TOF trigger rate study with the upgraded TOF detector and optional lead shielding

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I.Larin, D.Lawrence, R.Miskimen, A.Schick, E.Smith

Abstract

The random triggers from the dedicated CPP test in August 2020 (runs 72914–72915 and 72949–72958) were used to estimate the expected trigger rate for the CPP experiment [1]. The setup included the upgraded TOF detector (50 counters per plane and increased central hole size from 12x12 cm to 18x18 cm, [2]). This note describes the conditions of the test, observed rates, and effect of lead shielding sheets placed upstream of the TOF to investigate how those rates changed.

1 Run condition and event selection

The data for the test have been taken with the following modifications to the standard GlueX conditions: RANDOM trigger rate increased from 100 Hz to 30 kHz; coherent peak edge position shifted down to 6 GeV (fig. 1); DIRC detector was removed for runs 72949–72958; lead shielding was installed in runs 72953–72956. JD70-105 47 μm 0/90 PARA diamond radiator ($\sim 4\times10^{-4}$ rad.len.) was used. Livetime was at the level of 98-99 % during the test runs. Each run has four different beam current intervals: 10, 20, 30, and 40 nA. These conditions are summarized in the Table 1. The square shaped lead shielding has the following parameters: outer size 60×60 cm, inner size matching TOF plane hole ($\sim$18×18 cm), and a thickness of 0.86 ($\pm$0.02) rad. len. for single thickness ("1" in the Table 1). For runs 72952, 72953 two shielding sheets were used ("2" for double thickness in the Table 1).

To extract CPP trigger rate we used the methodology described in Ref. [3]. The random triggers were analyzed to estimate the rate for the CPP experiment for a trigger based on TOF scintillators only. In addition, the time between FCAL trigger events, which were taken concurrently with random triggers, was used to compute the FCAL trigger rate.

Table 2 shows event ranges for certain beam current values with beam trips being cut off. According to the EPICS data, the beam current was within 10 % of the nominal value given in the table for the selected intervals. The results were scaled linearly from the actual EPICS value to the nominal beam current.

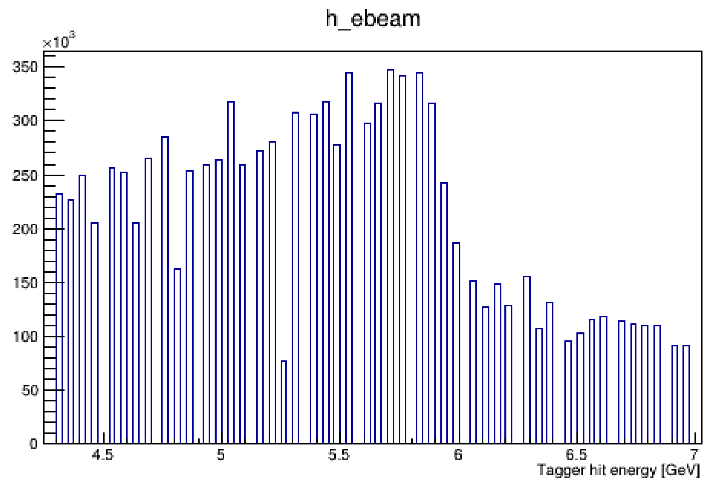

Figure 1: Tagger hit energy distribution for CPP test runs

Table 1: TOF trigger test run configuration

Run	Shielding	Target	DIRC
72914	No	LH2	In
72915	No	Empty	In
72949	No	LH2	Out
72950	1	LH2	Out
72952	2	LH2	Out
72953	2	Empty	Out
72954	1	Empty	Out
72956	No	Empty	Out

