PHYSICAL STUDY OF THE BESⅢ TRIGGER SYSTEM

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ABSTRACT

Physical study of the BESⅢ trigger system is introduced including detector simulations, generation and optimization of the sub-detectors' trigger conditions, global trigger simulations (Combining the trigger conditions from different detectors to find out the trigger efficiencies of the physical events and the rejection factors of the backgrounds events.) and hardware implementation feasibility considerations.

Brief introduction to the BESⅢ

BESⅢ is a large particle detector system running on the BEPCⅡ. It mainly includes the MDC(Main Drift Chamber) for charged particles' tracking, EMC(ElectroMagnetic Calorimeter) for electromagnetic showering, TOF(Time of Flight) for time of flight measurements of charged particles, μ Identifier for μ identifications and Super Conducting Solenoid magnet to provide the constant magnet field for the MDC. As shown in Fig. 1.

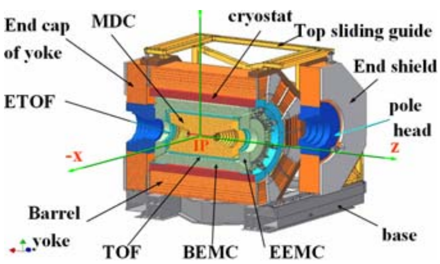


Fig. 1 Main components of the BESⅢ

Characteristics of the main components are :

- ●MDC – Single wire resolution better than 130μm;
- ●EMC – Energy resolution better than 2.5% @ 1GeV;
- ●TOF – Time resolution better than 100ps;
- ●Super Conducting Solenoid magnet – 1 Tesla magnetic field;
- ●μ Identifier – RPC based.

Physical study of the trigger system

Scheme of the trigger simulations

Trigger simulations contain mainly three parts. The first part is the event generators including the generation of physical events with BES sober, beam-related backgrounds with BESⅢ Turtle and cosmic-ray backgrounds with self-coded program. The second part is the detector response simulations based on GEANT3 and the third part is the trigger conditions' simulation including the generation and optimization of the different trigger conditions.

Fig. 2 shows the scheme of the trigger simulations.

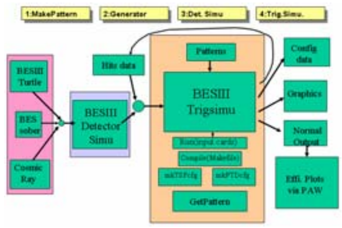
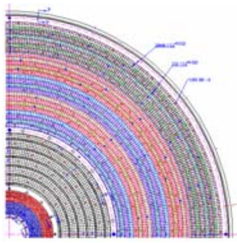


Fig. 2 Scheme of the trigger simulations

Simulations of the MDC sub-trigger

There are total 43 signal layers and 6796 signal wires for the MDC. As shown in Fig. 3.



super layer number	signal layer number	number of signal wires of each layer				total layers	total wires	pivot layer	number of reference wires
		L1	L2	L3	L4				
SL-1	ST-1/2/3/4	40	44	48	56	4	188	3	48
SL-2	ST-5/6/7/8	64	72	80	80	4	296	3	80
SL-3	AX-9/10/11/12	76	76	88	88	4	328	3	88
SL-4	AX-13/14/15/16	100	100	112	112	4	424	3	112
SL-5	AX-17/18/19/20	128	128	140	140	4	536	2	128
SL-6	ST-21/22/23/24	160	160	160	160	4	640	2	160
SL-7	ST-25/26/27/28	176	176	176	176	4	704	2	176
SL-8	ST-29/30/31/32	208	208	208	208	4	832	2	208
SL-9	ST-33/34/35/36	240	240	240	240	4	960	2	240
SL-10	AX-37/38/39/40	256	256	256	256	4	1024	2	256
SL-11	AX-41/42/43	288	288	288	0	3	864	2	288
total number							6796	/	1784

Fig. 3 Layer arrangement of the MDC

Track findings are divided into two steps. The first one is TSF (Track Segment Finding) in each super layer. The second one is TF (Track Finding, combining all TSFs for track decision). To simplify the hardware implementations, we use the super layers 1–5 and 10 as MDC sub-trigger sources. Fig. 4 shows some examples of tracks in the MDC.

