Chapter 3

KEKB Accelerator and BELLE Detector

3.1 KEKB Accelerator

The KEKB accelerator is being constructed at KEK in Tsukuba, Japan, reusing the tunnel of decommissioned TRISTAN accelerator. The construction started in April of 1994 and it is completed in November, 1998. It is now under detailed tuning of the machine.

KEKB is an asymmetric energy electron positron collider to make the generated particles run along the beam axis by Lorenz boost. Electrons and positrons are stored in two separate rings. The electron energy is 8 GeV and the positron energy is 3.5 GeV. They collide at the center-of-mass energy of 10.58 GeV and the energy is used to produce $\Upsilon(4S)$ which decays into a $B\bar{B}$ mesons ($M_B = 5279$ MeV). The velocity of cms in the laboratory (β) becomes 0.39 and the Lorenz factor (γ) is $\gamma = \frac{1}{\sqrt{1-\beta^2}} = 1.09$. Since the kinetic energy of the B meson in cms is only 11 MeV, the produced B mesons fly in the direction of the electron with the velocity β. The life time τ of B^0 is 1.6 $\times$ 10^{-12} s, and B mesons run about 200 μm ($= \beta c\tau\gamma$) before it decays in the laboratory system. Specific decay channels of B meson will be studied for the CP violation and the measurement of CKM matrix element. Since many of interesting decay modes have a branching fraction of 10^{-4} or less, a very high luminosity is required. The goal of the luminosity is 10^{34} cm^{-2}s^{-1} and this corresponds to two orders of magnitude higher luminosity than those of the existing accelerators. The high luminosity is achieved mostly by increasing the beam current stored in many bunches. The number of bunches of electron and positron are 5000 and the beam current is 2.6 A and 1.1 A for electron

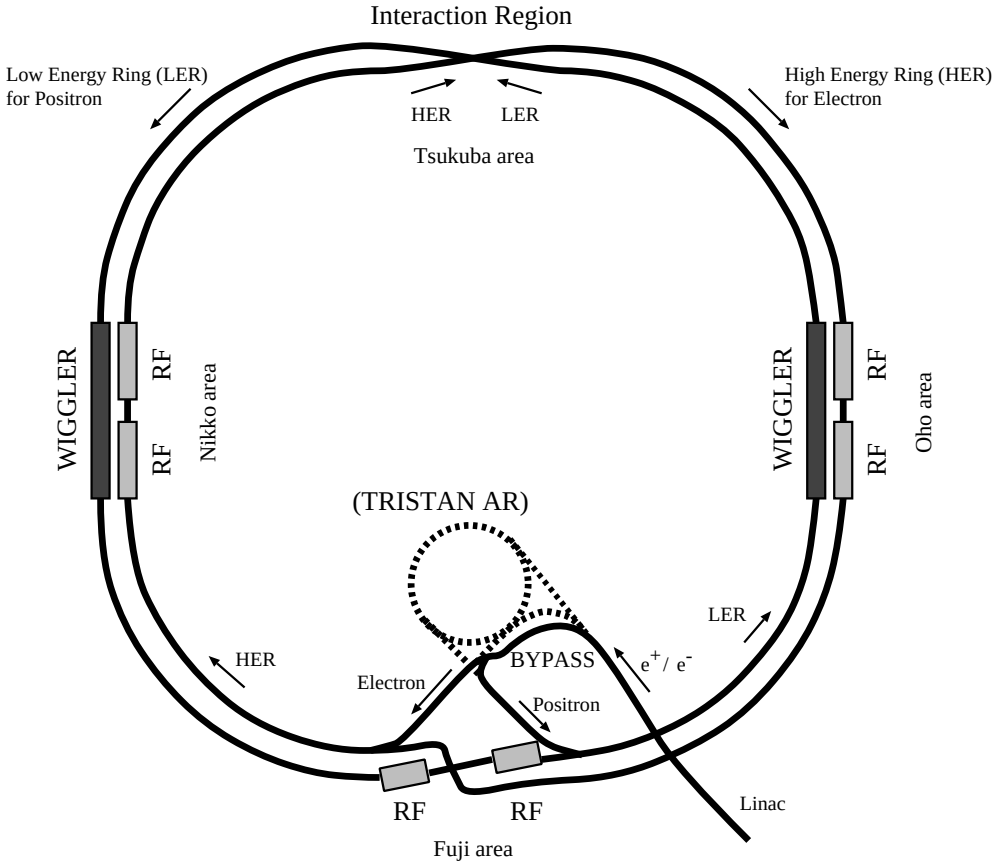


Figure 3.1: Configuration of KEKB accelerator system.

and positron beams. Fig. 3.1 shows the configuration of KEKB and Table 3.1 shows the parameter of the collider[38].