Table 2: Beam current in the selected event intervals

Run	Beam, [nA]	Event range, [M]
72914	20	0.1-2.9, 5.7-9.0, 14.4-18.4, 19.8-22.0
72914	40	43.9-54.3
72914	30	61.0-68.3
72914	10	71.4-75.9, 77.0-84.6
72915	40	0.1-4.2, 8.4-10.0
72915	30	15.0-22.0
72915	10	44.8-47.6, 48.8-53.9
72949	20	0.2-2.6, 3.5-17.7, 19.6-26.2
72949	40	29.8-30.2, 31.1-31.5, 31.7-32.6, 33.0-42.7, 43.6-44.8, 45.1-50.3, 51.1-62.8
72949	30	65.6-69.7, 75.1-78.3, 79.0-85.2
72949	10	102.4-110.5, 111.6-117.5, 117.7-129.7
72950	20	4.6-8.1, 8.4-12.7, 19.4-21.1
72950	40	27.0-31.6, 33.3-35.6, 40.0-42.8, 43.0-47.6
72950	30	54.6-63.2, 75.0-76.9
72950	10	77.8-95.9, 96.6-99.1
72952	20	8.2-20.7
72952	40	35.1-44.8, 46.3-47.4, 53.0-54.3
72952	30	57.7-65.5, 65.8-67.1, 68.6-74.1
72952	10	86.5-86.7, 92.5-92.7, 98.4-98.5
72953	20	0.8-2.6, 3.4-14.2, 14.4-21.4
72953	40	26.0-30.0, 30.6-30.8, 40.1-48.9
72953	30	54.8-58.6, 58.9-65.0, 68.1-69.8
72953	10	85.0-91.6, 94.4-103.0
72954	20	0.1-7.0, 7.2-15.6, 16.7-20.7
72954	40	27.8-34.8, 36.0-38.4
72954	30	62.6-76.4, 76.6-77.7
72954	10	86.3-89.0, 90.1-96.9, 97.8-98.8, 99.0-100.2
72956	20	3.1-5.1, 6.4-8.6, 9.9-15.1, 17.3-19.0, 20.3-26.0
72956	40	29.7-35.2, 35.4-39.4, 41.5-46.4, 48.0-49.2
72956	30	52.3-53.0, 54.3-55.2, 73.0-90.1
72956	10	95.4-100.5, 101.5-106.8, 109.6-114.8
72958	40	0.1-2.6, 4.5-4.9, 5.2-5.5, 5.7-9.7, 10.0-14.3, 14.6-16.2, 16.4-20.8, 22.1-27.2, 27.4-32.6, 32.8-73.5

2 CPP trigger rates

The results of the TOF trigger rate analysis were calculated for four optional conditions:
1) The "default" TOF trigger condition (threshold ∼30 mV): at least one trigger group fired in each TOF plane and at least four groups in both TOF planes. Trigger grouping will be discussed in more detail in section 3, page 8;
2) same with the increased TOF hit amplitude threshold to 280 counts (∼50 mV);
3) with the requirement of at least two groups per TOF plane;
4) same with the assumption that every individual TOF counter has its own trigger bit in the trigger word, i.e. no groupping of TOF counters; trigger word has 100 bits (as many as TOF counters).

To calculate the rate for the first three conditions the grouping pattern shown on Fig. 2 has been used.

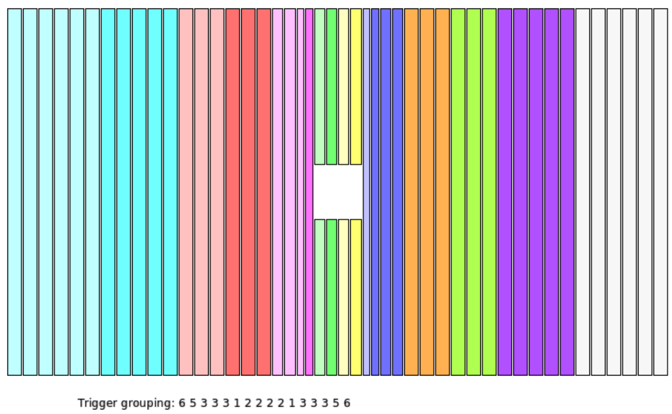

Figure 2: TOF counters grouping pattern initially used in the analysis. Counters marked with the same color belong to the same group

