# Trigger efficiencies at BES III

N. Berger[1;1)] K. Zhu[1;2)] Z.A. Liu[1] D.P. Jin[1] H. Xu[1] W.X. Gong[1] K. Wang[1] G. F. Cao[1]

[1]: Institute of High Energy Physics, Chinese Academy of Sciences, Beijing 100049, China

**Abstract** Trigger efficiencies at BES III were determined for both the $J/\psi$ and $\psi'$ data taking of 2009. Both dedicated runs and physics datasets are used; efficiencies are presented for Bhabha-scattering events, generic hadronic decay events involving charged tracks, dimuon events and $\psi' \longrightarrow \pi^+\pi^- J/\psi$, $J/\psi \longrightarrow \ell^+\ell^-$ events. The efficiencies are found to lie well above 99% for all relevant physics cases, thus fulfilling the BES III design specifications.

**Key words** trigger, efficiency, BES III

**PACS** 07.05.Hd, 29.85.Ca

## 1 Introduction

The Beijing Spectrometer III (BES III) experiment at the Beijing Electron-Positron Collider II (BEPC II) was designed to make use of the world's largest luminosity in the $\tau$-charm energy region for studies of the light hadron spectrum, charmonia, open charm and $\tau$-lepton production. In order to exploit the luminosities of up to $10^{33}$ cm$^{-2}$s$^{-1}$, BES III requires a fast data acquisition as well as an efficient and highly selective trigger system.

The BES III trigger system as used for the 2009 data taking combines information from the electromagnetic calorimeter (EMC), the main drift chamber (MDC) and the time-of-flight system (ToF) to select the interactions of interest for readout*. A detailed description of the system can be found in [1, 3].

The subsystems provide a set of *trigger conditions* each (48 in total, see table 1), which are combined to up to 13 *trigger channels* by the global trigger logic (GTL). In addition, there is a *random trigger* and two different *prescales*†. If any enabled trigger channel is active, the event will be read out. A typical *trigger menu* (combination of trigger conditions to trigger channels) used in physics data taking is shown in Table 2.

There are two groups of EMC based trigger conditions, one is based on clusters (localized deposits of energy above a threshold) and their distribution in polar and azimuthal angle. The second group is based on the total energy deposited in the calorimeter. ToF conditions are based on the number and relative location in azimuth of signals in the scintillator bars. MDC conditions finally are derived from the patterns of active cells in the drift chambers. Hits in four neighbouring layers within a *super layer* are flagged as *track segments* if they are compatible with the trajectory of a particle originating from the beam line. This matching is performed in four super layers. If there are matching segments from the innermost three super layers, this is considered a *short track*, if a segment is also present in the fourth super layer (which restricts the track to be contained in the barrel region), a *long track* is formed.

Events not seen by the trigger are lost forever; thus a high efficiency is desirable. On the other hand, the capacity of the readout system is limited; the trigger should also be highly selective. The trigger efficiency needs to be considered in the overall normalisation of any physics analysis‡. For the precursor experiments BES I and II, trigger efficiencies were determined both using data [4, 5] and simulations [6, 7]. In the present paper, trigger efficiencies are determined from data. The methods employed are introduced in the next section. This is followed by a description of the data sample and selection employed. The re-

1) E-mail: nberger@mail.ihep.ac.cn

2) E-mail: zhuk@mail.ihep.ac.cn

*The system also incorporates trigger conditions based on the muon counter (MUC) and coincidences between subsystems (*match*-trigger) these were however not used in the 2009 running.

†Not used for the 2009 data taking.

‡A detailed simulation of the BESIII trigger for use with Monte Carlo simulation events is currently being implemented, has however not reached full maturity at the time of writing.

sults of the study in Section 4 are followed by a brief conclusion.

## 2 Efficiency determination

As all the data available for trigger studies have actually been triggered, the main challenge in the efficiency determination is to reduce any bias caused by this to a minimum. Ideally, the trigger efficiency would be determined from random trigger events, this however suffers from very low statistics as soon as a physics selection is applied. Instead, samples triggered by independent trigger channels are used. The MDC and ToF based trigger conditions are checked using events triggered by trigger Channel 11, which is based on EMC conditions only. Conversely, EMC based trigger conditions are checked using the MDC and ToF condition based Channels 2 and 3[§]. In addition to the standard $\psi'$ and $J/\psi$ runs, special runs with a trigger set-up geared especially at efficiency determination were taken in May and July of 2009 respectively. They will be designated as *trigger test runs* in the following in order to discern them from standard data taking. The experience gained during the $\psi'$ running allowed to set up such monitor triggers also for the endcap conditions in the $J/\psi$ test run.