As shown in Fig. 3.1, the interaction point is only one in the Tsukuba experimental area where the BELLE detector is installed.

3.2 BELLE Detector

3.2.1 Overall Design

The BELLE is an international collaboration, which includes institutes and universities from many countries (Australia, China, India, Japan, Korea, Phillipines, Poland, Russia, Taiwan, U.S.A.). The collaboration started in 1994 and the detector construction is completed in December 1998. The BELLE detector is illustrated in Fig. 3.2. This is a combination of several detectors to detect many types of particles.

Ring	LER	HER	
Energy (E)	3.5	8.0	GeV
Circumference (C)	3016.26		m
Luminosity (L)	1×10^{34}		$\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$
Crossing angle (θ_x)	± 11		mrad
Tune shifts (ξ_x/ξ_y)	0.039/0.052		
Beta function at IP (β_x^*/β_y^*)	0.33/0.01		m
Beam current (I)	2.6	1.1	A
Natural bunch length (σ_z)	0.4		cm
Energy spread (σ_E)	7.1×10^{-4}	6.7×10^{-4}	
Bunch spacing (s_B)	0.59		m
Particles/bunch	3.3×10^{10}	1.4×10^{10}	
Emittance ($\varepsilon_x/\varepsilon_y$)	$1.8 \times 10^{-8}/3.6 \times 10^{-10}$		m
Synchrotron tune (ν_s)	$0.01 \sim 0.02$		
Betatron tune (ν_x/ν_y)	45.52/45.08	47.52/46.08	
Momentum compaction factor (α_p)	$1 \times 10^{-4} \sim 2 \times 10^{-4}$		
Energy loss/turn (U_0)	$0.81^*/1.5^\dagger$	3.5	MeV
RF voltage (V_c)	$5 \sim 10$	$10 \sim 20$	MV
RF frequency (f_{RF})	508.887		MHz
Harmonic number (h)	5120		
Longitudinal damping time (τ_ϵ)	$43^*/23^\dagger$	23	ms
Total beam power (P_b)	$2.7^*/4.5^\dagger$	4.0	MW
Radiation power (P_{SR})	$2.1^*/4.0^\dagger$	3.8	MW
HOM power (P_{HOM})	0.57	0.15	MW
Bending radius (ρ)	16.3	104.5	m
Length of bending magnet (l_b)	0.915	5.86	m

* without wigglers †with wigglers

Table 3.1: Parameters of KEKB accelerator.