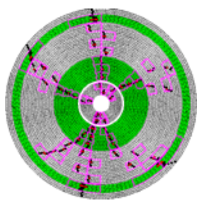


Fig. 4 Tracks in the MDC

TSF is done within the 4 signal layers in one super layer. As shown in Fig. 5. Possible cases are as follows:

1) All the four layers have hits, called 4/4 logic

2) Only three of the four layers have hits, called 3/4 logic

3) Only two of the four layers have hits, called 2/4 logic

4) Only one of the four layers have hits, called 1/4 logic

Simulations show that case 3) has a probability of less than 1% for a full track segment with the wires' efficiency of 95%. So, only case 1) and 2) are considered in the TSF findings.

Combinations used for the hardware implementations are obtained by Monte Carlo simulations. For each pivot cell of each pivot layer, tracks penetrating the pivot cell are generated with random momentum and angles in certain ranges. Then the hits of the other cells in the other layers besides the pivot cell are got. If enough tracks are generated, then we can believe that all the possible combinations are contained in the results.

The most probable combinations are used in hardware implementation for implementation convenience and TSF efficiency considerations.

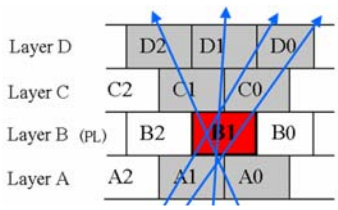


Fig. 5 Track Segment Finding

3/4 logic is useful for wire efficiencies less than 100% As illustrated in Fig. 6. So, it is used in hardware implementations.

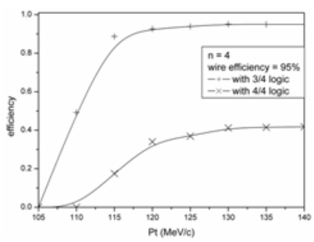


Fig. 6 Relations between Track Finding efficiency and *pt* with 4/4 and 3/4 TSF logic

Track Finding is similar to Track Segment Finding. Super layer 5 is used as the pivot layer for related cells minimization considerations. Tracks penetrating super layer 3, 4, 5 and 10 are called Long Tracks, tracks penetrating super layer 3, 4 and 5 are called Short Tracks.

Tracks that can reach super layer 10 and super layer 5 should have a minimum radial momentum of 110MeV/c and 70MeV/c respectively under a solenoid field of 1 Tesla. To reject cosmic and beam-related backgrounds effectively, radial momentums of 120MeV/c and 90MeV/c are used for Long Track and Short Track decisions respectively.

Fig. 7 shows the TF efficiencies versus the radial momentum *pt*.

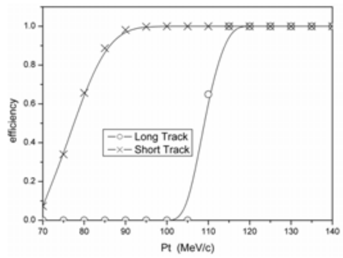


Fig. 7 Relations between TF efficiency and *pt*

Fig. 8 shows the track finding efficiencies in the r-ϕ plane and Z direction. For a distance of 15 cm in the r-ϕ plane, the TF efficiency is about 30% for 3/4 TSF logic. For a distance of 50 cm in the Z direction, it is about 28%. This is good to reject backgrounds far from the Interaction Point.