### 2.1 Trigger condition efficiencies

As all the trigger conditions used in the 2009 running are determined from a single sub-detector, a data sample triggered by a trigger channel not using that sub-detector can be used as a reference:

$$\epsilon = \frac{N_{(sel,channel,condition)}}{N_{(sel,channel)}}. \quad (1)$$

Here $N$ stands for the number of events, the label *sel* for events passing the physics selection, *channel* for events having triggered the reference channel and *condition* for events with the trigger condition under study active.

### 2.2 Timing dependence

The high bunch crossing frequency of 125 MHz at BEPC II is not resolved by the trigger electronics. This, together with the different latencies, time resolutions and latch times of the trigger subsystems poses a challenge to trigger timing. Checks of the trigger timing and the proper coincidence of subsystem signals are thus of utmost importance.

The BES III trigger system is not able to resolve individual bunch crossings. Data in a broad timing window around the time of the trigger are read out and the exact event timing $(\widehat{0})$ is determined off-line. It is thus very important that both the position of the readout window with regard to the trigger signal is correct as well as that the trigger conditions actually coincide (as opposed to being active somewhere in the readout window).

Table 1. Trigger conditions. Note that $N$ used in conditions 39 and 43 was set to 16 for the 2009 running. Trigger conditions 23 to 37 are reserved for the muon system trigger and a trigger matching information from different subdetectors.

| | Short Name | Condition |
|---|---|---|
| | Electromagnetic calorimeter (EMC) | |
| 0 | `NClus.GE.1` | Number of clusters $\geq 1$ |
| 1 | `NClus.GE.2` | Number of clusters $\geq 2$ |
| 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 $\varphi$ |
| 6 | `EClus_Phi` | Endcap cluster balance in $\varphi$ |
| 7 | `BEtot_H` | Barrel energy, high threshold |
| 8 | `EEtot_H` | Endcap energy, high threshold |
| 9 | `Etot_L` | Total energy, low threshold |
| 10 | `Etot_M` | Total energy, medium threshold |
| 11 | `BL_EnZ` | Energy balance in $z$ direction |
| 12 | `NBClus.GE.1` | Number of barrel clusters $\geq 1$ |
| 13 | `NEClus.GE.1` | Number of endcap clusters $\geq 1$ |
| 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 $\geq 2$ |
| 19 | `NETOF.GE.1` | Number of endcap ToF hits $\geq 1$ |
| 20 | `NBTOF.GE.2` | Number of barrel ToF hits $\geq 2$ |
| 21 | `NBTOF.GE.1` | Number of barrel ToF hits $\geq 1$ |
| 22 | `NTOF.GE.1` | Number of ToF hits $\geq 1$ |
| | Main drift chamber (MDC) | |
| 38 | `STrk_BB` | Short tracks back-to-back |
| 39 | `STrk.GE.N` | Number of short tracks $\geq N$ |
| 40 | `STrk.GE.2` | Number of short tracks $\geq 2$ |
| 41 | `STrk.GE.1` | Number of short tracks $\geq 1$ |
| 42 | `LTrk_BB` | Long tracks back-to-back |
| 43 | `LTrk.GE.N` | Number of long tracks $\geq N$ |
| 44 | `LTrk.GE.2` | Number of long tracks $\geq 2$ |
| 45 | `LTrk.GE.1` | Number of long tracks $\geq 1$ |
| 46 | `ITrk.GE.2` | Number of inner tracks $\geq 2$ |
| 47 | `ITrk.GE.1` | Number of inner tracks $\geq 1$ |

The efficiency of EMC and MDC signals was determined relative to the ToF signals, which provide

[§]For the $J/\psi$ running, Channel 3 was not active, so only Channel 2 was used.

the greatest timing accuracy (minimum signal width of 4 cycles of the 40 MHz clock in the trigger, corresponding to 12 bunch crossings). The ToF reference signal (usually `NBTOF.GE.1`) is required to be on in the four nominal cycles with regard to the event $\widehat{0}$. If the trigger condition under study has its signal on in any of these four cycles, this is treated as a coincidence and counted in the numerator of the efficiency fraction. In order to minimize the effects of the limited readout window size, the event $\widehat{0}$ is also required to lie within the nominal range.

