Chinese Physics C

Study of BESIII trigger efficiencies with the 2018 J/ψ data *

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Abstract: Using a dedicated data sample taken in 2018 on the J/ψ peak, we perform a detailed study of the trigger efficiencies of the BESIII detector. The efficiencies are determined from three representative physics processes, namely Bhabha scattering, dimuon production and generic hadronic events with charged particles. The combined efficiency of all active triggers approaches 100% in most cases, with uncertainties small enough not to affect most physics analyses.

Keywords: BESIII, trigger efficiency, Bhabha, dimuon, hadronic events

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I. INTRODUCTION

The Beijing Electron-Positron Collider (BEPCII) is a double-ring multi-bunch e^+e^- collider with a design luminosity of 1×10^{33} cm^{-2} s^{-1}, optimized for a center-of-mass energy of 2×1.89 GeV, an increase of a factor of 100 more than its predecessor. The Beijing Spectrometer III (BESIII) detector operating at BEPCII is a multipurpose detector designed for the precision study of $\tau-$charm physics [1-3].

BEPCII collides electron and positron bunches at a frequency of 125 MHz. The main backgrounds in BESIII are caused by lost beam particles and their interaction with the detector, and the background event rate is estimated to be about 13 MHz [3]. In comparison, the signal rate at the J/ψ resonance is about 2 kHz and the BESIII data acquisition system can record events at a rate of up to 4 kHz. The task of the trigger system is thus to suppress backgrounds by more than three orders of magnitude whilst maintaining a high efficiency for signal events.

Monitoring the trigger efficiency carefully is important in order not to lose events due to inefficient triggers. A trigger efficiency study was performed in 2010 for data samples of J/ψ and $\psi(2S)$ events recorded in 2009 [4]. Slightly changed trigger conditions in 2018 motivate the study presented here.

The BESIII trigger system combines the information from the electromagnetic calorimeter (EMC), the main drift chamber (MDC), the time-of-flight system (TOF) and the muon counter (MUC) to form a total of 48 trigger conditions (Table 1) to select for readout of interest-

Table 1. Trigger conditions.

No.	Trigger Condition	Comments
	Electromagnetic calorimeter (EMC)	
0	NClus.GE.1	Number of Clusters ⩾ 1
1	NClus.GE.2	Number of Clusters ⩾ 2
2	BClus_BB	Barrel Cluster Back to Back
3	EClus_BB	Endcap Cluster Back to Back
4	Clus_Z	Cluster Balance in z direction
5	BClus_Phi	Barrel Cluster Balance in ϕ direction
6	EClus_Phi	Endcap Cluster Balance in ϕ direction
7	BEtot_H	Barrel total Energy, Higher threshold
8	EEtot_H	Endcap total Energy, Higher threshold
9	Etot_L	Total Energy, Lower threshold
10	Etot_M	Total Energy, Middle threshold
11	BL_EnZ	Energy Balance in z direction
12	NBClus.GE.1	Number of Barrel Clusters ⩾ 1
13	NEClus.GE.1	Number of Endcap Clusters ⩾ 1
14	BL_BBLK	Barrel Energy Block Balance
15	BL_EBLK	Endcap Energy Block Balance
	Time of flight system (ToF)	
16	ETOF_BB	Endcap TOF Back to Back
17	BTOF_BB	Barrel TOF Back to Back
18	NETOF.GE.2	Number of Endcap TOF hits ⩾ 2
19	NETOF.GE.1	Number of Endcap TOF hits ⩾ 1
20	NBTOF.GE.2	Number of Barrel TOF hits ⩾ 2
21	NBTOF.GE.1	Number of Barrel TOF hits ⩾ 1
22	NTOF.GE.1	Number of TOF hits ⩾ 1
	Muon counter (MUC)	
32	NABMU.GE.1	Barrel Tracks number ⩾ 1 for A
33	NAEMU.GE.1	Endcap Tracks number ⩾ 1 for A
34	NCBMU.GE.1	Barrel Tracks number ⩾ 1 for C
35	NCEMU.GE.1	Endcap Tracks number ⩾ 1 for C
36	CBMU_BB	Barrel Track Back to Back for C
37	CEMU_BB	Endcap Track Back to Back for C
	A: 2 of 4 Tracking; C: 3 of 4 Tracking	
	Main drift chamber (MDC)	
38	STrk_BB	Short Tracks Back to Back
39	NSTrk.GE.N	Number of Short Tracks ⩾ N
40	NSTrk.GE.2	Number of Short Tracks ⩾ 2
41	NSTrk.GE.1	Number of Short Tracks ⩾ 1
42	LTrk_BB	Long Tracks Back to Back
43	NLTrk.GE.N	Number of Long Tracks ⩾ N
44	NLTrk.GE.2	Number of Long Tracks ⩾ 2
45	NLTrk.GE.1	Number of Long Tracks ⩾ 1
46	NItrk.GE.2	Number of Inner Tracks ⩾ 2
47	NItrk.GE.1	Number of Inner Tracks ⩾ 1