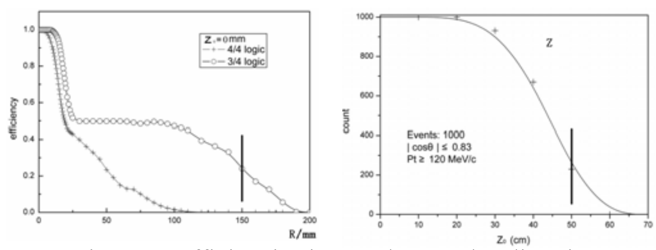


Fig. 8 TF efficiencies in r-ϕ plane and Z direction

Use of the inner two super layers helps to reduce backgrounds, but also causes the loss of some particles with short lifetimes, such as K_s and λ. As shown in table 1.

Table 1 Fractions passed of different types of events

Types of events	Passed/Total with only axial layers	Passed/Total with both axial and the inner two stereo layers
J/ψ→ Anything	9,490/10,000	9435/10,000

Cosmic rays	197/10,000	135/10,000
Beam-related backgrounds	52/1,000,000	28/1,000,000

Total 9 trigger conditions are generated for the MDC, they are

- ●NLtrk >= 1
- ●NLtrk >= 2
- ●NLtrk >= N; for too many MDC wires' hits due to occasional high voltage problems
- ●NStrk >= 1
- ●NStrk >= 2
- ●NStrk >= N; for too many MDC wires' hits due to occasional high voltage problems
- ●Strk_BB; Short Tracks back to back within 160 degrees
- ●NItrk >= 1; Number of the Track Segments of the SL1 and SL2 are equal to or greater than 1
- ●NItrk >= 2; Number of the Track Segments of the SL1 and SL2 are equal to or greater than 2

Simulations of the EMC sub-trigger

The EMC has 5280(z*φ=44*120) crystals in barrel and 480 ones in each endcap. The fundamental unit of the EMC sub-trigger is trigger cell, which is composed of some neighbored crystals. A trigger cell should be large enough to collect most of the showered energy of a particle and be not too large for precise positioning of a shower. From simulations, trigger cells of 4*4 crystals for barrel and those of 15 crystals for each endcap are decided. As shown in Fig. 9 to Fig. 11.

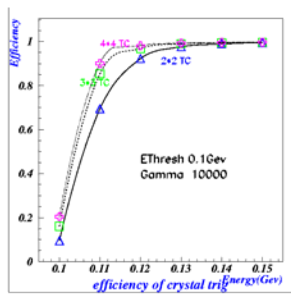


Fig. 9 Selection of trigger cell sizes

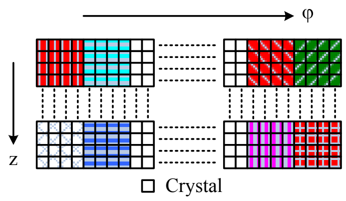


Fig. 10 Trigger cells of barrel EMC

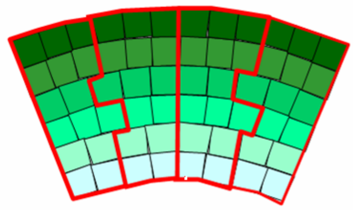


Fig. 11 Trigger cells of endcap EMC(1/8)

For physical events, the lower the threshold of the trigger cells, the higher the trigger efficiency. But, too low a threshold will cause much more backgrounds. An adjustable threshold in the range of 60-80 MeV is determined for both physics and backgrounds considerations. As shown in Fig. 12.

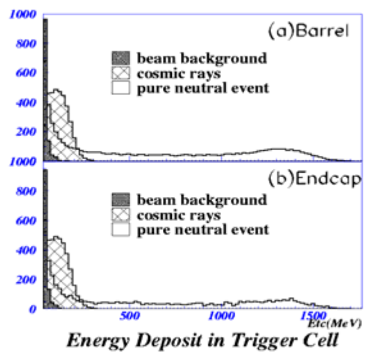


Fig. 12 Energy deposit in trigger cells

A showered cluster may fire several trigger cells. A cluster finding logic should be established to find out the trigger cell that should stand for the cluster. From simulations and experiences of the other experiments, the logic in Fig. 13 is developed for our case. Fig. 14 shows some examples.