### 2.3 Trigger channel efficiencies

The efficiency of trigger channels can be determined analogously to the efficiency of the trigger conditions if a fully independent trigger channel exists (i.e. Channels 2 and 3, which do not depend on the EMC and Channel 11, which depends solely on the EMC). Otherwise, correlations between the channels have to be accounted for. The overall trigger efficiency is then obtained by combining all the channels, where again correlations need to be considered.

Assuming that the readout window is wide enough, the trigger channel efficiency determined for the independent channels from the trigger decision readout is trigger timing independent. This is not the case for the mathematical combination; checks for Bhabha and Hadron data however indicate that the timing effects are small, certainly below 0.5% for the studied event topologies.

## 3 Sample selection

The selections employed in the trigger studies are less refined than those employed in physics analyses. The intention is not so much the selection of a very pure sample but the identification of a large number of events that share the main features (as far as the trigger is concerned) with the signal events.

In general, objects with a polar angle $\vartheta$ in the range $|\cos\vartheta| < 0.97$ are considered. The barrel region is defined as $|\cos\vartheta| < 0.8$, the endcap region as $0.83 < |\cos\vartheta| < 0.97$. Tracks in the main drift chamber are required to have a distance of closest approach to the run-averaged interaction point of less than 1 cm in the radial direction and less than 5 cm along the beam direction to be considered in the selection.

### 3.1 Bhabha selection

The Bhabha selection requires two calorimeter clusters with an energy within 10% of the beam energy and an opening angle larger than 166°. In addition, two charged tracks with an opening angle of more than 175° are required.

### 3.2 Charged hadron selection

In the inclusive charged hadron selection, two or more charged tracks are required to be present in the event. If there are exactly two tracks, their opening angle is required to be less than 170° in order to suppress Bhabha and dimuon events.

Table 2. Trigger settings for the 2009 $\psi'$ running. Channel 0 is designed for endcap Bhabha events, Channels 1 to 5 for events with charged particles in the barrel region and Channel 11 for all-neutral events. For the $J/\psi$ runs, the same set-up without Channel 3 was used.

| Channel | Conditions |
|---|---|
| 0 | `STrk_BB && NETOF.GE.1 && NEClus.GE.1` |
| 1 | `NLTrk.GE.2 && NBTOF.GE.2 && NBClus.GE.1` |
| 2 | `NLTrk.GE.2 && NBTOF.GE.2` |
| 3 | `LTrk_BB && NBTOF.GE1` |
| 4 | `NLTrk.GE.1 && NBTOF.GE.1 && Etot_L` |
| 5 | `NLtrk.GE.2 && NBTOF.GE.1 && NBClus.GE.1` |
| 9 | Random trigger at 60 Hz |
| 11 | `NClus.GE.2 && Etot_M` |

### 3.3 Dimuon selection

The dimuon selection requires two good charged tracks with opposite charge and a spacial angle between them larger than 177.6°. In addition, we require that the momentum of each track is less than 2 GeV/$c$ and 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 in the $(2.8 \sim 3.3, -0.1 \sim 0.1, -0.1 \sim 0.1, -0.2 \sim 0.2)$ GeV/$c$ region for $J/\psi$ data (for the $\psi'$ data, the energy region is $3.2 \sim 4$ GeV/$c$) after assuming each track is a muon.

### 3.4 $\psi' \longrightarrow \pi^+\pi^- J/\psi$ Selection

The $\psi' \to \pi^+\pi^- J/\psi$ selection requires four good charged tracks, two positive and two negative. The good charged tracks are defined as in the previous selections. Then we assume the softer tracks of each charge are pions and harder tracks are leptons. After that assumption we also require the recoil mass of the two pions to fall into the region (3.08, 3.12) GeV/$c^2$, the invariant mass of two leptons is required to be in the region (3.0, 3.2) GeV/$c^2$, and the total energy of the event should be in the range (3, 4) GeV.

## 4 Results

### 4.1 Trigger condition efficiencies

Using the methods described in the previous sections, the efficiency for the trigger conditions used in the trigger menus was determined. The numerical results are shown in Table 3 and 4. In Figure 1 the threshold behaviour of various EMC conditions is shown. Figure 2 depicts the dependence of the efficiency of an MDC condition (two or more long tracks) on the number of off-line reconstructed tracks. Figure 3 does the same for a ToF condition (two or more hits in the barrel). The figures were derived from the $J/\psi$ trigger test run data using the inclusive charged hadron selection, they are, however, virtually indistinguishable from the corresponding figures derived from any of the other data sets.