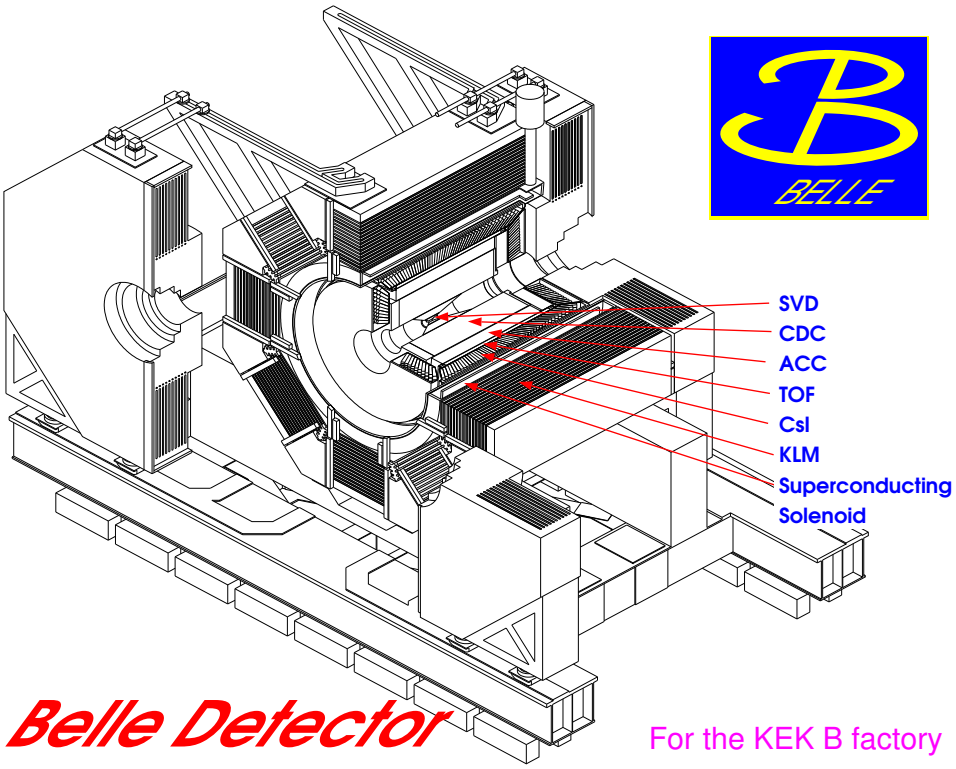


Figure 3.2: BELLE detector.

The following subdetectors are installed around the interaction point.

- A vertex detector to measure the decay point (SVD).
- A tracking detector to measure the momentum of charged particles in the magnetic field (CDC).
- A calorimeter to measure the particles in the extreme forward region(EFC).
- A particle identification detector for the separation of $\pi^{\pm}$ and $K^{\pm}$ (CDC,TOF,ACC).
- A calorimeter to measure the energy of gamma rays and electrons (CsI).
- A detector to identify muons and K_L^0 (KLM).

The BELLE detector is approximately 7 m in diameter and 7 m long. It's weight is about 2000 tons. The parameter of each detector is tabulated in Table. 3.2.

The requirement of the detector is to identify the type of each particle (e, μ, γ, $\pi^{\pm}$, $K^{\pm}$, K_L^0 etc.) and to measure their vectors as precise as possible. The reconstruction of the mother particles and their decay processes are achieved from the information of them. Since the momentum of detected particle is low, the material composing each detector should be as thin as possible to reduce the influence of scattering and particle interaction.

3.2.2 Beam Pipe

The BELLE beam pipe should be strong enough to stand the vacuum pressure and the heat generated by the high current beam. The configuration is shown in Fig. 3.3. Since the multiple scattering for the same thickness of the material is proportional to the atomic number Z, it is better to use a small Z material for the beam pipe. It is made by the double wall of 0.5 mm thick beryllium (Z = 4) cylinders separated by 2 mm [39]. The helium gas flows between two walls for cooling. Both ends of the beryllium cylinder are attached to the aluminum beam pipe. The cooling of this part is done with water.

3.2.3 Silicon Vertex Detector(SVD)

In the BELLE experiment, it is important to distinguish two decay points of B mesons. Because the difference of the decay time has to be measured as mentioned in the

Detector	Type	Configuration	Readout	Performance
Beam pipe	Berylium double-wall	Cylindrical, r = 2.3 cm 0.5 mm Be/ 2 mm He /0.5 mm Be		
SVD	Double sided Si strip	300 μm thick, 3 layers r = 3.0 - 5.8 cm Length = 22 - 34 cm	ϕ: 41k θ: 41k	$\sigma_{\Delta z} \sim 105$ μm
EFC	BGO	2 cm × 1.5 cm × 12 cm	θ : 5 ϕ : 32	
CDC	Small cell drift chamber	Anode : 52 layers Cathode : 3 layers r = 8.5 - 90 cm -77 $\leq$ z $\leq$ 160 cm	 A: 8.4k C: 1.5k	$\sigma_{r\phi} = 130$ μm $\sigma_z = 200 \sim 1{,}400$ μm $\sigma_{p_t}/p_t = 0.3$ % $\sqrt{p_t^2 + 1}$ $\sigma_{dE/dx} = 6$ %
ACC	n : 1.01 $\sim$ 1.03 Silica Aerogel	$\sim 12 \times 12 \times 12$ cm ^{3} blocks 960 barrel / 228 endcap FM - PMT readout	 1,788 ch	 $\mu_{eff} = \geq 6$ K/π 1.2 $\leq$ p $\leq$ 3.5 GeV/c
TOF	Plastic Scintillator	128 ϕ segmentation r = 120 cm, 3 m long	 128 × 2 ch	$\sigma_t = 100$ ps K/π =up to 1.2 GeV/c
ECL	CsI	Tower structure $\sim 5.5 \times 5.5 \times 30$ cm^3 crystals Barrel : r = 125 - 162 cm Endcap : z = -102 and +196 cm	 6,624(B) 1,152(FE) 960(BE)	σ_E/E $= \frac{0.066(\%)}{E} \oplus \frac{0.81(\%)}{E^{1/4}} \oplus 1.34(\%)$ $\sigma_{pos} = 0.5$ cm / $\sqrt{E}$ E in GeV
MAGNET	super conducting	inn.rad. = 170 cm		B = 1.5 T
KLM	Resistive plate counter	14 layers (5 cm Fe + 4 cm gap) 2 RPCs in each gap θ and ϕ strips	 θ: 16k ϕ: 16k	$\Delta\phi = \Delta\theta = 30$ mrad for K_L $\sigma_t = 1$ ns 1 % hadron fakes

