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

M. Ablikim(麦迪娜)[1] M. N. Achasov[10,c] P. Adlarson[67] S. Ahmed[15] M. Albrecht[4] R. Aliberti[28] A. Amoroso[66A,66C] M. R. An(安美儒)[32] Q. An(安琪)[49,63] X. H. Bai(白旭红)[57] Y. Bai(白羽)[48] O. Bakina[29] R. Baldini Ferroli[23A] I. Balossino[24A,1] Y. Ban(班勇)[38,k] K. Begzsuren[26] N. Berger[28] M. Bertani[23A] D. Bettoni[24A] F. Bianchi[66A,66C] J. Bloms[60] A. Bortone[66A,66C] I. Boyko[29] R. A. Briere[5] H. Cai(蔡浩)[68] X. Cai(蔡啸)[1,49] A. Calcaterra[23A] G. F. Cao(曹国富)[1,54] N. Cao(曹宁)[1,54] S. A. Cetin[53B] J. F. Chang(常劲帆)[1,49] W. L. Chang(常万玲)[1,54] G. Chelkov[29,b] D. Y. Chen(陈端友)[6] G. Chen(陈刚)[1] H. S. Chen(陈和生)[1,54] M. L. Chen(陈玛丽)[1,49] S. J. Chen(陈申见)[35] X. R. Chen(陈旭荣)[25] Y. B. Chen(陈元柏)[1,49] Z. J Chen(陈卓俊)[20,l] W. S. Cheng(成伟帅)[66C] G. Cibinetto[24A] F. Cossio[66C] X. F. Cui(崔小非)[36] H. L. Dai(代洪亮)[1,49] X. C. Dai(戴鑫琛)[1,54] A. Dbeyssi[15] R. E. de Boer[4] D. Dedovich[29] Z. Y. Deng(邓子艳)[1] A. Denig[28] I. Denysenko[29] M. Destefanis[66A,66C] F. De Mori[66A,66C] Y. Ding(丁勇)[33] C. Dong(董超)[36] J. Dong(董静)[1,49] L. Y. Dong(董燎原)[1,54] M. Y. Dong(董明义)[1] X. Dong(董翔)[68] S. X. Du(杜书先)[c] Y. L. Fan(范玉兰)[68] J. Fang(方建)[1,49] S. S. Fang(房双世)[1,54] Y. Fang(方易)[1] R. Farinelli[24A] L. Fava[66B,66C] F. Feldbauer[4] G. Felici[23A] C. Q. Feng(封常青)[49,63] J. H. Feng[50] M. Fritsch[4] C. D. Fu(傅成栋)[1] Y. Gao(高雅)[64] Y. Gao(高扬)[49,63] Y. Gao(高原宁)[38,k] Y. G. Gao(高勇贵)[6] I. Garzia[24A,24B] P. T. Ge(葛潘婷)[68] C. Geng(耿聪)[50] E. M. Gersabeck[58] A Gilman[61] K. Goetzen[11] L. Gong[33] W. X. Gong(龚文煊)[1,49] W. Gradl[28] M. Greco[66A,66C] L. M. Gu(谷立民)[35] M. H. Gu(顾旻皓)[1,49] S. Gu(顾珊)[2] Y. T. Gu(顾运厅)[13] C. Y Guan(关春懿)[1,54] A. Q. Guo(郭爱强)[22] L. B. Guo(郭立波)[34] R. P. Guo(郭如盼)[40] Y. P. Guo[9,h] A. Guskov[29] T. T. Han(韩婷婷)[41] W. Y. Han(韩文颖)[32] X. Q. Hao(郝喜庆)[16] F. A. Harris[56] H Hüsken[22,28] K. L. He(何康林)[1,54] F. H. Heinsius[4] C. H. Heinz[28] T. Held[4] Y. K. Heng(衡月昆)[1] C. Herold[51] M. Himmelreich[11,f] T. Holtmann[4] Y. R. Hou(侯颖锐)[54] Z. L. Hou(侯治龙)[1] H. M. Hu(胡海明)[1,54] J. F. Hu[47] T. Hu(胡涛)[1] Y. Hu(胡誉)[1] G. S. Huang(黄光顺)[49,63] L. Q. Huang(黄麟钦)[64] X. T. Huang(黄性涛)[41] Y. P. Huang(黄燕萍)[1] Z. Huang(黄震)[38,k] T. Hussain[65] W. Ikegami