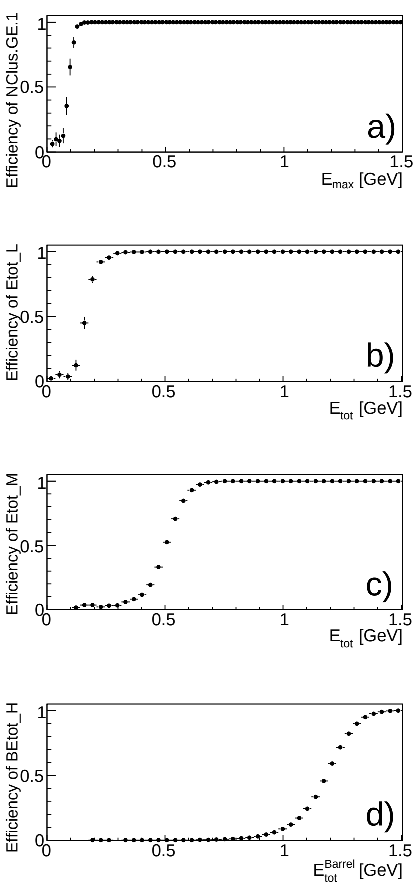


Fig. 1. Threshold behaviour of the EMC trigger conditions in the $J/\psi$ running. From top to bottom: a) Efficiency of the NClus.GE.1 condition versus maximum cluster energy, b) Efficiency of the low energy threshold versus total EMC energy, c) Efficiency of the medium energy threshold versus total EMC energy, d) Efficiency of the barrel high energy threshold versus barrel EMC energy.

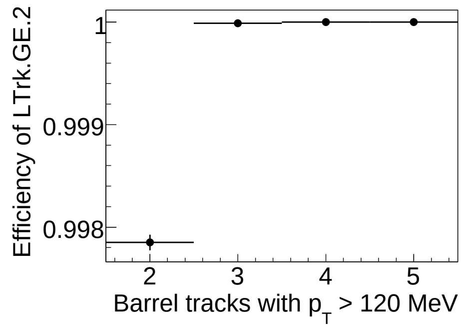


Fig. 2. Efficiency of the *two or more long tracks* MDC trigger condition versus the number of tracks with $p_T$ larger than 120 MeV in the barrel.

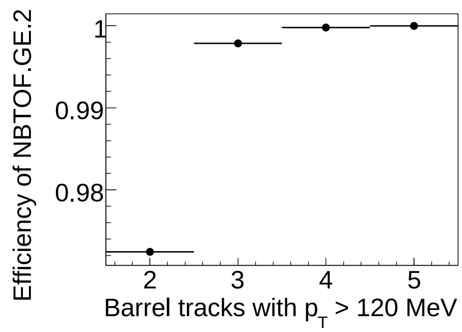


Fig. 3. Efficiency of the *two or more hits* ToF trigger condition versus the number of tracks with $p_T$ larger than 120 MeV in the barrel.

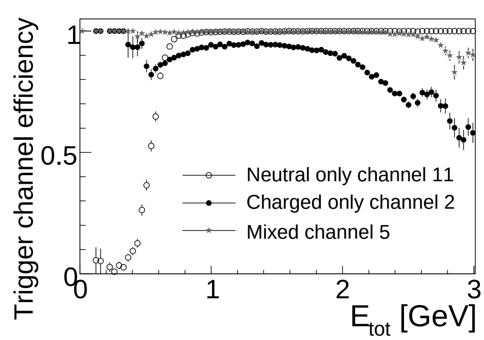


Fig. 4. Efficiency of a selection of trigger channels in $J/\psi$ running versus the total energy deposit in the EMC.

### 4.2 Global trigger efficiencies

Efficiencies of the various trigger channels employed in the $\psi'$ and $J/\psi$ physics run can be found in Table 5 and 6 respectively. Figure 4 shows the dependence of the trigger efficiency of the all-neutral, MDC and ToF only and the minimal MDC, ToF and EMC requirement trigger channels versus the total energy deposit in the EMC.

### 4.3 Noise levels

In order to determine noise levels and check the selectivity of the (barrel) trigger conditions, *endcap* Bhabha events triggered by endcap-only trigger conditions were selected. In this sample, the fraction of events with a specific *barrel* condition fulfilled is determined. This results in an upper limit of the noise ratio, as some of the conditions may also be activated by signal leaking from the endcaps into the barrel. Table 7 shows the noise fractions in the $J/\psi$ trigger test run.