Table 3.2: Performance parameters of the BELLE detector

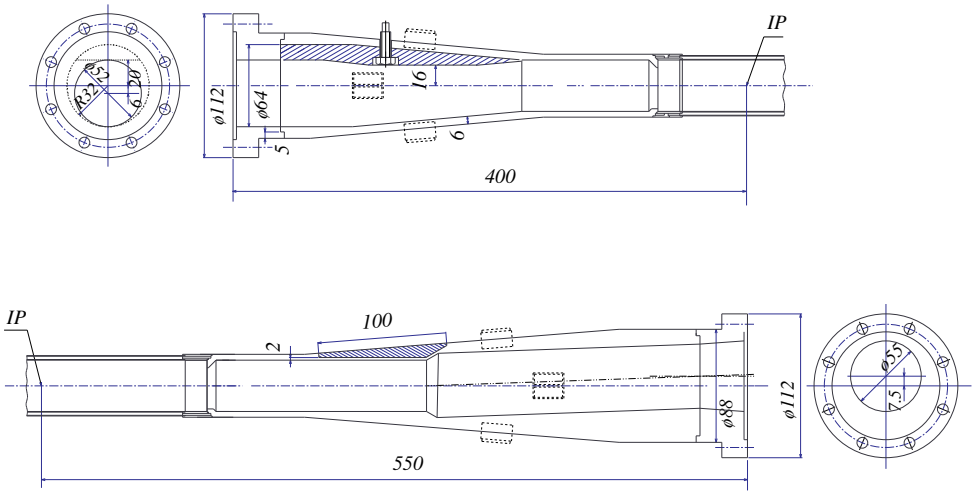


Figure 3.3: Beam pipe.

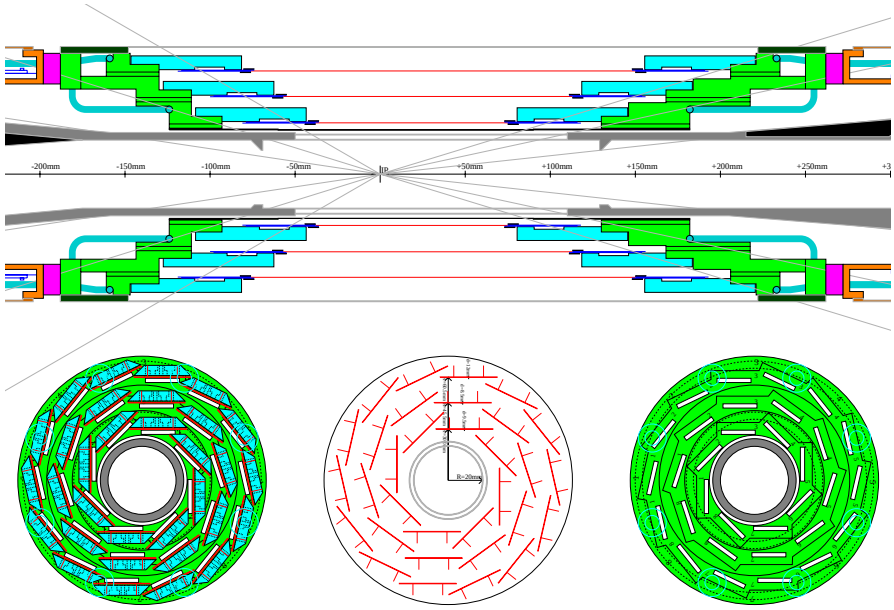


Figure 3.4: Silicon vertex detector.