Andersson[67] W. Imoehl[22] M. Irshad[49,63] S. Jaeger[4] S. Janchiv[26,j] Q. Ji(纪全)[1] Q. P. Ji(姬清平)[16] X. B. Ji(季晓斌)[1,54] X. L. Ji(季筱璐)[1,49] H. B. Jiang(姜侯兵)[41] X. S. Jiang(江晓山)[1] J. B. Jiao(焦健斌)[41] Z. Jiao(焦铮)[18] S. Jin(金山)[35] Y. Jin(金毅)[57] T. Johansson[67] N. Kalantar-Nayestanaki[55] X. S. Kang(康晓珅)[33] R. Kappert[55] M. Kavatsyuk[55] B. C. Ke(柯百谦)[1,43] I. K. Keshk[4] A. Khoukaz[60] P. Kiese[28] R. Kiuchi[1] R. Kliemt[11] L. Koch[30] O. B. Kolcu[53B,e] B. Kopf[4] M. Kuemmel[4] M. Kuessner[4] A. Kupsc[67] M. G. Kurth[1,54] W. Kühn[30] J. J. Lane[58] J. S. Lange[30] P. Larin[15] A. Lavania[21] L. Lavezzi[66A,66C,1] Z. H. Lei(雷祚弘)[49,63] H. Leithoff[28] M. Lellmann[28] T. Lenz[28] C. Li(李翠)[39] C. H. Li(李春花)[32] Cheng Li(李澄)[49,63] D. M. Li(李德民)[c] F. Li(李飞)[1,49] G. Li(李刚)[1] H. Li(李慧)[43] H. Li(李贺)[49,63] H. B. Li(李海波)[1,54] H. J. Li(李惠静)[9,h] J. L. Li(李井文)[41] J. Q. Li[4] J. S. Li(李静舒)[50] Ke Li(李科)[1] L. K. Li(李龙科)[1] Lei Li(李蕾)[3] P. R. Li(李培荣)[31] S. Y. Li(栗帅迎)[52] W. D. Li(李卫东)[1,54] W. G. Li(李卫国)[1] X. H. Li(李旭红)[49,63] X. L. Li(李晓玲)[41] Z. Y. Li(李紫源)[50] H. Liang(梁昊)[49,63] H. Liang(梁浩)[1,54] H. Liang(梁浩)[27] Y. F. Liang(梁勇飞)[45] Y. T. Liang(梁羽铁)[25] L. Z. Liao(廖龙洲)[1,54] J. Libby[21]

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C. X. Lin(林创新)[50] B. J. Liu(刘北江)[1] C. X. Liu(刘春秀)[1] D. Liu(刘栋)[49,63] F. H. Liu(刘福虎)[44]
Fang Liu(刘芳)[1] Feng Liu(刘峰)[6] H. B. Liu(刘宏邦)[13] H. M. Liu(刘怀民)[1,54] Huanhuan Liu(刘欢欢)[1]
Huihui Liu(刘汇慧)[17] J. B. Liu(刘建北)[49,63] J. L. Liu(刘佳俊)[64] J. Y. Liu(刘晶译)[1,54] K. Liu(刘凯)[1]
K. Y. Liu(刘魁勇)[33] Ke Liu(刘珂)[6] L. Liu(刘亮)[49,63] M. H. Liu[9,h] P. L. Liu(刘佩莲)[1] Q. Liu(刘倩)[54]
Q. Liu(刘淇)[68] S. B. Liu(刘树彬)[49,63] Shuai Liu(刘帅)[46] T. Liu(刘桐)[1,54] W. M. Liu(刘卫民)[49,63] X. Liu(刘翔)[31]
Y. Liu[31] Y. B. Liu(刘玉斌)[36] Z. A. Liu(刘振安)[1] Z. Q. Liu(刘智青)[41] X. C. Lou(娄辛丑)[1] F. X. Lu(卢飞翔)[16]
F. X. Lu[50] H. J. Lu(吕海江)[18] J. D. Lu(陆嘉达)[1,54] J. G. Lu(吕军光)[1,49] X. L. Lu(陆小玲)[1]
Y. Lu(卢宇)[1] Y. P. Lu(卢云鹏)[1,49] C. L. Luo(罗成林)[34] M. X. Luo(罗民兴)[b] P. W. Luo(罗朋威)[50]
T. Luo(罗涛)[9,h] X. L. Luo(罗小兰)[1,49] S. Lusso[66C] X. R. Lyu(吕晓睿)[54] F. C. Ma(马凤才)[33] H. L. Ma(马海龙)[1]
L. L. Ma(马连良)[41] M. M. Ma(马明明)[1,54] Q. M. Ma(马秋梅)[1] R. Q. Ma(马润秋)[1,54] R. T. Ma(马瑞廷)[54]
X. X. Ma(马新鑫)[1,54] X. Y. Ma(马骁妍)[1,49] F. E. Maas[15] M. Maggiora[66A,66C] S. Maldaner[4] S. Malde[61]
Q. A. Malik[65] A. Mangoni[23B] Y. J. Mao(冒亚军)[38,k] Z. P. Mao(毛泽普)[1] S. Marcello[66A,66C] Z. X. Meng(孟召霞)[57]