The rates obtained without lead shielding are presented in the Table 3, and the rates for the configuration #3, defined in the beginning of this section (two or more triggered TOF groups per plane), are presented in the Table 4 and in Fig. 3 below. The beam with the nominal CPP conditions produces ∼30 kHz TOF trigger rate, which is well below the Hall–D DAQ limits. The lead shielding now gives only about 15%-20% rate reduction (compare with 40%-50% reduction effect observed with the old TOF detector and larger size shielding). Multiplicity of hits in TOF, FCAL, and BCAL banks for 20 nA current, no DIRC, and no shielding installed are shown in Fig. 4. The TOF multiplicity was significantly lower than previous tests when the TOF aperture was $12 \times 12\text{cm}^2$.

Table 3: The measured TOF trigger rates without shielding. Values are in kHz and errors are statistical. The item marked with red color shows the nominal CPP beam conditions.

Beam current, [nA]	Condition (see the text)			
	#1	#2	#3	#4
with DIRC, full target				
10	13.0±0.1	8.7±0.1	10.4±0.1	17.0±0.2
20	24.8±0.2	16.7±0.1	19.8±0.2	32.2±0.2
30	37.9±0.3	25.3±0.2	30.3±0.3	48.8±0.4
40	53.8±0.5	35.7±0.4	42.8±0.4	69.3±0.6
with DIRC, empty target				
10	5.0±0.2	3.5±0.1	4.0±0.1	6.3±0.2
20				
30	13.5±0.2	9.7±0.1	11.1±0.1	16.9±0.2
40	17.8±0.3	12.5±0.2	14.5±0.2	22.6±0.5
No DIRC, full target				
10	20.3±0.1	13.7±0.1	16.2±0.1	25.4±0.1
20	38.1±0.1	25.4±0.1	30.2±0.1	47.3±0.1
30	59.4±0.2	39.4±0.1	46.5±0.1	73.5±0.2
40	85.7±0.1	56.2±0.1	66.5±0.1	105.3±0.2
No DIRC, empty target				
10	7.6±0.1	5.6±0.1	6.3±0.1	9.3±0.1
20	14.6±0.1	10.6±0.1	12.0±0.1	17.7±0.1
30	21.9±0.1	15.8±0.1	18.0±0.1	26.6±0.1
40	30.0±0.1	21.6±0.1	24.6±0.1	36.2±0.1

Table 4: The measured TOF trigger rates for minimum two groups triggered per TOF plane condition. Values are in kHz and errors are statistical. The item marked with red color shows the nominal CPP beam conditions.

Beam current, [nA]	Shielding		
	None	Single	Double
No DIRC, full target			
10	16.2±0.1	12.2±0.1	12.2±0.3
20	30.2±0.1	23.0±0.1	23.5±0.1
30	46.5±0.1	35.1±0.2	34.5±0.1
40	66.5±0.1	47.8±0.2	46.8±0.2
No DIRC, empty target			
10	6.3±0.1	5.4±0.1	5.1±0.1
20	12.0±0.1	10.2±0.1	10.2±0.1
30	18.0±0.1	15.3±0.1	14.5±0.1
40	24.6±0.1	20.1±0.1	19.9±0.1