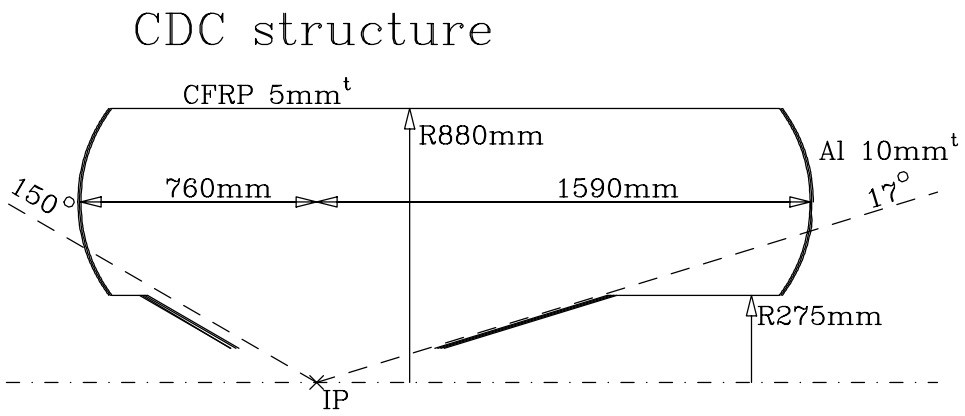


Figure 3.5: Central drift chamber.

previous chapter, the vertex detector is required to have a good position resolution of ~ 10 μm.

The configuration of the silicon vertex detector (SVD) is shown in Fig. 3.4. The SVD has three cylindrical detection layers consisting of 8, 10 and 14 units of the double sided silicon detectors (DSSD). Each DSSD width is 300 μm and the 2 dimensional position is measured in one layer. The vertex δz resolution is estimated to be 113 μm including the effect of the beam background [40].

3.2.4 Extreme Forward Calorimeter(EFC)

The extreme forward calorimeter (EFC) detects particles produced near the beam line ($6.4^\circ < \theta < 12.4^\circ$ and $162.2^\circ < \theta < 173.4^\circ$)[41]. It is attached to the front nose of the cryostat of the QCS magnet surrounding the beam pipe. The QCS magnet is the final focusing quadrupole of the KEKB accelerator. EFC is for the measurement of the energy of electrons and photons which can not be detected by large angle calorimeter. It is also used to detect the charged particles in this region. A radiation hard BGO crystals [42] are used for EFC. EFC measures scintillation light in the BGO crystal produced by the electromagnetic shower of electrons and photons as the CsI electromagnetic calorimeter.

3.2.5 Central Drift Chamber(CDC)

The charged particle makes a spiral motion in a uniform magnetic field and its radius is proportional to the transverse momentum of the particle. Then the transverse mo-

mentum is measured by the reconstruction of the track and the known strength of the magnetic fields.

The central drift chamber of BELLE is installed outside of the SVD. The size is shown in Fig. 3.5. It is asymmetric in z to cover $17^\circ \leq \theta \leq 150^\circ$. The sense wires are made of 30 μm diameter gold plated tungsten and the 126 μm diameter aluminum wire is used for field wires. A mixture of Helium 50 % and C_2H_6 50 % gas is used for the operation of the chamber. The use of low-Z Helium gas and the aluminum field wire is to reduce the multiple scattering and to obtain a good momentum resolution at low energy. The number of layers are 40 and it is possible to measure the momentum of the charged particles with $\frac{0.3\%}{p_t^2+1}$ resolution[39].

3.2.6 Aerogel Čerenkov Counter(ACC)

When the particle velocity becomes larger than the propagation velocity of the light (= light velocity in vacuum / refractive index) in the material, the Čerenkov light is emitted. The Aerogel Čerenkov Counter(ACC) of BELLE uses Čerenkov light to separate $\pi^\pm$ and $K^\pm$ in the momentum region between 1.2 GeV/c and $2.5 - 3.5$ GeV/c. The upper limit depends on the polar angle. The configuration is shown in Fig. 3.6. The Čerenkov light is detected using a fine-mesh photomultiplier to use inside the high magnetic field [39].

3.2.7 Time of Flight Counter(TOF)

The low momentum particle which is not identified by ACC is recognized by the timing of plastic scintillation counters. This counter measures the time of flight from the vertex point with 100 ps resolution. The π/K separation is possible up to 1.2 GeV. The signal from this counter is used as the clean event timing for BELLE trigger as well.