ing interactions. A detailed description of the trigger system can be found in Refs. [2, 5]. The trigger conditions are combined into 16 trigger channels (Table 2) by the global trigger logic (GTL). The trigger conditions included in trigger channel 12 are delayed by 576 ns in order to distinguish neutral events from charged events. The event is read out if any enabled trigger channel is active.

Compared to earlier data taking periods, for the 2018 J/ψ data taking the CH09 trigger channel described in Table 2 was added as a high efficiency selection for neutral events with precise timing information. The CH03 channel described in Table 2 had to be disabled due to increased noise in the MDC, and some other trigger channels were not used, as marked in Table 2, since the trigger conditions in these trigger channels are already included or implied in "used" trigger channels.

Table 2. Trigger channels.

Channel	Conditions combination	Comments
CH01	NEClus.GE.1&& NETOF.GE.1&& STrk_BB	For Charged
CH02	NBClus.GE.1&& NBTOF.GE.2&& NLtrk.GE.2	For Charged
CH03	NBTOF.GE.2&& NLtrk.GE.2	Not used
CH04	BTOF_BB&& LTrk_BB	For Charged
CH05	Etot_L&& NBTOF.GE.1&& NLtrk.GE.1	For Charged
CH06	NBClus.GE.1&& NBTOF.GE.1&& NLtrk.GE.2	For Charged
CH07	–	Not used
CH08	–	Not used
CH09	NClus.GE.1&& BEtot_H	For Neutral
CH10	–	Random
CH11	NBTOF.GE.2&& LTrk_BB	Not used
CH12	NClus.GE.2&& Etot_M	Delayed Neutral
CH13	Etot_L&& NTOF.GE.1	Not used
CH14	BTOF_BB	Not used
CH15	NClus.GE.1	Not used
CH16	ECLUS_BB	Not used

Using a similar approach to that described in Ref. [4], we study the trigger efficiency for the J/ψ events taken in 2018 in order to understand the performance for the updated trigger system.

II. DATA SET

A. Trigger menu for the 2018 data taking

Table 3 shows the trigger menu used for the 2018 J/ψ data taking campaign, which has not changed since 2012, with the exception of CH03 mentioned above. The enabled channels are categorized into three almost independent groups, namely endcap charged, barrel charged

Table 3. Trigger menu for 2018 J/ψ data taking.

Channel	Conditions	Group
CH01	NEClus.GE.1&& NETOF.GE.1&& STrk_BB	Endcap Charged
CH02	NBClus.GE.1&& NBTOF.GE.2&& NLtrk.GE.2	
CH04	BTOF_BB&& LTrk_BB	Barrel Charged
CH05	Etot_L&& NBTOF.GE.1&& NLtrk.GE.1	
CH06	NBClus.GE.1&& NBTOF.GE.1&& NLtrk.GE.2	
CH09	NClus.GE.1&& BEtot_H	Neutral
CH12	NClus.GE.2&& Etot_M	

and neutral.

B. Data sample for trigger study

To study the trigger efficiency, we took two dedicated runs (run 56199 and run 56200) where a single trigger was enabled in order to determine the efficiencies of all trigger conditions using a set of independent conditions. The corresponding trigger menus are shown in Table 4.

Table 4. Trigger menu for the 2018 J/ψ test runs.

Channel	Run number
CH03	56199
CH12	56200

III. CONTROL SAMPLE SELECTION

Control samples were selected from the 2018 J/ψ test runs (56199 and 56200). As widely used in BESIII physics analyses, only tracks with a polar angle θ (defined relative to the positron beam direction) for which $|\cos\theta| \leqslant 0.93$ are taken into account. The barrel region is defined as $|\cos\theta| < 0.8$, and the endcap region as $0.86 < |\cos\theta| < 0.92$. The definitions of "barrel" and "endcap" vary slightly between the analysis definitions and the trigger system, for which the "barrel" and "endcap" are decided by the structure of the sub-detector (such as MDC, EMC,...). The charged lepton or hadron selection defines good charged particle tracks as those with a distance of closest approach to the interaction point within 10 cm along the beam direction and 1 cm in the plane transverse to the beam direction. The control samples were selected similarly to those in Ref. [4] and are described in the following subsections.