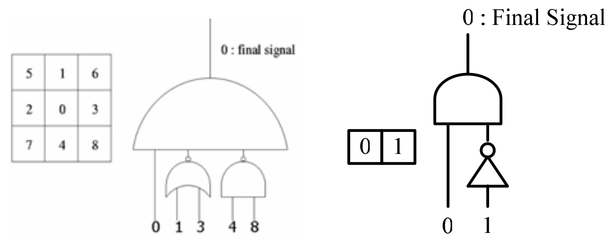


Fig. 13 Isolated cluster finding

(left : barrel, right : endcap)

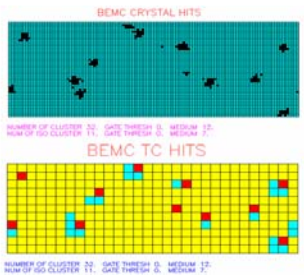


Fig. 14 Examples of barrel EMC cluster finding

Measurement of energy deposition is the main task of the EMC, For trigger system, three energy thresholds are set for different purposes.

●Etot_L ~ 200MeV, to reject beam-related backgrounds

●Etot_M ~ 700MeV, for neutral physical events

●BEtot_H, EEtot_H ~ 2.3GeV, for Bhabha events

Fig. 15 shows total energy depositions of different types of events. We can see that a threshold of 700MeV can reject most of the beam-related and cosmic backgrounds.

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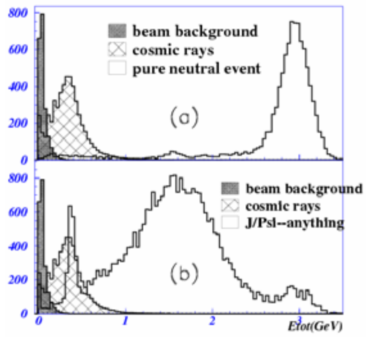

Fig. 15 Total energy deposition in the EMC

For trigger system, the EMC is divided into some energy blocks. Those in the barrel part are shown in Fig. 18, and each endcap part is an energy block called EBLK (East BLocK) or WBLK (West BLocK). Also, the barrel part is divided into two halves as shown in Fig. 19 and the east and west endcap parts are called Endcap East and Endcap West respectively.

Total 16 trigger conditions are generated. They are:

●NClus >= 1 : Number of clusters equal to or greater than 1.

●NClus >= 2 : Number of clusters equal to or greater than 2.

●BClus_BB : Barrel clusters back to back, see Fig. 16.

●EClus_BB : Endcap clusters back to back, see Fig. 17.

●Clus_PHI(φ) : Clusters balance in φ direction, see Fig. 19.

●Clus_Z : One cluster in the east half (barrel and endcap), one cluster in the west half (barrel and endcap)

Note : The neighbored two clusters in the endcap are combined into one except for the trigger conditions NClus >= 1 and NClus >= 2.

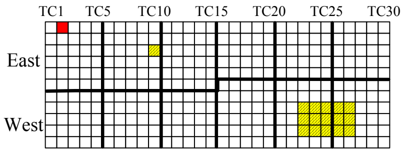

Fig. 16 Barrel clusters back to back

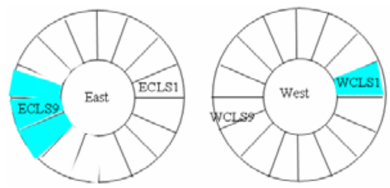

Fig. 17 Endcap clusters back to back

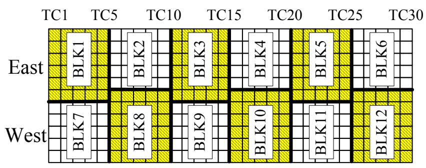

Fig. 18 Energy blocks in barrel EMC

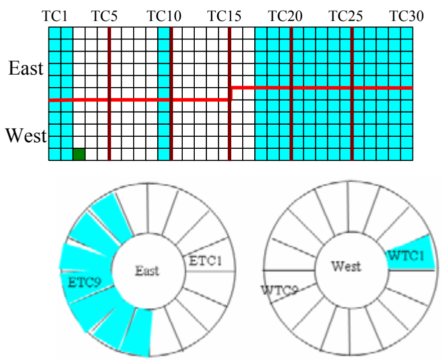

Fig. 19 Clusters balance in φ direction

(top : barrel, bottom : endcap)