J. G. Messchendorp[55] G. Mezzadri[24A,1] T. J. Min(闵天觉)[35] R. E. Mitchell[22] X. H. Mo(莫晓虎)[1]
Y. J. Mo(莫玉俊)[6] N. Yu. Muchnoi[10,c] H. Muramatsu[59] S. Nakhoul[11,f] Y. Nefedov[29] F. Nerling[11,f]
I. B. Nikolaev[10,c] Z. Ning(宁哲)[1,49] S. Nisar[8,i] S. L. Olsen[54] Q. Ouyang(欧阳群)[1] S. Pacetti[23B,23C] X. Pan[9,h]
Y. Pan[58] A. Pathak[1] P. Patteri[23A] M. Pelizaeus[4] H. P. Peng(彭海平)[49,63] K. Peters[11,f] J. Pettersson[67]
J. L. Ping(平加伦)[34] R. G. Ping(平荣刚)[1,54] R. Poling[59] V. Prasad[49,63] H. Qi(齐航)[49,63] H. R. Qi(漆红荣)[52]
K. H. Qi(祁康辉)[25] M. Qi(祁鸣)[35] T. Y. Qi(齐天钰)[2] T. Y. Qi[9] S. Qian(钱森)[1,49] W.-B. Qian(钱文斌)[54]
Z. Qian(钱圳)[50] C. F. Qiao(乔从丰)[54] L. Q. Qin(秦丽清)[12] X. S. Qin[4] Z. H. Qin(秦中华)[1,49] J. F. Qiu(邱进发)[1]
S. Q. Qu(屈三强)[36] K. H. Rashid[65] K. Ravindran[21] C. F. Redmer[28] A. Rivetti[66C] V. Rodin[55] M. Rolo[66C]
G. Rong(荣刚)[1,54] Ch. Rosner[15] M. Rump[60] H. S. Sang(桑昊榆)[63] A. Sarantsev[29,d] Y. Schelhaas[28] C. Schnier[4]
K. Schoenning[67] M. Scodeggio[24A,24B] D. C. Shan(单多琛)[46] W. Shan(单葳)[19] X. Y. Shan(单心钰)[49,63]
J. F. Shangguan(上官剑锋)[46] M. Shao(邵明)[49,63] C. P. Shen[9] P. X. Shen(沈培迅)[36] X. Y. Shen(沈肖雁)[1,54]
H. C. Shi(石煌超)[49,63] R. S. Shi(师荣盛)[1,54] X. Shi(史欣)[1,49] X. D Shi(师晓东)[49,63] W. M. Song(宋维民)[1,27]
Y. X. Song(宋昀轩)[38,k] S. Sosio[66A,66C] S. Spataro[66A,66C] K. X. Su(苏可馨)[68] P. P. Su(苏彭彭)[46]
F. F. Sui(隋风飞)[41] G. X. Sun(孙功星)[1] H. K. Sun(孙浩凯)[1] J. F. Sun(孙俊峰)[16] L. Sun(孙亮)[68]
S. S. Sun(孙胜森)[1,54] T. Sun(孙童)[1,54] W. Y. Sun(孙文玉)[34] W. Y. Sun[27] X Sun(孙翔)[20,l] Y. J. Sun(孙勇杰)[49,63]
Y. K. Sun(孙艳坤)[49,63] Y. Z. Sun(孙永昭)[1] Z. T. Sun(孙振田)[1] Y. H. Tan(谭英华)[68] Y. X. Tan(谭雅星)[49,63]
C. J. Tang(唐昌建)[45] G. Y. Tang(唐光毅)[1] J. Tang(唐健)[50] J. X. Teng(滕佳秀)[49,63] V. Thoren[67] I. Uman[53D]
B. Wang(王斌)[1] C. W. Wang(王成伟)[35] D. Y. Wang(王大勇)[38,k] H. J. Wang[31] H. P. Wang(王宏鹏)[1,54]
K. Wang(王科)[1,49] L. L. Wang(王亮亮)[1] M. Wang(王萌)[41] M. Z. Wang[38,k] Meng Wang(王蒙)[1,54] W. Wang[50]
W. H. Wang(王文欢)[68] W. P. Wang(王维平)[49,63] X. Wang[38,k] X. F. Wang(王雄飞)[31] X. L. Wang[9,h]
Y. Wang(王越)[49,63] Y. Wang(王莹)[50] Y. D. Wang[37] Y. F. Wang(王贻芳)[1] Y. Q. Wang(王雨晴)[1] Y. Y. Wang[31]
Z. Wang(王铮)[1,49] Z. Y. Wang(王至勇)[1] Ziyi Wang(王子一)[54] Zongyuan Wang(王宗源)[1,54] D. H. Wei(魏代会)[12]