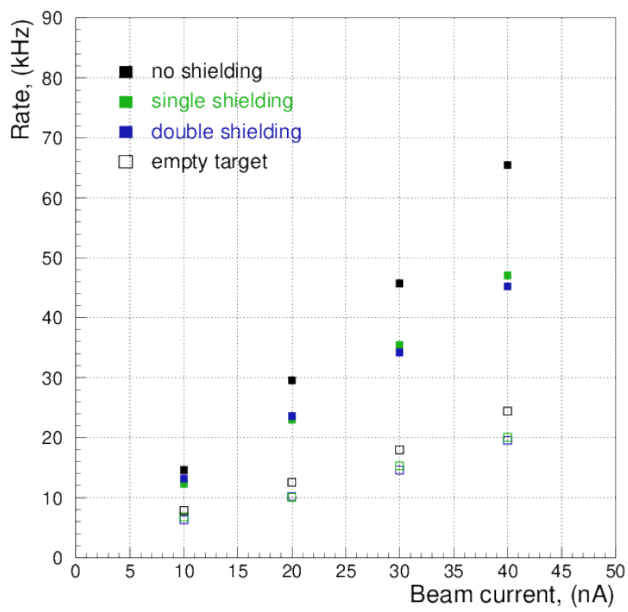

Figure 3: TOF trigger rate values presented in the Table 4 as a function of beam current. Filled squares – LH_2 target, empty squares – empty target. Black color – no shielding, green – single lead sheet installed, blue – two lead sheet installed. The rates are given for the minimum of two active TOF groups per plane condition.

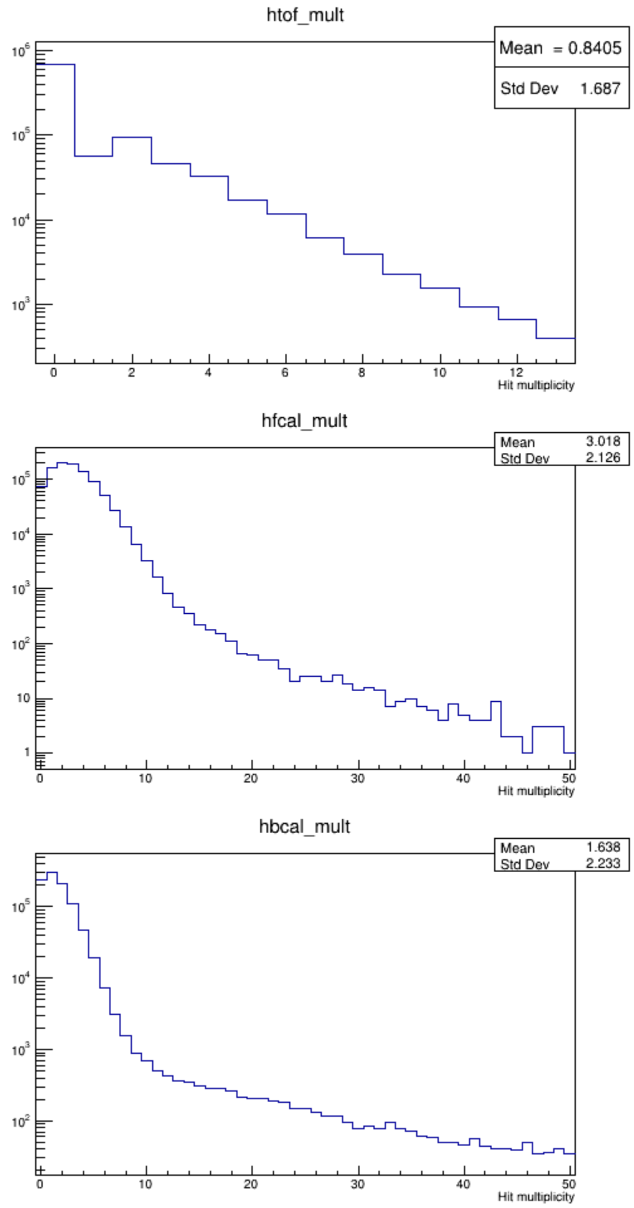

Figure 4: Hit multiplicities in TOF (top), FCAL (middle) and BCAL (bottom) for a beam current of 20 nA, with the DIRC and lead shielding removed.

