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Abstract

A redundant muon trigger system was implemented at the TOPAZ detector for the phase-II TRISTAN experiment. This system is mainly based on fast signals from barrel muon chambers, and is free from the other tracking detectors. The trigger rate has been stable at 0.5 Hz, which was dominated by cosmic-ray background. The trigger efficiency was obtained to be $92.5 \pm 0.7\%$ for the $e^+e^- \rightarrow \mu^+\mu^-(\gamma)$ process in the polar-angular region of $|\cos\theta_\mu| < 0.63$. With this system, the inefficiency of the previous trigger system was measured with an accuracy of $O(0.1\%)$ for the above process.

1 Introduction

Since 1991 the TRISTAN e^+e^- collider has been operated at high luminosity (phase-II stage) at $\sqrt{s}=58$ GeV. The main purposes of the phase-II experiments are precise measurements of the e^+e^- annihilation process and collisions between two quasi-real photons. The integrated luminosity has exceeded 300 pb^{-1} in each experimental group. One of the most interesting subjects is the measurement of total cross section for $e^+e^- \rightarrow \mu^+\mu^-(\gamma)$, since it has been reported to be less than the standard model(SM) expectation[1], while LEP measurements at the Z^0 resonance show very good agreement with the SM[2]. In order to confirm our measurement and understand this difference, eliminations of possible uncertainties in the trigger efficiency were necessary. For this purpose, we added a muon trigger system to the TOPAZ trigger system in 1992, which served as a second trigger system for muon pair events.

Figure 1: Cross-sectional view of the TOPAZ detector.

The TOPAZ detector is a general-purpose magnetic spectrometer at TRISTAN (Fig. 1). The central tracking device is a time-projection chamber (TPC)[3] covering the polar angular region $|\cos\theta| < 0.87$. Inside the TPC there are two tracking chambers, a trigger chamber (TCH) and a vertex chamber (VTX). Time-of-flight counters (TOF)[4] surround the TPC. These are located in a solenoidal magnetic field of 1 Tesla. The electromagnetic calorimeters comprise forward calorimeters (FBC,LUM)[5], an endcap calorimeter (ECL)[6], a barrel calorimeter (BCL)[7] and a ring calorimeter (RCL) to cover the gap between the ECL and BCL, which together are hermetic down to $\theta = 60$ mrad. Muon chambers are the outermost devices used to measure muons penetrating iron absorbers (Muon Filter), and comprise barrel (BMU) and forward (FMU) muon chambers in the barrel region and both ends. The BMU consists of three layers of drift chambers interleaved with the Muon Filters, while the FMU is made of one layer behind a Muon Filter.

The muon trigger system uses signals from the BMU and the TOF, while the previous trigger system for charged tracks uses the signals from the TCH, the TPC and the TOF. Because of this complementary usage of detectors, this system can eliminate the major uncertainties in the determinations of trigger efficiency for muon pair events.

Figure 2: Overview of the trigger system.

2 Trigger system

The TOPAZ trigger system comprises three levels according to the maximum decision times, which are $1.5 \mu\text{sec}$, $30 \mu\text{sec}$ and 1.5 msec for the first-, second-, and third-level triggers, respectively (schematically shown in Fig. 2). The general features of the trigger system before a muon trigger are described briefly [8,9,10].

The first-level trigger (pretrigger) [8] comprises one forced and one track pretrigger. The forced pretrigger comprises: (i) an energy trigger requiring that the total energy deposits in the BCL and the ECL are more than 4 and 10 GeV, respectively; (ii) the other energy triggers of the FBC and the LUM require at least one energy deposit of more than 10 GeV at both ends, where the LUM-trigger is scaled down by 10; and (iii) a random trigger with a frequency of 0.1 Hz. The track pretrigger is made from the coincidence between the TCH and the TOF, requiring that two or more tracks are found with their opening angle being more than 45° , typically in the transverse plane. The pretrigger opens the gating grid of the TPC to initiate the TPC digitization cycle. The forced pretrigger remains as the final trigger to read out all signals, while the track pretrigger passes the decision to the next level trigger. The typical pretrigger rate was 10-100 Hz, depending on the beam conditions, while the forced pretrigger rate was about 1 Hz, mainly due to cosmic rays. The second-level trigger (TPC trigger) [8,9] requires two or more tracks to be found in the TPC where the z-vertex positions along the beam direction (V_z) were reconstructed so as to be in the vicinity of the interaction point by the hard-wired