P. Weidenkaff[28] F. Weidner[60] S. P. Wen(文硕频)[1] D. J. White[58] U. Wiedner[4] G. Wilkinson[61] M. Wolke[67]
L. Wollenberg[4] J. F. Wu(吴金飞)[1,54] L. H. Wu(伍灵慧)[1] L. J. Wu(吴连近)[1,54] X. Wu[9,h] Z. Wu(吴智)[1,49]
L. Xia(夏磊)[49,63] H. Xiao[9,h] S. Y. Xiao(肖素玉)[1] Z. J. Xiao(肖振军)[34] X. H. Xie(谢昕海)[38,k]
Y. G. Xie(谢宇广)[1,49] Y. H. Xie(谢跃红)[6] T. Y. Xing(邢天宇)[1,54] G. F. Xu(许国发)[1] Q. J. Xu(徐庆君)[14]
W. Xu(许威)[1,54] X. P. Xu(徐新平)[46] F. Yan[9,h] L. Yan[9,h] W. B. Yan(鄢文标)[49,63] W. C. Yan(闫文成)[c]
Xu Yan(闫旭)[46] H. J. Yang(杨海军)[42,g] H. X. Yang(杨洪勋)[1] L. Yang(杨玲)[43] S. L. Yang[54]
Y. X. Yang(杨永栩)[12] Yifan Yang(杨翊凡)[1,54] Zhi Yang(杨智)[25] M. Ye(叶梅)[1,49] M. H. Ye(叶铭汉)[7]
J. H. Yin(殷俊昊)[1] Z. Y. You(尤郑昀)[50] B. X. Yu(俞伯祥)[1] C. X. Yu(喻纯旭)[36] G. Yu(余刚)[1,54]
J. S. Yu(俞洁晟)[20,l] T. Yu(于涛)[64] C. Z. Yuan(苑长征)[1,54] L. Yuan(袁丽)[2] X. Q. Yuan[38,k] Y. Yuan(袁野)[1]
Z. Y. Yuan(袁朝阳)[50] C. X. Yue[32] A. Yuncu[53B,a] A. A. Zafar[65] Y. Zeng(曾云)[20,l] B. X. Zhang(张丙新)[1]
Guangyi Zhang(张广义)[16] H. Zhang[63] H. H. Zhang(张宏浩)[50] H. H. Zhang[27] H. Y. Zhang(章红宇)[1,49]
J. J. Zhang(张进军)[43] J. L. Zhang(张杰磊)[a] J. Q. Zhang[34] J. W. Zhang(张家文)[1] J. Y. Zhang(张建勇)[1]

J. Z. Zhang(张景芝)[1,54] Jianyu Zhang(张剑宇)[1,54] Jiawei Zhang(张嘉伟)[1,54] L. Q. Zhang(张丽青)[50]
Lei Zhang(张雷)[35] S. Zhang(张澍)[50] S. F. Zhang(张思凡)[35] Shulei Zhang[20,l] X. D. Zhang[37]
X. Y. Zhang(张学尧)[41] Y. Zhang[61] Y. H. Zhang(张银鸿)[1,49] Y. T. Zhang(张亚腾)[49,63] Yan Zhang(张言)[49,63]
Yao Zhang(张瑶)[1] Yi Zhang[9,h] Z. H. Zhang(张正好)[6] Z. Y. Zhang(张振宇)[68] G. Zhao(赵光)[1] J. Zhao(赵静)[32]
J. Y. Zhao(赵静宜)[1,54] J. Z. Zhao(赵京周)[1,49] Lei Zhao(赵雷)[49,63] Ling Zhao(赵玲)[1] M. G. Zhao(赵明刚)[36]
Q. Zhao(赵强)[1] S. J. Zhao(赵书俊)[c] Y. B. Zhao(赵豫斌)[1,49] Y. X. Zhao(赵宇翔)[25] Z. G. Zhao(赵政国)[49,63]
A. Zhemchugov[29,b] B. Zheng(郑波)[64] J. P. Zheng(郑建平)[1,49] Y. Zheng[38,k] Y. H. Zheng(郑阳恒)[54]
B. Zhong(钟彬)[34] C. Zhong(钟翠)[64] L. P. Zhou(周利鹏)[1,54] Q. Zhou(周巧)[1,54] X. Zhou(周详)[68]
X. K. Zhou(周晓康)[54] X. R. Zhou(周小蓉)[49,63] A. N. Zhu(朱傲男)[1,54] J. Zhu(朱江)[36] K. Zhu(朱凯)[1]
K. J. Zhu(朱科军)[1] S. H. Zhu(朱世海)[62] T. J. Zhu[a] W. J. Zhu(朱文静)[36] W. J. Zhu[9,h] Y. C. Zhu(朱莹春)[49,63]
Z. A. Zhu(朱自安)[1,54] B. S. Zou(邹冰松)[1] J. H. Zou(邹佳恒)[1]

(BESIII Collaboration)

[1]Institute of High Energy Physics, Beijing 100049, China
[2]Beihang University, Beijing 100191, China
[3]Beijing Institute of Petrochemical Technology, Beijing 102617, China
