N_{events}	Eff $_{T-counters}$, %	Eff $_{layer2}$, %	Eff $_{T.2}$, %
1	1652	98.3	99.3	98.1
2	1560	98.0	99.2	97.4
3	1585	98.0	99.2	97.5
4	1523	97.7	99.5	97.4
5	1399	98.1	99.5	97.9
6*	1428	91.2	99.2	90.7
7**	1509	91.6	98.9	90.9
8	1416	94.2	99.6	94.0
9	1488	98.7	99.4	98.5
10	1369	97.4	99.6	97.4
11*	1348	98.3	99.8	98.2
12	1516	97.3	99.6	97.2
13	1613	97.5	99.5	97.4
14	1628	98.0	99.0	97.7
15	1621	98.2	99.4	97.8
16	1609	97.7	98.5	96.6
17	1593	97.9	99.6	97.8
18	1694	99.0	99.5	98.8
19	1705	98.4	99.5	98.1
20	1721	97.9	99.7	97.8
21	1698	98.9	99.2	98.4
22	1634	97.4	99.4	97.2
23	1566	99.1	99.5	98.8
24	1569	98.1	99.3	97.8
All sectors	**37444**	**97.4**	**99.4**	**97.1**
All sectors[1]	**33091**	**98.1**	**99.4**	**97.8**

*Single end logic
**Bad cable connector
[1]Sectors 6,7, 8 are excluded

5 Breaking fibers

We investigated how broken fibers degrade the light output of the counter. For this purpose we used a spare T-counter with broken fibers at one end. Another readout end was in a normal state, and was used for the test. Light yield had been measured with a collimated ^{106}Ru source across the counter. Then one fiber closest to an edge had been broken, and the light measurement scan was repeated. This process took a place untill 4 neighboring fibers were broken. Results are shown in Fig. 5. One can see that 2 broken fibers do not degrade significantly the detection efficiency of the whole counter. Light output is reduced by 40% in the area where these fibers are located. However, 4 broken fibers can create the area with the low detection efficiency. But still this area is not completely dead.

From Fig. 5 it is possible to calculate the fraction of the scintillation light collected by a single fiber (see Fig. 6). Central fiber (#0) closest to the charge particle hit position collects about 17% of light. 50% of the light is collected by 4 fibers, and 11 fibers collect about 100% of light.

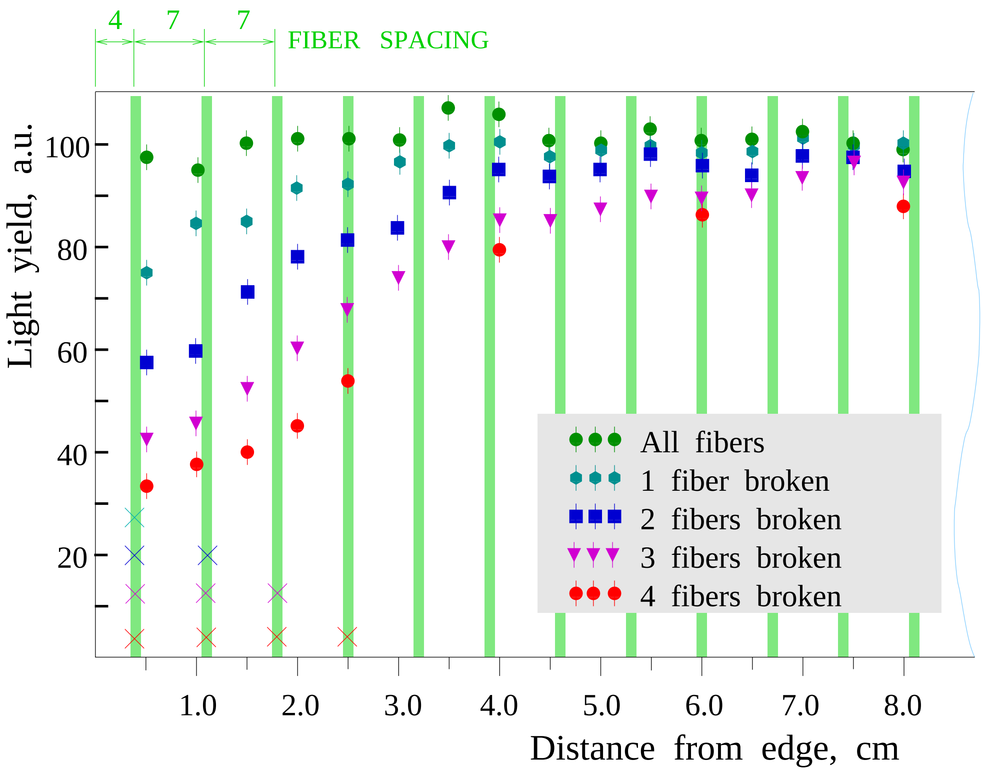

Figure 5: Ligh yield scan across the counter with different number of the broken fibers. WLS fibers are spaced at 7 mm.

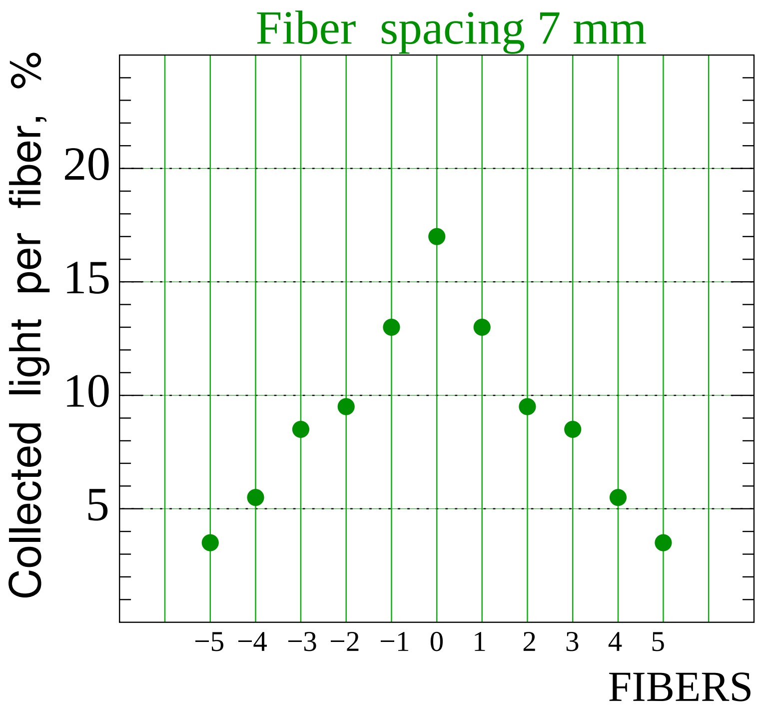

Figure 6: Fraction of scintillation light captured by a single fiber. All fibers collect 100% of the light (normalization). Central fiber corresponds to the hit position.

6 Conclusions

1. Average detection efficiency of T-counters is about 99% and close to the efficiency of 2-nd layer. Many inefficient hits in both layers are not correlated.

2. We have not found the strong effect of beam intensity on the detection efficiency of RS counters. Efficiency is almost stable though some reduction (∼0.5%) is observed in the most intensive Runs 48xxx-49xxx.

3. In the case of failed readout from one end the another end can be used to restore the detection performance. Fragile fiber readout is the main factor which can degrade the detection efficiency.

4. Gaps between neighboring RS counters lead to the loss of 3.7% of all events. Gaps between T-counters reduce their detection capability by 2.2% while the gaps between 2-nd layer look wider (2.7%).