●BEtot_H : High threshold of barrel EMC total energy, 2.3GeV.

●EEtot_H : High threshold of endcap EMC total energy, 2.3GeV.

●Etot_L : Low threshold of the whole EMC total energy, 200MeV.

●Etot_M : Middle threshold of the whole EMC total energy, 700MeV.

●BL_Z : Balance in z direction. Both total energy of east half (barrel and endcap) and that of west half exceed 300MeV.

●Diff_B : Total energy difference of the two barrel halves, if the difference if less than 600MeV, then Diff_B is true.

●Diff_E : Total energy difference of the two endcap halves, if the difference if less than 600MeV, then Diff_E is true.

●BL_BLK : Balance of energy blocks. Threshold for each block is 1070MeV. For balance in barrel, refer to Fig. 20. For balance in endcap, since there is only one block in each end, if both of the total energies of the two blocks exceed 1070MeV, then BL_BLK is true.

●BL_BEMC : Balance of the two barrels. If both of the total energies of the two barrels exceed 800MeV, then BL_BEMC is true

●BL_EEMC : Balance of the two endcaps. If both of the total energies of the two endcaps exceed 800MeV, then BL_EEMC is true

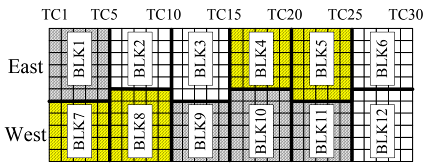

Fig. 20 Block energy balance of barrel EMC

TOF trigger conditions

Six trigger conditions are generated for the TOF sub-trigger. They are:

●NBTOF >= 1 : Number of hits of barrel TOF equal to or greater than 1.

●NBTOF >= 2 : Number of hits of barrel TOF equal to or greater than 2.

●NETOF >= 1 : Number of hits of endcap TOF equal to or greater than 1.

●NETOF >= 2 : Number of hits of endcap TOF equal to or greater than 2.

●TBB : Barrel TOF back to back. Refer to Fig. 21.

●ETBB : Endcap TOF back to back. Refer to Fig. 21.

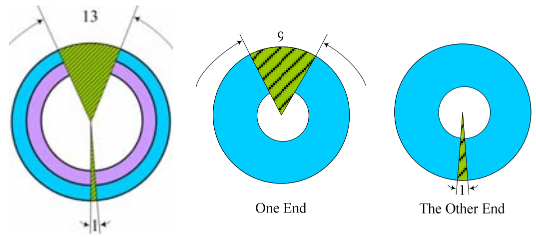

Fig. 21 TOF back to back (left : barrel, right : endcap)

Global trigger and final simulation results

Global trigger is the center of the trigger system, it collects the trigger conditions from the different sub-trigger systems and gives out the event-decision results.

The tolerable events rate for the Data AcQuisition system is 4KHz. With an events rate of about 2KHz of physical events, the backgrounds ones should be less than 2KHz. This is challenging for us. Table 2 shows the preliminary trigger table. The trigger conditions from Muon sub-trigger and Match sub-trigger systems are not included in yet and they will be implemented in the hardware design for future uses. Table 3 shows the fractions of different types of events passing the global trigger logic.