[4]Bochum Ruhr-University, D-44780 Bochum, Germany
[5]Carnegie Mellon University, Pittsburgh, Pennsylvania 15213, USA
[6]Central China Normal University, Wuhan 430079, China
[7]China Center of Advanced Science and Technology, Beijing 100190, China
[8]COMSATS University Islamabad, Lahore Campus, Defence Road, Off Raiwind Road, 54000 Lahore, Pakistan
[9]Fudan University, Shanghai 200443, China
[10]G.I. Budker Institute of Nuclear Physics SB RAS (BINP), Novosibirsk 630090, Russia
[11]GSI Helmholtzcentre for Heavy Ion Research GmbH, D-64291 Darmstadt, Germany
[12]Guangxi Normal University, Guilin 541004, China
[13]Guangxi University, Nanning 530004, China
[14]Hangzhou Normal University, Hangzhou 310036, China
[15]Helmholtz Institute Mainz, Johann-Joachim-Becher-Weg 45, D-55099 Mainz, Germany
[16]Henan Normal University, Xinxiang 453007, China
[17]Henan University of Science and Technology, Luoyang 471003, China
[18]Huangshan College, Huangshan 245000, China
[19]Hunan Normal University, Changsha 410081, China
[20]Hunan University, Changsha 410082, China
[21]Indian Institute of Technology Madras, Chennai 600036, India
[22]Indiana University, Bloomington, Indiana 47405, USA
[23](A)INFN Laboratori Nazionali di Frascati, I-00044, Frascati, Italy; (B)INFN Sezione di Perugia, I-06100, Perugia, Italy; (C)University of Perugia, I-06100, Perugia, Italy
[24](A)INFN Sezione di Ferrara, I-44122, Ferrara, Italy; (B)University of Ferrara, I-44122, Ferrara, Italy
[25]Institute of Modern Physics, Lanzhou 730000, China
[26]Institute of Physics and Technology, Peace Ave. 54B, Ulaanbaatar 13330, Mongolia
[27]Jilin University, Changchun 130012, China
[28]Johannes Gutenberg University of Mainz, Johann-Joachim-Becher-Weg 45, D-55099 Mainz, Germany
[29]Joint Institute for Nuclear Research, 141980 Dubna, Moscow region, Russia
[30]Justus-Liebig-Universitaet Giessen, II. Physikalisches Institut, Heinrich-Buff-Ring 16, D-35392 Giessen, Germany
[31]KVI-CART, University of Groningen, NL-9747 AA Groningen, The Netherlands
[32]Lanzhou University, Lanzhou 730000, China
[33]Liaoning Normal University, Dalian 116029, China
[34]Liaoning University, Shenyang 110036, China
[35]Nanjing Normal University, Nanjing 210023, China
[36]Nanjing University, Nanjing 210093, China
[37]Nankai University, Tianjin 300071, China