The counters dimension are given in Fig. 3.7. The number of counters is 128 and each counter has a dimension of 40 mm $\times$ 60 mm $\times$ 2550 mm. These counters are mounted on the inner wall of the CsI detector at 1175 mm radius.

3.2.8 Electromagnetic Calorimeter(CsI)

The energy measurement of electron and photon is done by the electromagnetic calorimeter. For this purpose, 8736 pieces of CsI(Tℓ) crystals are used. These crystals measure the scintillation light generated by electromagnetic shower and determine the energy of the particles. This detector is elaborated in the next chapter.

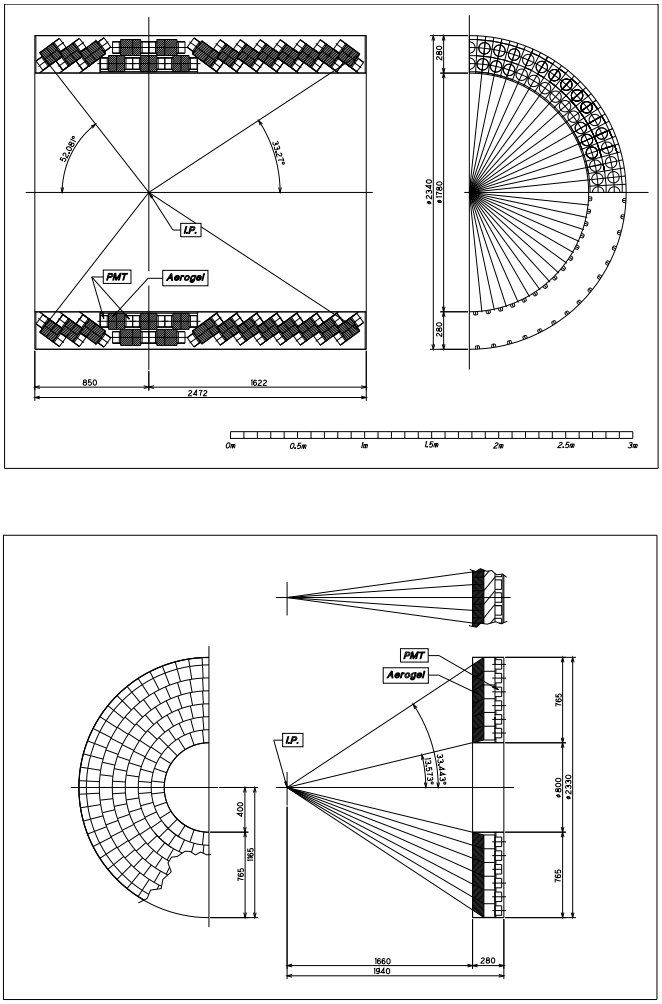
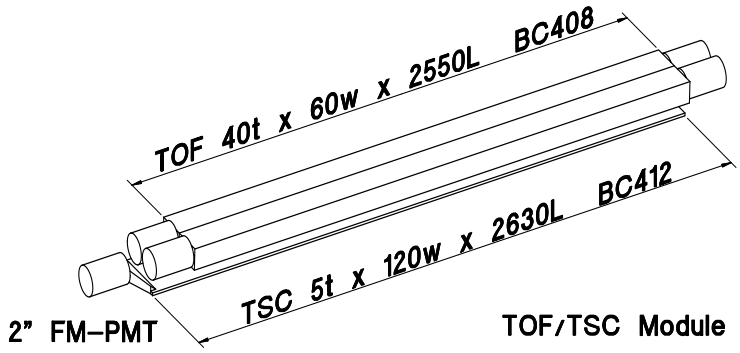


Figure 3.6: Aerogel Čerenkov counters. (a)barrel (b)endcap.