logic circuits. The FWHM of the V_Z distribution was obtained to be 60 cm by an offline analysis, where most of the tracks came from beam-gas events which were distributed uniformly along a beam line. The typical trigger rate was 2-10 Hz, which also depended on the beam conditions. The third-level trigger (software trigger)[10] further requires more precise V_Z reconstruction by software employing four micro-processors. The resultant FWHM of the V_Z was 40 cm. It typically reduced the TPC trigger rate by half.

3 Muon trigger system

Since the muon trigger system comprises only signals of the BMU and TOF, it was made by hard-wired logic circuits and installed into the forced pretrigger, as shown in Fig. 2. The relevant aspects of the BMU and TOF are described as follows.

Since the TPC is an octagonally shaped detector (TPC-octagon), the BMU chambers are also grouped into eight sectors forming a BMU octagon(Fig. 3(a)). The BMU octagon is tilted from the TPC octagon by a half octant-angle (22.5°). The sector comprises three layers numbered from inside to outside (layer 1 to 3). Each layer is made of two planes of drift tubes measuring the ϕ coordinates (ϕ tubes), except layer 3, which has an additional plane of drift tubes which measure the z coordinates (z tubes). For the muon trigger, only the ϕ tubes are used. The ϕ tubes have a single-cell structure with a cross section of 5×10 cm² and are 6.8 m long. The maximum drift time is approximately $1 \mu\text{sec}$. As a construction unit, eight tubes are grouped together as a module, as shown in Fig. 3(b). In each module, two planes of 4 tubes are staggered by a half cell. However, two modules in a sector comprise 6 tubes in order to fill the gap between the adjacent sectors. Layers 1,2 and 3 comprise 6,7 and 8 modules, respectively(Fig. 3(a)). For the readout of signals from the tubes, amplifiers and discriminators are attached to each tube in the module. The 8(6) signals from each module are combined into a fast-OR signal at the electronics hut, which are provided for the trigger system. The total number of the fast-OR signals is $168 = 8(\text{sectors}) \times (6(\text{layer 1})+7(\text{layer 2})+8(\text{layer 3}))$. In order to find tracks(muons) in the sector, the logic of six track-segments (t1–t6) was made, as indicated by the dashed lines in Fig. 3(a).

The TOF comprises 64 scintillators surrounding the TPC around the ϕ directions[4]. This segmentation was chosen to match that of the TCH for the track pretrigger. Exactly 8 counters cover the angular region of a single TPC and BMU sector (45°). Each TOF counter is 4 m long, 13 cm wide and 4.2 cm thick. The timing of the signals from the photomultipliers at both ends of the scintillator are averaged by mean-timers. Combining the signals from every adjacent counter, 32 TOF-signals are provided for the muon trigger as well as for the track pretrigger.

The general scheme of the muon trigger system is shown in Fig. 4. It comprises three kinds of electronic modules: (i) eight BMU/TRACK modules to reconstruct tracks in the sector; (ii) a BMU/TOF module to make a coincidence of the tracks and the TOF-signals, which are also used as fast-timing gates; and (iii) a topological(wide

Figure 3: Configuration of the BMU, TOF and TPC: (a) cross-sectional view of the octagons of the BMU and TPC, where one BMU-sector comprises 21 modules, among which two modules comprise six drift tubes indicated by shaded area while the others comprise the eight tubes, and 4 TOF-signals corresponding to a BMU sector is also depicted; (b) the structure (cross section) of a single module(8 tubes).