[38]Peking University, Beijing 100871, China
[39]Qufu Normal University, Qufu 273165, China
[40]Shandong Normal University, Jinan 250014, China
[41]Shandong University, Jinan 250100, China
[42]Shanghai Jiao Tong University, Shanghai 200240, China
[43]Shanxi Normal University, Linfen 041004, China
[44]Shanxi University, Taiyuan 030006, China
[45]Sichuan University, Chengdu 610064, China
[46]Soochow University, Suzhou 215006, China
[47]Southeast University, Nanjing 211100, China
[48]State Key Laboratory of Particle Detection and Electronics, Beijing 100049, Hefei 230026, China
[49]Sun Yat-Sen University, Guangzhou 510275, China

[50]Tsinghua University, Beijing 100084, China
[51](A)Ankara University, 06100 Tandogan, Ankara, Turkey; (B)Istanbul Bilgi University, 34060 Eyup, Istanbul, Turkey; (C)Uludag University, 16059 Bursa, Turkey; (D)Near East University, Nicosia, North Cyprus, Mersin 10, Turkey
[52]University of Chinese Academy of Sciences, Beijing 100049, China
[53]University of Hawaii, Honolulu, Hawaii 96822, USA
[54]University of Jinan, Jinan 250022, China
[55]University of Manchester, Oxford Road, Manchester, M13 9PL, United Kingdom
[56]University of Minnesota, Minneapolis, Minnesota 55455, USA
[57]University of Muenster, Wilhelm-Klemm-Str. 9, 48149 Muenster, Germany
[58]University of Oxford, Keble Rd, Oxford, UK OX13RH
[59]University of Science and Technology Liaoning, Anshan 114051, China
[60]University of Science and Technology of China, Hefei 230026, China
[61]University of South China, Hengyang 421001, China
[62]University of the Punjab, Lahore-54590, Pakistan
[63](A) University of Turin, I-10125, Turin, Italy; (B) University of Eastern Piedmont, I-15121, Alessandria, Italy; (C) INFN, I-10125, Turin, Italy
[64]Uppsala University, Box 516, SE-75120 Uppsala, Sweden
[65]Wuhan University, Wuhan 430072, China
[66]Xinyang Normal University, Xinyang 464000, China
[67]Zhejiang University, Hangzhou 310027, China
[68]Zhengzhou University, Zhengzhou 450001, China
[a]Also at Bogazici University, 34342 Istanbul, Turkey
[b]Also at the Moscow Institute of Physics and Technology, Moscow 141700, Russia
[c]Also at the Novosibirsk State University, Novosibirsk, 630090, Russia
[d]Also at the NRC "Kurchatov Institute", PNPI, 188300, Gatchina, Russia
[e]Also at Istanbul Arel University, 34295 Istanbul, Turkey