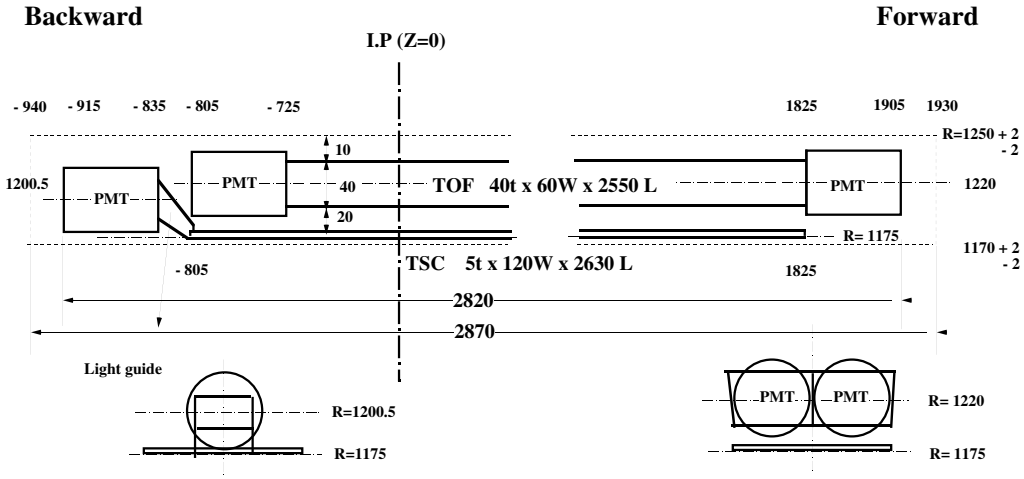


Figure 3.7: Time of flight counter and trigger scintillator.

3.2.9 Super Conducting Magnet

A super-conducting solenoid magnet has been designed to provide a 1.5 T magnet field in a cylindrical volume of 3.4 m in diameter and 4.4 m in length. The coil is surrounded by a multi layer steel return yoke to house the KLM detector.

3.2.10 K_L and Muon Detector(KLM)

The K_L particle makes a strong interaction with the material and emit the charged particles to be detected. The KLM is a sandwich of 14 layers 47 mm thick iron and 15 layers tracking device. The iron is the absorption material to generate the interaction of K_L. Resistive plate counter (RPC) modules which are planar spark counters made of glass are used as the tracking device.

High momentum muons ($\geq$ 600 MeV/c) which pass through the inner detector are also detected by KLM.