A. Bhabha event selection

To select Bhabha events, two EMC clusters are required to have an opening angle larger than 166° and an energy difference within 10% of the center-of-mass energy:

$$\frac{|E_{\rm emc}(e^+)+E_{\rm emc}(e^-)-3.097|}{3.097} \leqslant 10\% \,.$$

Two oppositely charged good tracks in the MDC with an opening angle of more than 175° are selected. Potential backgrounds have been investigated using an inclusive Monte Carlo (MC) sample, which consists of the production of the J/ψ resonance, and the continuum processes incorporated in *KKMC* [6], where the known decay modes were modeled with *EVTGEN* [7, 8] using branching fractions taken from the Particle Data Group [9], and the remaining unknown decays from the charmonium states were generated with *LUNDCHARM* [10, 11]. Using this sample, the impurity of the selected Bhabha sample is determined to be about 1.6×10^{-6}.

B. Dimuon event selection

To select dimuon candidate events, two oppositely charged good tracks are required to have an opening angle of at least 178°. In addition, we require that the momentum of each track be less than 2 GeV/c, and that the deposited energy in the EMC is less than 0.7 GeV. The total four-momentum $(E/c, P_x, P_y, P_z)$ is required to fall into the range (2.8 to 3.3, −0.1 to 0.1, −0.1 to 0.1, −0.2 to 0.2) GeV/c, assuming that both tracks are muons. By using the inclusive J/ψ decay MC sample, we investigate potential backgrounds, and find the background levels to be less than 0.4%.

C. Charged hadronic event selection

For the hadron selection, two or more good tracks are required in the MDC. If there are exactly two tracks, the opening angle between them is required to be less than 170° in order to suppress Bhabha and dimuon backgrounds.

IV. TRIGGER EFFICIENCY DETERMINATION

All of the 2018 J/ψ data (runs 53207–56520) available were taken using the same trigger conditions, and the main challenge in the efficiency determination is to reduce any bias to a minimum. Thus we use the two test runs triggered by independent trigger channels (Table 4) to determine the trigger efficiencies. It should be noted that since they cannot be used by themselves for the trigger efficiency study, the efficiencies of conditions/channels (Tables 5 and 6) related to "NClus.GE.2" and "Etot_M" are investigated from run 56199, and "NBTOF.GE.2" and "NLTrk.GE.2" are investigated from run 56200, respectively.

A. Determination of trigger efficiencies

The trigger efficiency for each trigger condition/trigger channel ($\varepsilon_{\rm cond.}$/ch) can be calculated using

Table 5. Trigger condition efficiencies (in %) (Note: The relative uncertainties of the items with no uncertainties indicated are less than 0.01%).