Figure 4: Muon trigger system

angle) module to find two tracks with a large opening angle. The various logic patterns have been derived from simulated muon pair events of $e^+e^- \rightarrow \mu^+\mu^-(\gamma)$ as well as from our experimental data[1]. The events have two high-energy muons with opening angle of about 180° with radiated photons. The muon trigger system was optimized to these events. In the following sections the details of these modules are described.

3.1 BMU/TRACK module

As mentioned in the previous section, the 21 Fast-OR signals from the sector are fed into one BMU/TRACK module. Track segments are then searched for, based on the coincidence logic shown in Fig. 5. In the BMU/TRACK module, Fast-OR signals of each layer are grouped into six segments, as listed in Table 1. For layers 2 and 3, the signals are shared with the adjacent segments so that muons crossing the boundaries between the segments can also be recognized. If the segments of the same number have signals in all three layers, a track is considered to be found in the corresponding segment.

The BMU/TRACK modules are made in a "wide CAMAC" standard[11], which has the same protocol and the same pin assignment at the back plane as that of the standard CAMAC while the larger ($28.7 \times 27.2 \text{ cm}^2$) printed circuit(PC) boards are used. A block diagram of the BMU/TRACK module is shown in Fig. 6. First, the

Figure 5: Coincidence logic of one track segment(t_1 as an example)

Layer #	Module # for six track segments					
1	1	2	3	4	5	6
2	1 , 2	2 , 3	3 , 4	4 , 5	5 , 6	6 , 7
3	1 , 2	2 , 3	3 , 4	4 , 5	6 , 7	7 , 8

Table 1: Assignments of signals(modules) in the six track segments for the three layers.

Figure 6: Block diagram of the BMU/TRACK module.

21 input signals at the ECL level are converted to ones in the TTL level. They are gated with a $1.5 \mu\text{sec}$ width to ensure the completion of the signals from the BMU. Then they are latched for the trigger logic circuit as well as for the veto trigger. The veto trigger is another software trigger used to reduce the BCL energy threshold down to 2 GeV, vetoing cosmic-ray background by using the pattern recognition of the BMU and the BCL[12]. Tracks penetrating all three layers are searched in the trigger logic circuit (as just mentioned above). The result of track finding is provided as an output of six signals corresponding to the six track-segments in the TTL level. In total, 48 signals are transferred from the eight BMU/TRACK modules to a BMU/TOF module. Optionally, the hit pattern of the 21 input signals can be read by a CAMAC read cycle(F(0)A(0)). Also, a test pattern for the input signals can be written by a CAMAC write cycle(F(16)A(0)) in order to check the trigger system. The other CAMAC functions are summarized in Table 2.

3.2 BMU/TOF module

The BMU/TOF module was also made with the wide CAMAC standard. Figure 7 shows a block diagram. As mentioned in the previous section, the input comprises 48 and 32 signals from the BMU and the TOF, respectively, where both are numbered counter-clockwise, as shown in Fig. 3(a). The 32 TOF signals are already gated with a 50 nsec beam-crossing timing. The 50 nsec gating was important for

F(0) A(0)	Read input BMU data (21 ch)
F(0) A(1)	Read output(BMU/TOF) data (6 ch)
F(9) A(0) S(2)	Clear the input data
F(9) A(1) S(2)	Clear the output data
F(16) A(0) S(1)	Write the input data
F(17) A(0) S(1)	Write the output data
F(24) A(0) S(2)	Disable to latch the written data
F(25) A(0) S(2)	Enable an external gate
F(26) A(0) S(2)	Enable to latch the written data

Table 2: CAMAC functions of the BMU/TRACK module.

Figure 7: Block diagram of the BMU/TOF module.