Table 2 Preliminary trigger table

	Charge 1	Charge 2	Charge 3	Common	Neutral A	Neutral B	Bhabha BEMC	Bhabha EEMC
NLtrk ≥1	Y	Y	--------	--------	--------	--------	--------	--------
NStrk ≥2	--------	Y	--------	--------	--------	--------	--------	--------
STrk-BB	--------	--------	Y	--------	--------	--------	Y	Y
Ntof ≥1	Y	--------	--------	--------	--------	--------	--------	--------
BclusBB	--------	--------	--------	--------	--------	--------	Y	--------
EclusBB	--------	--------	--------	--------	--------	--------	--------	Y
Clus_PHI	--------	--------	--------	Y	Y	--------	--------	--------
Clus_Z	--------	--------	--------	Y	--------	--------	--------	--------
Diff_E	--------	--------	--------	--------	--------	--------	--------	Y
BL_BLK	--------	--------	--------	--------	--------	--------	Y	--------
BL_EEMC	--------	--------	--------	--------	--------	--------	--------	Y
BL_Z	--------	--------	--------	--------	--------	Y	--------	--------
Etot_L	Y	--------	--------	Y	--------	--------	--------	--------
Etot_M	--------	--------	--------	--------	Y	--------	--------	--------
EEtot_H	--------	--------	--------	--------	--------	--------	--------	Y
NLtrk ≥2	--------	--------	--------	--------	--------	--------	--------	--------
NLtrk ≥N	--------	--------	--------	--------	--------	--------	--------	--------
NStrk ≥1	--------	--------	--------	--------	--------	--------	--------	--------
NStrk ≥N	--------	--------	--------	--------	--------	--------	--------	--------
NItrk ≥1	--------	--------	--------	--------	--------	--------	--------	--------
NItrk ≥2	--------	--------	--------	--------	--------	--------	--------	--------
Ntof ≥2	--------	--------	--------	--------	--------	--------	--------	--------
TBB	--------	--------	--------	--------	--------	--------	--------	--------
NClus ≥1	--------	--------	--------	--------	--------	--------	--------	--------
NClus ≥2	--------	--------	--------	--------	--------	--------	--------	--------
Diff_B	--------	--------	--------	--------	--------	--------	--------	--------
BL_BEMC	--------	--------	--------	--------	--------	--------	--------	--------
BEtot_H	--------	--------	--------	--------	--------	--------	--------	--------

Table 3 Passing fractions of different types of events

Events	Number of passing/Total	Passing Fraction
$J/\psi->Anything$	9766/10,000	97.66%
$\psi'->Anything$	9950/10,000	99.50%
$\psi''->D\bar{D}->Anything$	9990/10,000	99.90%
$J/\psi->\omega\eta->5\gamma$	9785/10,000	97.85%
$J/\psi->\gamma\eta->3\gamma$	9275/10,000	92.75%
$J/\psi->K^+K^-\pi^0$	9739/10,000	97.39%
$J/\psi->\pi^0 p\bar{p}$	9794/10,000	97.94%
$J/\psi->p\bar{p}$	9582/10,000	95.82%
Beam-related backgrounds	46/1,000,000	4.6×10^{-5}
Cosmic backgrounds	9,396/100,000	9.396%

The simulated event rate of the beam-related backgrounds is about 40MHz, and that of the cosmic backgrounds is about 921Hz, so, the event rates passing global trigger logic are 40MHz * 46/1,000,000 = 1.84KHz and 921Hz * 9.4% = 87Hz for the beam-related and cosmic backgrounds respectively. These rates can be tolerated by the DAQ (Data AcQuisition)system.

Most of the beam-related backgrounds passing the global trigger belong to the event channel "Charge 1". These events can be reduced from 46 to 10 by replacing the trigger condition NClus >= 1 with NClus >= 2 in the event channel "Charge 1". This change causes a little loss of physical events, which is less than 0.5% for most of the types of physical events.