	GTL	Condition	Bhabha		Dimuon		2-prong	4-prong
			Barrel	Endcap	Barrel	Endcap		
EMC	0	NClus.GE.1	100.00	$100.00^{+0.00}_{-0.41}$	99.93 ± 0.01	$94.74^{+4.35}_{-11.09}$	99.64 ± 0.01	99.97
	1	NClus.GE.2	98.69 ± 0.03	$98.20^{+0.62}_{-0.87}$	95.14 ± 0.08	$84.21^{+8.47}_{-13.01}$	$98.01^{+0.03}_{-0.02}$	$99.63^{+0.01}_{-0.02}$
	7	BEtot_H	100.00	0.17 ± 0.02	0.68 ± 0.03	$4.81^{+2.06}_{-3.12}$	89.88 ± 0.04	$93.25^{+0.03}_{-0.04}$
	9	Etot_L	100.00	$100.00^{+0.00}_{-0.41}$	99.82 ± 0.01	$100.00^{+0.00}_{-9.24}$	99.63 ± 0.01	99.99
	10	Etot_M	100.00	$100.00^{+0.00}_{-0.41}$	10.25 ± 0.11	$0.00^{+0.09}_{-0.00}$	97.01 ± 0.03	99.44 ± 0.02
	12	NBClus.GE.1	100.00	0.99 ± 0.01	99.93 ± 0.01	$0.00^{+0.09}_{-0.00}$	99.34 ± 0.01	99.90 ± 0.01
	13	NEClus.GE.1	0.94 ± 0.02	$100.00^{+0.00}_{-0.41}$	$1.68^{+0.04}_{-0.05}$	$94.74^{+4.35}_{-11.09}$	36.93 ± 0.06	41.85 ± 0.07
TOF	17	BTOF_BB	98.81 ± 0.01	$0.62^{+0.02}_{-0.03}$	99.98 ± 0.01	$0.00^{+0.02}_{-0.00}$	57.21 ± 0.06	83.21 ± 0.05
	19	NETOF.GE.1	61.98 ± 0.09	$99.90^{+0.00}_{-0.01}$	60.08 ± 0.17	$100.00^{+0.00}_{-2.14}$	$74.69^{+0.05}_{-0.06}$	77.87 ± 0.06
	20	NBTOF.GE.2	$99.69^{+0.01}_{-0.02}$	3.69 ± 0.06	$99.89^{+0.04}_{-0.06}$	$7.06^{+2.76}_{-3.99}$	$87.81^{+0.05}_{-0.06}$	99.04 ± 0.02
	21	NBTOF.GE.1	100.00	41.89 ± 0.14	100.00	$36.47^{+5.60}_{-5.95}$	99.63 ± 0.01	99.96
MDC	38	STrk_BB	$99.93^{+0.00}_{-0.01}$	99.95 ± 0.01	99.95 ± 0.01	$100.00^{+0.00}_{-1.75}$	46.62 ± 0.06	$83.01^{+0.05}_{-0.06}$
	42	LTrk_BB	$99.91^{+0.00}_{-0.01}$	$6.96^{+0.07}_{-0.08}$	$99.95^{+0.01}_{-0.02}$	$11.54^{+4.03}_{-3.19}$	37.34 ± 0.06	76.21 ± 0.06
	44	NLTrk.GE.2	$99.90^{+0.00}_{-0.01}$	21.74 ± 0.12	$99.87^{+0.05}_{-0.06}$	$18.82^{+5.22}_{-4.39}$	93.68 ± 0.05	99.86 ± 0.02
	45	NLTrk.GE.1	100.00	$38.92^{+0.13}_{-0.14}$	100.00	$30.59^{+5.80}_{-5.30}$	99.67 ± 0.01	99.98

Table 6. Global trigger efficiencies (in %) (Note: The relative uncertainties of the items with no uncertainties given are less than 0.01%).

Channel	Bhabha		Dimuon		2-prong	4-prong
	Barrel	Endcap	Barrel	Endcap		
CH01	0.65 ± 0.02	$99.10^{+0.43}_{-0.70}$	0.63 ± 0.03	$99.04^{+0.96}_{-11.09}$	15.88 ± 0.04	$31.30^{+0.03}_{-0.05}$
CH02	99.60 ± 0.02	0.03 ± 0.01	$99.76^{+0.06}_{-0.08}$	$1.18^{+0.85}_{-0.78}$	84.88 ± 0.06	98.97 ± 0.02
CH04	99.73 ± 0.01	0.06 ± 0.01	99.92 ± 0.01	$0.00^{+0.02}_{-0.00}$	29.15 ± 0.05	67.36 ± 0.07
CH05	100.00	17.45 ± 0.11	99.82 ± 0.01	$9.41^{+2.32}_{-1.69}$	99.04 ± 0.01	99.94
CH06	99.90 ± 0.01	$0.15^{+0.01}_{-0.02}$	$99.87^{+0.04}_{-0.06}$	$2.35^{+1.02}_{-0.72}$	$93.22^{+0.05}_{-0.06}$	99.78 ± 0.01
CH09	100.00	0.17 ± 0.01	0.68 ± 0.03	$5.88^{+2.79}_{-1.52}$	89.85 ± 0.04	93.23 ± 0.04
CH12	98.69 ± 0.03	$98.20^{+0.62}_{-0.87}$	9.79 ± 0.12	$0.00^{+0.09}_{-0.00}$	$96.42^{+0.04}_{-0.03}$	99.22 ± 0.02
Barrel Charged	$100.00^{+0.00}_{-0.02}$	$17.45^{+6.61}_{-6.91}$	$99.95^{+0.05}_{-0.10}$	$9.41^{+8.25}_{-7.06}$	99.04 ± 0.19	$99.94^{+0.06}_{-0.11}$
Endcap Charged	0.65 ± 0.02	$99.10^{+0.43}_{-0.70}$	0.63 ± 0.03	$99.04^{+0.96}_{-11.09}$	15.88 ± 0.04	$31.30^{+0.03}_{-0.05}$
Neutral	$100.00^{+0.00}_{-0.03}$	$98.20^{+1.80}_{-5.84}$	9.81 ± 0.45	$5.88^{+2.79}_{-1.52}$	$96.71^{+0.06}_{-0.05}$	99.32 ± 0.05
Total	100.00	$99.99^{+0.01}_{-0.04}$	$99.96^{+0.04}_{-0.09}$	$99.33^{+0.67}_{-9.46}$	99.97 ± 0.01	$100.00^{+0.00}_{-0.01}$