## 5 Conclusion

The efficiency of the BES III trigger for various physics channels has been determined. For most cases, the efficiency of the full trigger menu approaches 100% and can thus be safely neglected in physics analyses. Only for events with both a low track multiplicity and a small calorimetric energy deposit (e.g. dimuon events), there are sizeable inefficiencies that have to be taken into account.

Table 3. Trigger condition efficiencies for $\psi'$ data taking. The efficiency for the Bhabha events was determined taking into account the trigger signal timing; as the ToF signals serve as a reference in this method, their efficiency cannot be determined. The numbers have statistical errors of the order of 0.1% in efficiency.

| Condition | Efficiency Barrel Bhabha | Efficiency Hadron | Efficiency Dimuon | Efficiency $\psi' \to \pi^+\pi^- J/\psi$, $J/\psi \to \ell^+\ell^-$ |
|---|---|---|---|---|
| `NClus.GE.1` | 99.9 % | 99.2 % | 99.4 % | 99.7 % |
| `NClus.GE.2` | 98.8 % | 97.7 % | 96.3 % | 97.6 % |
| `Etot_L` | 100.0 % | 99.0 % | 99.9 % | 99.6 % |
| `Etot_M` | 100.0 % | 87.3 % | 1.4 % | 21.6 % |
| `NLTrk.GE.1` | 99.6 % | 99.9 % | 99.0 % | 99.8 % |
| `NLTrk.GE.2` | 99.7 % | 99.0 % | 98.9 % | 99.5 % |
| `NBTOF.GE.1` | | 99.6 % | 99.6 % | 99.7 % |
| `NBTOF.GE.2` | | 95.7 % | 96.0 % | 97.2 % |

Table 4. Trigger condition efficiencies for $J/\psi$ data taking. The numbers have statistical errors of the order of 0.1% in efficiency. The number of prongs for hadronic events refers to the number of charged tracks in the barrel. For the hadronic events, the effects of timing are considered; as the ToF system serves as a reference, no ToF efficiencies were determined. The short track conditions were found to be slightly out of time for barrel events.

| Condition | Efficiency Barrel Bhabha | Efficiency Endcap Bhabha | Efficiency 2-prong Hadrons | Efficiency 4-prong Hadrons | Efficiency Barrel Dimuon | Efficiency Endcap Dimuon |
|---|---|---|---|---|---|---|
| `NClus.GE.1` | 100.0 % | 100.0 % | 99.9% | 100.0% | 100.0 % | 86.3 % |
| `NClus.GE.2` | 99.0 % | 96.5 % | 94.3% | 97.6% | 96.8 % | 50.5 % |
| `Etot_L` | 100.0 % | 100.0 % | 100.0% | 100% | 100.0 % | 97.9 % |
| `Etot_M` | 100.0 % | 100.0 % | 96.2% | 99.1% | 7.6 % | 5.0 % |
| `BEtot_H` | 100.0 % | 0.0 % | 61.9% | 50.2% | 0.3 % | 0.1 % |
| `EEtot_H` | 0.1 % | 100.0 % | 0.3% | 0.1% | 0.1 % | 2.0 % |
| `NLTrk.GE.1` | 100.0 % | 17.2 % | 99.8% | 99.9% | 100.0 % | 32.9 % |
| `NLTrk.GE.2` | 100.0 % | 0.7 % | 98.7% | 99.9% | 100.0 % | 22.5 % |
| `NSTrk.GE.1` | 100.0 % | 100.0 % | 98.7% | 99.0% | 100.0 % | 100.0 % |
| `NSTrk.GE.2` | 100.0 % | 100.0 % | 98.5% | 99.2% | 100.0 % | 100.0 % |
| `NBTOF.GE.1` | 100.0 % | 17.0 % | | | 100.0 % | 17.2 % |
| `NBTOF.GE.2` | 98.2 % | 0.8 % | | | 97.6 % | 0.9 % |
| `NETOF.GE.1` | 22.5 % | 99.8 % | | | 21.8 % | 95.2 % |
| `NETOF.GE.2` | 1.6 % | 94.3 % | | | 1.6 % | 76.7 % |

Table 5. Global trigger efficiencies for $\psi'$ running. The statistical errors are below 0.1% in efficiency.