Hardware schemes and current status

Characteristics of the trigger system

- ●All signals from the detectors are pipelined to the trigger system with a clock frequency of 41.65MHz, a twelfth of the 499.8MHz radio frequency.
- ●Fiber transmissions are used between the trigger system and all the electronics systems to eliminate common-ground noises.
- ●Advanced and reliable FPGAs are used to provide great flexibility and reliablity.
- ●Rocket I/Os are used to reduce the inter-connect cables.
- ●Online reconfigurable techniques are used for some of the FPGAs to increase system flexibility.
- ●Types of PCBs are minimized to ease maintenance.

Scheme of the trigger system

Fig. 22 shows the hardware scheme of the trigger system. Signals from the detectors are collected by the corresponding electronic systems. Part of them are sent to the trigger system to generate the trigger conditions. Then these trigger conditions are sent to the global trigger system for final event decision and L1* signal is given out if there is a good event. Latency from the detectors to the L1* signal is about 6.4μs.

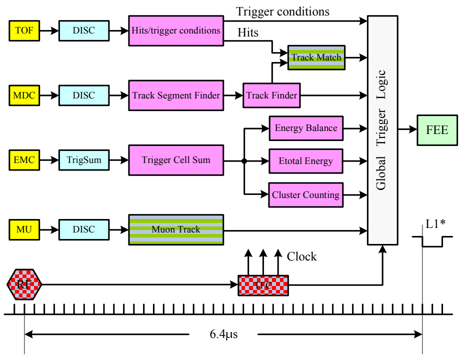

Fig. 22 Scheme of the trigger system

Fig. 23 to Fig. 26 show the schemes of the MDC, TOF, EMC and Global sub-trigger systems respectively.

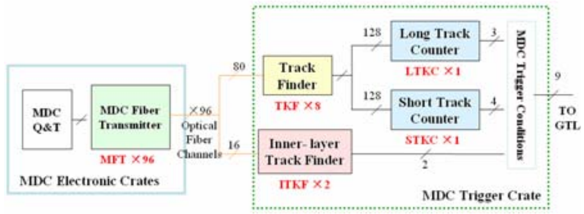

Fig. 23 Scheme of the MDC sub-trigger system

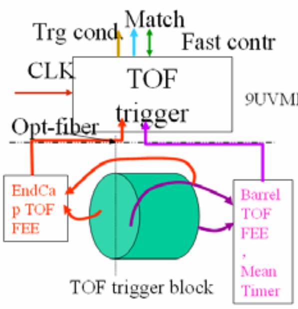

Fig. 24 Scheme of the TOF sub-trigger system

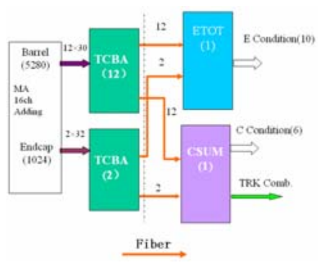

Fig. 25 Scheme of the EMC sub-trigger system

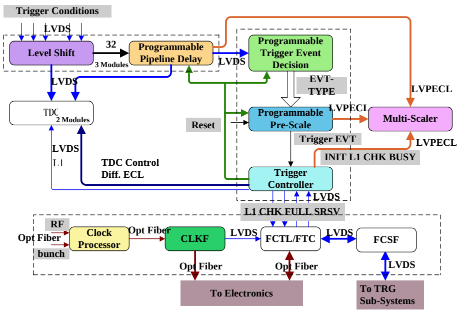

Fig. 26 Scheme of the GLT (GLobal Trigger) sub-trigger system

Progress of hardware design

At least one version has been finished for all the modules needed. There is no bottleneck found till now and main technical difficulties have all been overcome such as the fiber transmissions, use of Rocket I/Os, and treatments of analog signals. All are going smoothly.

Conclusions

We have done detailed simulations of the BESIII trigger system, especially for the MDC and EMC sub-triggers. The preliminary results show that the current design can fulfil the requirements from both the physics and the DAQ system Based on the simulations, the trigger conditions and hardware schemes are determined. Hardware implementations are going forward smoothly with no technical bottlenecks till now.