$$\varepsilon_{\rm cond./ch} = \frac{N(\text{sel, trig.condition/channel})}{N_{\rm sel}},$$

where "N" stands for the number of events, the label "sel" for events passing the physics selection, and "trig.condition/channel" for events in which the trigger condition/channel under study is active. The efficiencies of the trigger conditions which have been used for the 2018 J/ψ data taking are listed in Table 5. The Clopper-Pearson method [12, 13] has been used to estimate the confidence interval at the confidence level of $1-\alpha = 0.6827(1\sigma)$. It should be noted that the number of prongs for hadronic events refers to the number of charged tracks in the full detector, not only in the barrel or endcap.

B. Determination of trigger channel efficiencies

The efficiency of the trigger channels can be determined similar to the efficiency of the trigger conditions if a fully independent trigger channel exists. Otherwise, a mathematical combination of the condition efficiencies has to be performed. By considering the three almost independent groups of channels shown in Table 3, we can obtain the trigger channel efficiencies for 2018 J/ψ data taking as follows:

$$\varepsilon_{\rm final} = g_1 + g_2 + g_3 - (g_1g_2 + g_1g_3 + g_2g_3) + g_1g_2g_3,$$

where g_n is the efficiency of the $n^{\rm th}$ group of trigger channels.

The logical relationship between trigger channels (Table 3) is "or", and in each trigger channel, the relationship between trigger conditions is "and", so the efficiencies for the groups of trigger channels are the sum of all efficiencies of the channels in question with the overlap of the channels subtracted. The efficiencies of the groups of trigger channels can be calculated as:

$$g_1 = c_1, \quad g_2 = A - B + C - D, \quad g_3 = E - F$$

and,

$$\begin{aligned} A =& c_2 + c_4 + c_5 + c_6 \\ B =& c_2 \cdot P(4|2) + c_2 \cdot P(5|2) + c_2 \cdot P(6|2) + c_4 \cdot P(5|4) \\ &+ c_6 \cdot P(4|6) + c_6 \cdot P(5|6) \\ C =& c_2 \cdot P(4,5|2) + c_2 \cdot P(4,6|2) + c_2 \cdot P(5,6|2) + c_6 \cdot P(4,5|6) \\ D =& c_2 \cdot P(4,5,6|2), \quad E = c_9 + c_{12}, \quad F = c_9 \cdot P(12|9), \end{aligned}$$

where A and E are the sum of trigger channel efficiencies in the group, B, D and F are the overlap efficiencies for double-counting parts in A and E, C is the efficiency double-counted in B and D, c_n is the efficiency of the $n^{\rm th}$ channel, and $P(n,\ldots|m)$ is a conditional probability, *i.e.* how many events of condition $(n,\ldots)$ are involved in condition m, which is the overlap/correlations if the trigger channels are not independent of each other in the same group.

Using the combination methods outlined above, the overall efficiencies of the trigger channels and global trigger efficiencies are given in Table 6.

V. SUMMARY

The BESIII trigger system is a fundamental tool for the successful collection of data for physics analyses. With a dedicated data sample collected at the J/ψ peak, the trigger efficiencies for various physics channels were determined, and found to be close to 100% for most physics cases with small uncertainties. This conclusion is similar to that found by the trigger study for the 2009 run [4], showing that there has been no significant degradation in almost a decade of running. As the trigger menu studied here has been used for all data taking since 2012, the results of this study apply to all respective data samples. For most physics channels, the efficiency of the full trigger menu approaches 100% and can be neglected in physics analyses.

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