TOF ---- BMU/TRACK	TOF ---- BMU/TRACK	TOF ---- BMU/TRACK
T1 ---- t 4, t 5 T2 ---- t 5, t 6 T3 ---- t 6, t 7, t 8 T4 ---- t 8, t 9 T5 ---- t 10, t 11 T6 ---- t 11, t 12 T7 ---- t 12, t 13, t 14 T8 ---- t 14, t 15 T9 ---- t 16, t 17 T10 ---- t 17, t 18 T11 ---- t 18, t 19, t 20 T12 ---- t 20, t 21 T13 ---- t 22, t 23 T14 ---- t 23, t 24	T15 ---- t 24, t 25, t 26 T16 ---- t 26, t 27 T17 ---- t 28, t 29 T18 ---- t 29, t 30 T19 ---- t 30, t 31, t 32 T20 ---- t 32, t 33 T21 ---- t 34, t 35 T22 ---- t 35, t 36 T23 ---- t 36, t 37, t 38 T24 ---- t 38, t 39 T25 ---- t 40, t 41 T26 ---- t 41, t 42 T27 ---- t 42, t 43, t 44 T28 ---- t 44, t 45	T29 ---- t 46, t 47 T30 ---- t 47, t 48 T31 ---- t 48, t 1, t 2 T32 ---- t 2, t 3 <hr/> <div style="border: 1px solid black; padding: 5px; width: fit-content; margin: 10px auto;"> Typical BMU/TOF logic </div> <div style="margin-top: 10px;"> T3 (TOF#3) t 6(BMU #6) t 7(BMU #7) t 8(BMU #8) </div> <div style="margin-top: 10px; text-align: right;"> Ti=1~32 ti=1~48 </div>

Table 3: Logic of the coincidence between the BMU and the TOF.

Figure 8: Four typical kinds of combination-patterns for the BMU trigger, where the values in the parentheses are the numbers of patterns.

reducing the trigger rate due to cosmic-ray background to 0.5 Hz, which was proportional to the gate width. The coincident logic between the BMU and the TOF (BMU/TOF LOGIC) is listed in Table 3, which has also been derived from simulated and experimental muon pair events, as in the case of the BMU-track logic. After the BMU/TOF LOGIC, an output of 32 bits is provided for the wide-angle module, which has also been used in the track pretrigger system[8]. The opening angle of two tracks was set to be between 112.5° and 157.5° for the muon trigger.

In addition, the BMU/TOF module can also produce a trigger with only the BMU signals in order to check out the BMU system by itself, which is called a BMU trigger. The topologies of “two tracks” are generally classified into four by a RAM matrix (RAM: MB81C78A-35, Fujitsu, Japan), as shown in Fig. 8, and are listed in Table 4. The topologies are made for the sectors where the tracks are found. All the patterns for the topologies are written by the CAMAC write cycle (F(18)A(0)). The other CAMAC functions are summarized in Table 5, which are similar to those

	Combination -patterns of two sectors	# of patterns
(a)	S1*S5, S2*S6, S3*S7, S4*S8	4
(b)	S1*S2, S2*S3, S3*S4, S4*S5, S5*S6, S6*S7, S7*S8, S8*S1	8
(c)	S1*S3, S2*S4, S3*S5, S4*S6, S5*S7, S6*S8, S7*S1, S8*S2	8
(d)	S1*S4, S2*S5, S3*S6, S4*S7, S5*S8, S6*S1, S7*S2, S8*S3	8
	Total number of patterns	28

Table 4: Combination-patterns of two sectors used in the BMU trigger. S_i*S_j shows AND logic of two sectors of S_i and S_j where tracks are found.

F(0) A(0)	Read BMU/TRACK of 1-24 channels
F(0) A(1)	Read BMU/TRACK of 25-48 channels
F(0) A(2)	Read TOF data of 1-16 channels
F(0) A(3)	Read TOF data of 17-32 channels
F(1) A(0)	Read a matched pattern number(4 bits)
F(16) A(0) (S1)	Write TOF data of 1-16 channels
F(16) A(1) (S1)	Write TOF data of 17-32 channels
F(17) A(0) (S1)	Write a pattern of two sectors(8 bits)
F(18) A(0) (S1)	Write a corresponding pattern no. (4 bits)
F(24) A(0) (S1)	Disable to output BMU trigger
F(26) A(0) (S1)	Enable to output BMU trigger

Table 5: CAMAC functions of the BMU/TOF module

of the BMU/TRACK module.