3 TOF grouping into trigger word

The TOF trigger has been organized by grouping 50 TOF counters per plane into 16 trigger bits per plane. We have tested various grouping patterns for the registration of pion pairs (in the mass region up to 500 MeV) efficiency and for the background rate using the simple tool [4]. While the most efficient in terms of signal acceptance pattern is obviously assigning to every TOF counter an individual trigger bit (let's call it the "reference" pattern), such trigger logic would produce higher trigger rates. The optimal grouping should have high signal efficiency (>90%) and minimize the total trigger rate. We have selected the set of patterns for testing, which are symmetrical vs left-right and upside-down reflection. For the full length counters for the TOF, we assume that the number of counters in each the group is equal to or larger than the preceding group closer to the beamline. For the half length counters we have selected 6 different patterns: 1) all counters are in one group; 2) two groups: top and bottom counters; 3) two groups: left and right counters; 4) four groups: top and bottom counters in every "column" are grouped together; 5) four groups: top-left, top-right, bottom-left, and bottom-right counters; 6) all 8 central counters have an individual group assigned. The whole tested set included 3990 patterns. All patterns shown on Fig. 5 as a function of two parameters: efficiency related to the "reference" pattern efficiency (marked with red square), and ratio of the efficiency to total trigger rate. We have selected six patterns with the best efficiency and signal/trigger rate parameters set (shown with red stars and red numbers on the right plot) and presented in Fig. 6. Table 5 gives their grouping scheme, acceptance, and signal to trigger rate ratio.

Table 5: The selected TOF grouping pattern parameters. The star (*) indicated repeated groups. For example 8*1 denotes eight groups of one counter, i.e. 8*1 is equivalent to 11111111. $2^{\boxplus}$ denotes half size counters grouping as shown in Fig. 6, and $2^{||||}$ is for grouping counters in the same column (Fig. 2).

Pattern	number of groups	grouping scheme	relative acceptance	acceptance / trigger rate, [a.u.]
1	4	21-4-4-21	0.888	1.28
2	6	21-4*$2^{\boxplus}$-21	0.918	1.29
3	6	20-1-4-4-1-20	0.942	1.10
4	8	19-2-4*$2^{\boxplus}$-2-19	0.977	1.07
5	10	19-1-1-4*$2^{\boxplus}$-1-1-19	0.994	0.99
6	12	18-1-1-1-4*$2^{\boxplus}$-1-1-1-18	0.999	0.93
"reference"	50	50*1	≡1	0.79
from fig. 2	16	6-5-3-3-3-1-4*$2^{||||}$-1-3-3-3-5-6	0.957	0.85