3.2.11 Trigger and DAQ System

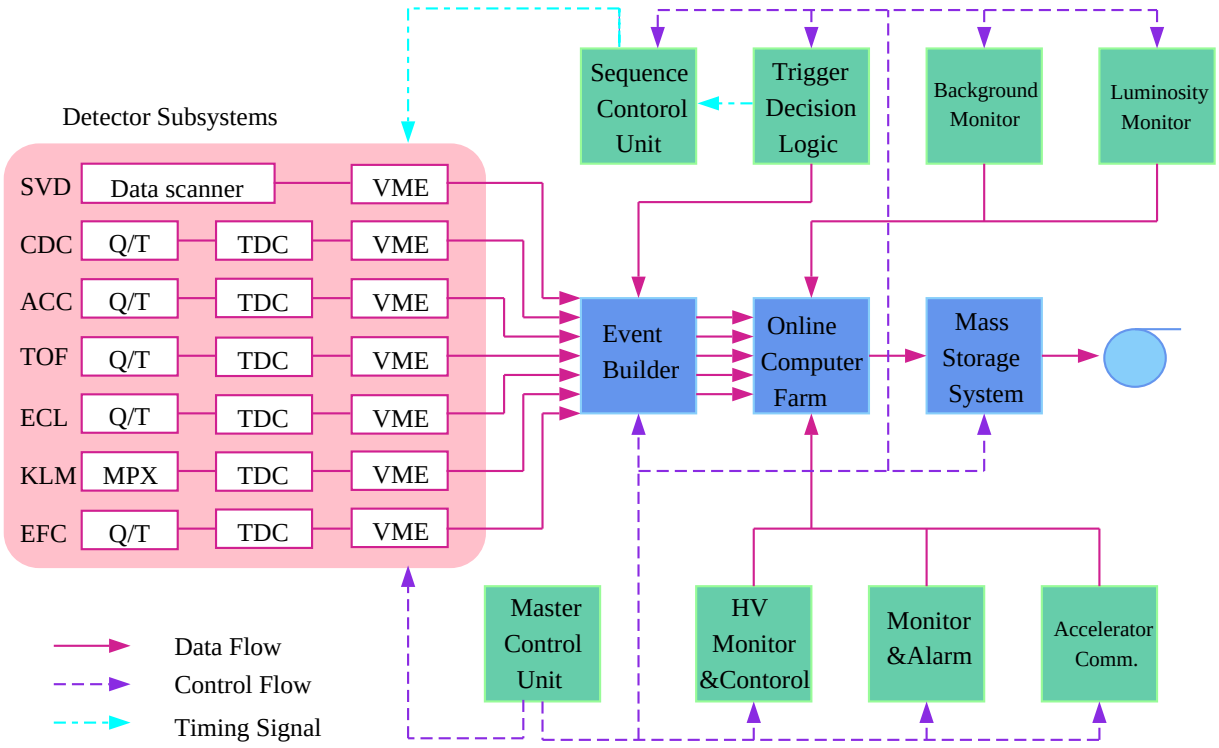


Figure 3.8: BELLE DAQ system

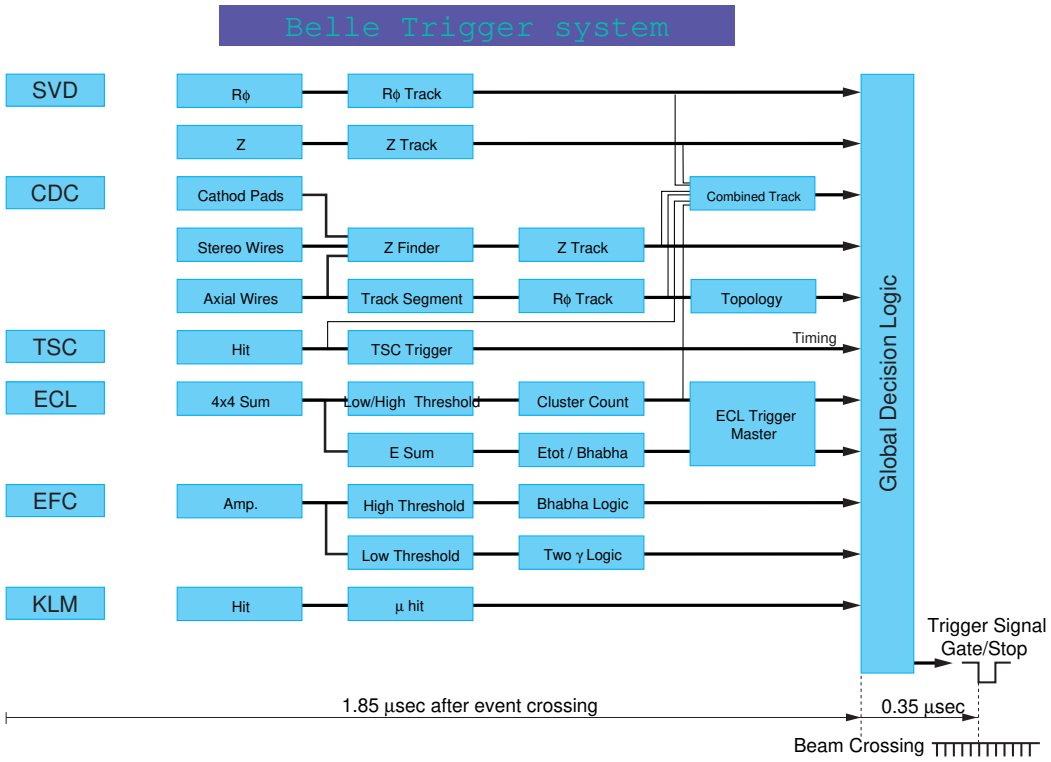


Figure 3.9: BELLE trigger scheme.

A schematic view of the BELLE data acquisition system is shown in Fig. 3.8. The readout of each sub-detector runs in parallel at 200 Hz. The signal from sub-detectors are converted to a time signal by Q-to-T converter except for KLM which provides the time-multiplexed information on a single line. All sub-detectors use TDC readout and it is controlled by VME and FUSTBUS. The SVD is an exception and its data is sent to flash ADC (FADC) and gathered to a memory module.

The readout data is transfered to the Event Builder and the detector-wise parallel data is sorted to event-wise parallel data here. The data is then shipped to each node of the online farm. The data passed the farm are sent to the computer center and stored in the Mass Storage system.

The trigger for the data acquisition is provided by several sub-detectors (see Fig. 3.9). There are two major types of triggers in BELLE system. One is provided by the tracking information from CDC and the other is provided by the energy information from the calorimeter. The global decision logic (GDL) combines the trigger signal from each sub-detector and makes a final decision to initiate a BELLE-wide data acquisition.