4 Performance

The muon trigger system has been properly working for experiments since February, 1992. The performance of the muon trigger system was investigated by using 1622 muon pair events at $\sqrt{s} = 58$ GeV for an integrated luminosity of 154 pb^{-1} since then. The relevant selection criteria are briefly described below for these events[1]. These events were selected without using the BMU. Muon pairs were identified as high-momentum tracks of $p > 1/3 E_{beam}$ with small energy deposits in the BCL. The time differences measured by the TOF were required to be less than 5 nsec to reject any cosmic-ray background. The opening angle of the muons had to be greater than 170° . Their polar angular region was tightened to be $|\cos \theta| < 0.63$ in order to ensure that they were fully reconstructed in the BMU.

Figure 9: The $\cos\theta$ distribution of muons in $e^+e^- \rightarrow \mu^+\mu^-(\gamma)$ events, where the vertical axes are numbers of muons per a cosine bin of 0.04. The muons which were triggered by the present trigger system are plotted by black circles, while four histograms show muons which were missed by (a) the previous trigger (a sum of (b),(c) and (d)), (b) the second level trigger, (c) the third level trigger and (d) the track pretrigger.

The $\cos\theta$ distributions of those muons are shown in Fig. 9. By using the muon trigger as a reference, the inefficiencies of the original track trigger system were obtained as a function of $\cos\theta$, which is shown as the histogram in Fig. 9. Because of the existence of a central membrane in the TPC, the total inefficiency distribution has a sharp peak at $|\cos\theta| < 0.1$, as already reported[1,9]. In the previous $\mu^+\mu^-$ analysis before installing the muon triggers, we excluded this region from the analysis. The total inefficiency was measured to be $5.9\pm 0.6\%$, while it was $1.5\pm 0.3\%$ for $|\cos\theta| > 0.1$. Figure 9 also shows the distributions of inefficiencies at each step of the trigger. The inefficiencies were measured to be $0.9\pm 0.2\%(0.7\pm 0.2\%)$, $4.4\pm 0.5\%(0.2\pm 0.1\%)$ and $0.6\pm 0.2\%(0.5\pm 0.2\%)$ at the track pretrigger, the second-level trigger, and the third-level trigger, respectively; the values in the parentheses were those for $|\cos\theta| > 0.1$. It is clear that the inefficiency was dominated by the second-level trigger, where the TPC signals were used exclusively. The inefficiency of the third-level trigger was consistent with the previously estimated value of 0.5%[10].

Inversely, by using the original trigger system as a reference, the efficiency of the muon trigger was estimated. In the total 1622 $\mu^+\mu^-$ events, 1501 events were actually triggered by the muon trigger. This corresponds to a trigger efficiency of $92.5\pm 0.7(\text{statistical})\%$. Among the reasons for the inefficiency, the dominant one was due to the geometrical gaps between the sector boundaries of the BMU, whose inefficiency was estimated to be $5.1\pm 0.5\%$.

5 Summary

A muon trigger system was developed for the TOPAZ experiment at TRISTAN. The role of this system was to strengthen our reliability of triggering muon pair events which had been triggered only by the TPC trigger before the installation. This system was based on the BMU signals as well as the TOF signals with no requirement of the TCH and the TPC signals. It was installed as one of the forced pretriggers, such as the energy triggers, whose decision time was typically 1.5 μsec . In this sense, the muon trigger system was redundant to the previous system. The performance was studied by using the measured muon pair events after the installation. The overall trigger efficiency was $92.5\pm 0.7\%$, whose inefficiency was dominated by the sector boundaries of the BMU. No enhancement of the inefficiency was observed in the vicinity of the central membrane of the TPC, where the corresponding angular region ($|\cos\theta| < 0.1$) had been excluded in the published analysis. The inefficiencies in the track pretrigger as well as the second- and third-level triggers were measured with an accuracy of $O(0.1\%)$, which were consistent with the previously estimated values. Therefore, we can confidently trust the trigger efficiency for muon pair events. This is very important for precise measurements at the phase-II TRISTAN experiment.

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