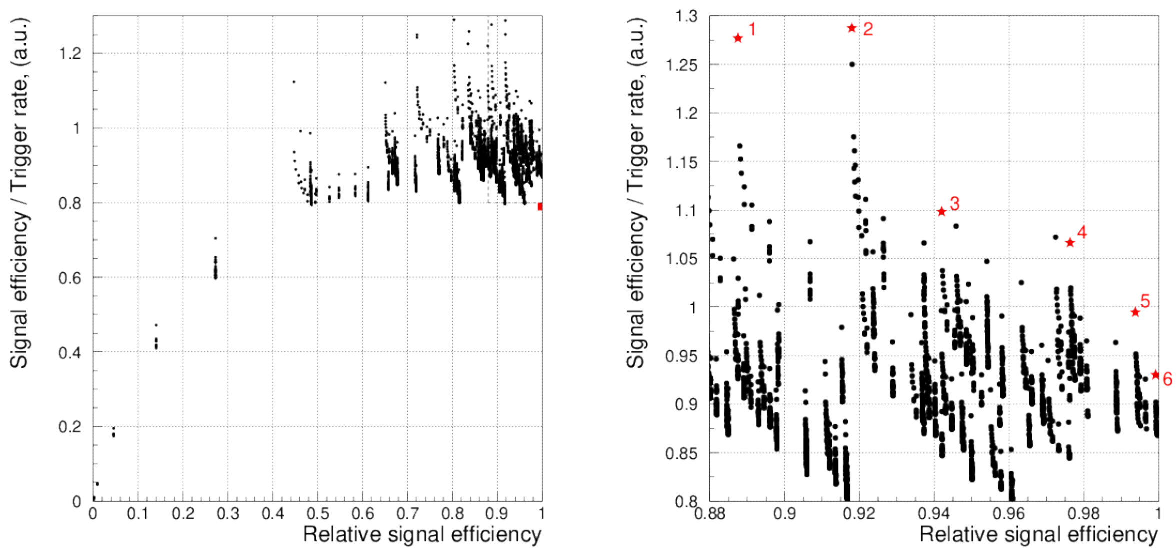

Figure 5: Tested TOF grouping patterns as a function of efficiency related to the "reference" pattern, and efficiency to background rate ratio in arbitrary units. The "reference" pattern is marked with a red square on the left plot. The right plot is a blow-up of the left plot. The enumerated patterns are marked with red stars.