| Trigger channel group | Barrel Bhabha efficiency | Hadron efficiency | Dimuon efficiency | $\psi' \to \pi^+\pi^- J/\psi$, $J/\psi \to \ell^+\ell^-$ efficiency |
|---|---|---|---|---|
| Channel 0 | 0.3 % | 31.8 % | 0.4 % | 13.7 % |
| Channel 1 | 93.5% | 92.1 % | 95.0 % | 94.7 % |
| Channel 2 | 93.5% | 93.1 % | 98.5 % | 96.7 % |
| Channel 3 | 98.9% | 72.8 % | 98.6 % | 93.5 % |
| Channel 4 | 99.0% | 98.7 % | 98.7 % | 99.2 % |
| Channel 5 | 98.9% | 96.1 % | 98.0 % | 97.2 % |
| Channel 11 | 98.5 % | 85.9 % | 1.3 % | 21.1 % |
| Barrel charged | 99.0 % | 99.7 % | 98.7 % | 99.6 % |
| Endcap charged | 0.3 % | 31.8 % | 0.4 % | 13.7 % |
| Neutral | 98.5 % | 85.9 % | 1.3 % | 21.1 % |
| Total | 99.99 % | 99.97 % | 98.7 % | 99.7 % |

Table 6. Global trigger efficiencies for $J/\psi$ running. The statistical errors are below 0.1% in efficiency.

| Trigger channel group | Barrel Bhabha efficiency | Endcap Bhabha efficiency | Hadron efficiency | Barrel Dimuon efficiency | Endcap Dimuon efficiency |
|---|---|---|---|---|---|
| Channel 0 | 0.14 % | 99.8 % | 25.6 % | 0.2 % | 94.3 % |
| Channel 1 | 98.2 % | 0.0 % | 98.5 % | 97.6 % | 0.0 % |
| Channel 2 | 98.2 % | 0.1 % | 98.6 % | 97.6 % | 0.2 % |
| Channel 4 | 99.96 % | 0.7 % | 99.98 % | 99.9 % | 3.3 % |
| Channel 5 | 99.99 % | 2.9 % | 99.85 % | 99.9 % | 5.5 % |
| Channel 11 | 99.0 % | 96.5 % | 97.7 % | 7.3 % | 2.5 % |
| Barrel charged | 99.99 % | 2.9 % | 99.99 % | 99.9 % | 5.6 % |
| Endcap charged | 0.14 % | 99.8 % | 25.6 % | 0.2 % | 94.3 % |
| Neutral | 99.0 % | 96.5 % | 97.7 % | 7.3 % | 2.5 % |
| Total | 100.0 % | 99.99 % | 100.0% | 99.94 % | 94.8 % |

Table 7. Barrel trigger condition noise levels as determined from endcap Bhabha events in the $J/\psi$ trigger test run.

| | Short Name | Noise fraction |
|---|---|---|
| | Electromagnetic calorimeter (EMC) | |
| 2 | `BClus_BB` | 0.0014% |
| 5 | `BClus_Phi` | 0.011% |
| 7 | `BEtot_H` | 0.017% |
| 12 | `NBClus.GE.1` | 0.19% |
| 14 | `BL_BBLK` | 0.036% |
| | Time of flight system (ToF) | |
| 17 | `BTOF_BB` | 0.099% |
| 20 | `NBTOF.GE.2` | 0.80% |
| 21 | `NBTOF.GE.1` | 17.1% |
| | Main drift chamber (MDC) | |
| 42 | `LTrk_BB` | 1.2% |
| 43 | `LTrk.GE.N` | 0.08% |
| 44 | `LTrk.GE.2` | 3.8% |
| 45 | `LTrk.GE.1` | 12.0% |

## References


1

2 M. Ablikim *et al.* [BESIII Collaboration], "Design and Construction of the BESIII Detector," Nucl. Instrum. Meth. A **614** (2010) 345 [arXiv:0911.4960 [physics.ins-det]].

3 Z.-A. Liu, "*Preliminary design of BES-III trigger system*", Prepared for CHEP'01: Computing in High-Energy Physics and Nuclear, Beijing, China, 3-7 Sep 2001.

4 Z. Yu *et al.*, "*Trigger Efficiency Measurement of BES*", Chinese Physics C **19**, 1062 (1995).

5 G. Huang *et al.*, "*Trigger Efficiency Measurement in R Scan Experiment*", Chinese Physics C **25**, 889 (2001).

6 B. Liu *et al.*, "*Simulation of BES Trigger*", Chinese Physics C **25**, 1 (2001).

7 X. Shi *et al.*, "*Study of VC Trigger Efficiency on BES II*", Chinese Physics C **28**, 982 (2004).