[f]Also at Goethe University Frankfurt, 60323 Frankfurt am Main, Germany
[g]Also at Key Laboratory for Particle Physics, Astrophysics and Cosmology, Ministry of Education; Shanghai Key Laboratory for Particle Physics and Cosmology; Institute of Nuclear and Particle Physics, Shanghai 200240, China
[h]Also at Key Laboratory of Nuclear Physics and Ion-beam Application (MOE) and Institute of Modern Physics, Fudan University, Shanghai 200443, China
[i]Also at Harvard University, Department of Physics, Cambridge, MA, 02138, USA
[j]Currently at: Institute of Physics and Technology, Peace Ave.54B, Ulaanbaatar 13330, Mongolia
[k]Also at State Key Laboratory of Nuclear Physics and Technology, Peking University, Beijing 100871, China
[l]School of Physics and Electronics, Hunan University, Changsha 410082, China

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 $\geqslant$ 1
1	NClus.GE.2	Number of Clusters $\geqslant$ 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 $\geqslant$ 1
13	NEClus.GE.1	Number of Endcap Clusters $\geqslant$ 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 $\geqslant$ 2
19	NETOF.GE.1	Number of Endcap TOF hits $\geqslant$ 1
20	NBTOF.GE.2	Number of Barrel TOF hits $\geqslant$ 2
21	NBTOF.GE.1	Number of Barrel TOF hits $\geqslant$ 1
22	NTOF.GE.1	Number of TOF hits $\geqslant$ 1
	Muon counter (MUC)	
32	NABMU.GE.1	Barrel Tracks number $\geqslant$ 1 for A
33	NAEMU.GE.1	Endcap Tracks number $\geqslant$ 1 for A
34	NCBMU.GE.1	Barrel Tracks number $\geqslant$ 1 for C
35	NCEMU.GE.1	Endcap Tracks number $\geqslant$ 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 $\geqslant$ N
40	NSTrk.GE.2	Number of Short Tracks $\geqslant$ 2
41	NSTrk.GE.1	Number of Short Tracks $\geqslant$ 1
42	LTrk_BB	Long Tracks Back to Back
43	NLTrk.GE.N	Number of Long Tracks $\geqslant$ N
44	NLTrk.GE.2	Number of Long Tracks $\geqslant$ 2
45	NLTrk.GE.1	Number of Long Tracks $\geqslant$ 1
46	NItrk.GE.2	Number of Inner Tracks $\geqslant$ 2
47	NItrk.GE.1	Number of Inner Tracks $\geqslant$ 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	$100.00^{+0.00}_{-0.01}$

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

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 determ-

ined 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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