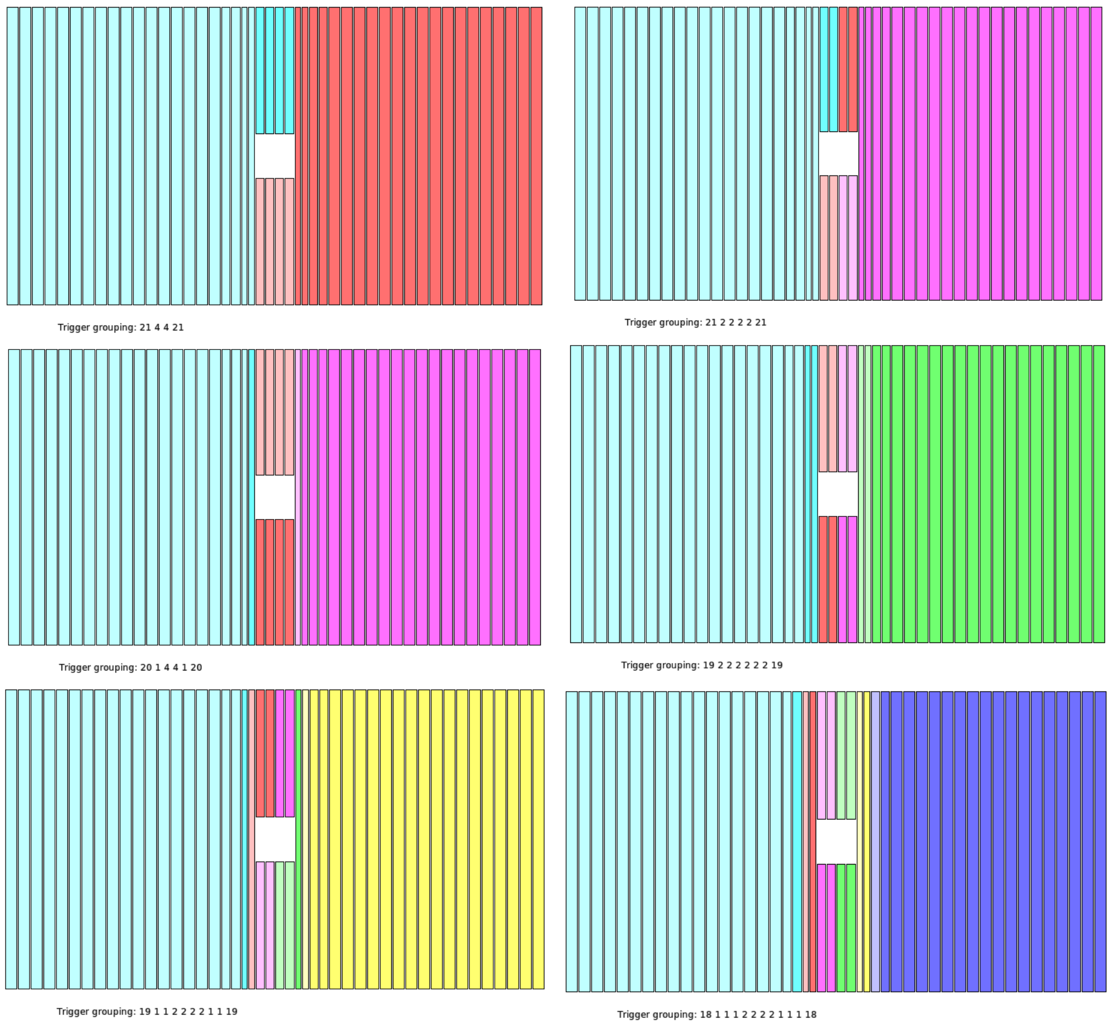

Figure 6: Selected patterns from Fig. 5: top left – 1; top right – 2; ...; bottom right – 6. The TOF groups are marked with different colors.

4 Results

The main result of the test is that the rates measured with the new TOF is about 7 times lower than observed during the February 2019 test, due to the enlarging of the TOF aperture around the beam hole from 12×12 cm^2 to 18×18 cm^2. The rates observed with the DIRC installed were about 1.5 times lower, than after removal of this detector. Another result of the test is that the lead shielding with the enlarged aperture matching the TOF aperture reduces the rate only by 15%-20% (compare with 40%-50% effect observed during the Feb-2019 test). The double lead shielding had about the same reduction effect as a single sheet. That is likely due to the harder spectrum of electrons at larger distances (from 6 to 9 cm) from the beam line. The trigger rate values obtained during the test should be scaled (up) from 3% to 5% rad. len. target and from the trigger grouping pattern used in analysis to the pattern which is going to be used during the CPP experiment. We put the result of these calculations to the Table 6 below (minimum two active TOF groups per plane). The

Table 6: The expected TOF trigger rate (in kHz) for 5% rad. len. target

Pattern (table 5)	Relative Aceptance	Beam current 20 nA	Beam current 30 nA
1	0.888	26	40
2	0.918	27	42
3	0.942	32	50
4	0.977	34	54
5	0.994	38	59
6	0.999	41	63
"ref."	$\equiv 1$	48	77

patterns 2 and 4 look preferable, and pattern 1, which has top signal/background ratio, looks simple enough (for minimization of systematics coming from geometry acceptance) to be considered as well. All rate values are below the Hall–D DAQ limits for 20 and 30 nA current.

5 FCAL trigger rate

FCAL triggers will provide a valuable source of events during the CPP experiment. First, because they may be used to determine the efficiency of the TOF trigger. Second, the experiment to measure the neutral pion polarizability [5] will run concurrently with CPP and require a calorimeter-only trigger to select photon showers from π^0 decays. Therefore, we have extracted the rate for FCAL triggers during the test to estimate the contribution of this trigger type to the total rate. FCAL triggers were present in the data stream during the test using the standard GlueX energy sum threshold. This allowed us to extract FCAL trigger rate. For this purpose we plotted the time difference between two subsequent triggers and fit the distribution with the exponential function. Figure 7 shows this distribution for 20 nA beam current for runs without DIRC and lead shielding, with LH2 and empty targets. The time units used here are milliseconds, thus the slope from the fit gives directly the trigger rate in kHz. The expected rate for the 5% rad.len. target can be estimated by scaling up the rate from 3% rad. len. LH2 target: $Rate(5\%) = \frac{5}{3}\{Rate(3\%) - Rate(empty)\} + Rate(empty)$. Which gives in our case **13 kHz value for 20 nA beam** and standard GlueX energy threshold. Fig. 8 shows FCAL hits energy sum distribution for FCAL trigger events, the threshold is around 0.5 GeV value.

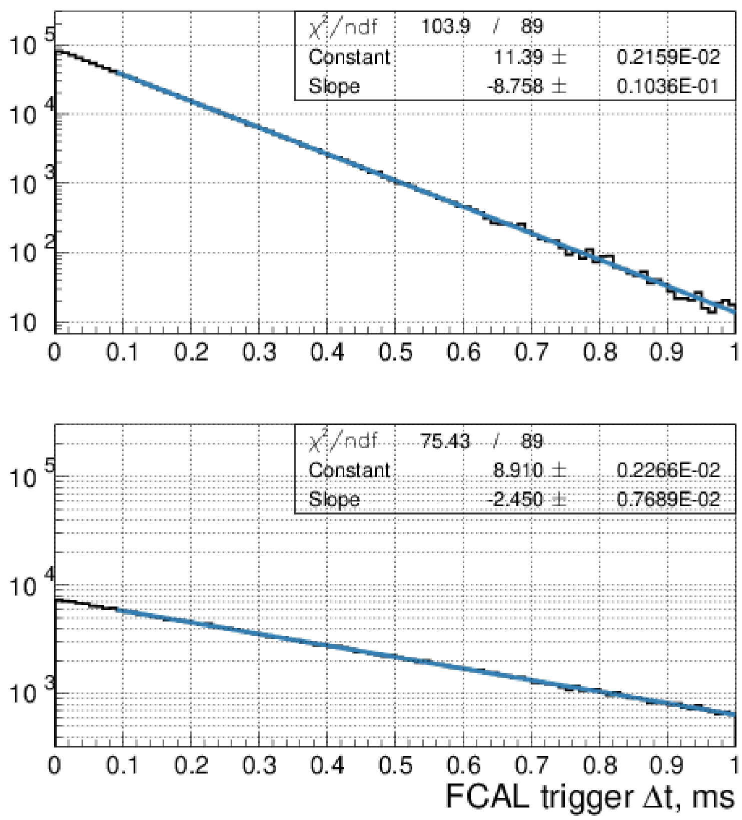

Figure 7: Time between two adjacent FCAL trigger events for 20 nA beam current. Top – LH2 target, bottom – empty target.

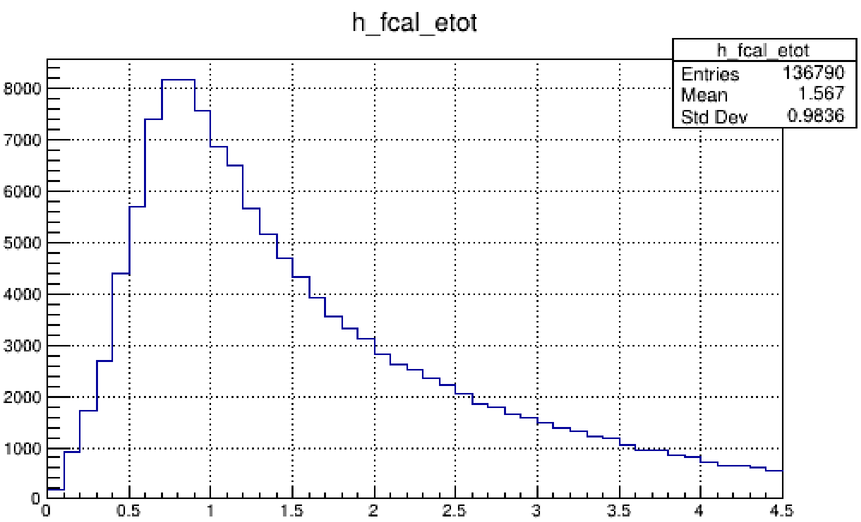

Figure 8: Sum of FCAL modules energy in FCAL trigger events.

References

[1] $https://halldweb.jlab.org/DocDB/0021/002199/004/PionPolarizabilityPAC40.pdf$

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[3] I. Larin, D. Lawrence, R. Miskimen, A. Schick, E. Smith,
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$https://halldweb.jlab.org/DocDB/0040/004065/001/tof\_shielding\_test.pdf$

[4] $https://github.com/ilyalarin/cpp\_tof\_grouping.git$

[5] $https://halldweb.jlab.org/doc-public/DocDB/ShowDocument?docid=4373$