4.9 Instrumentation and Control

4.9.1 Instrumentation

Introduction

Since the beam itself does not have a self-stabilization mechanism, it must be stabilized artificially by a fast feedback system. Thus, the beam measurement and control are essential for the high performance of linear colliders.

What quantities are to be measured are determined from the requirement of operation and beam tuning. The fundamental quantities are the beam position (X, Y, Z), the size (σ_x, σ_y, σ_z), and the intensity (N_e). The others are derived from these fundamental quantities by using various methods.

Basically, these measurements have to be done on a pulse-by-pulse basis at the repetition rate, 150 Hz in our case. The control system must also have a fast responce. Collecting and analyzing the data and exciting the correction elements have to be done by the time the next beam pulse comes. In some cases, although rare, the measurement has to be done for each bunch in a train separately, demanding much faster responce down to nanoseconds.

The requirement on the instrumentation for JLC-I is summarized in Tab. 4.29.

Table 4.29: Summary of Instrumentation for Fundamental Quantities.

Meas.		accuracy	bunch train	location	number of unit	possible candidates
X,Y		$\pm 40\mu m$	average	Injector S-band Linac	200	strip line BPM
		$< 1\mu m$	av.	Damping Ring	300	Button BPM(strip line)
	Transverse	$< 10\mu m$	av.	Bunch Compressor	100	strip line BPM
	Beam	$< 10\mu m$	av.	Pre Linac	300	strip line BPM
	Position	$< 10\mu m$	av.	Beam Transport	1000	strip line BPM
		$< 0.1\mu m$	av.	/each Main Linac	7000	strip line/cavity BPM
		$\pm 10nm$	av.	Final Focus	200	cavity BPM
Z	Longitudinal	0.01mm(0.03ps)	each	Bunch Compressor	8	streak camera
	Beam Position	0.01mm(0.03ps)	each	Main Linac	20	streak camera
σ_x,σ_y		$10\%(\approx 50\mu m)$	av.	Injector S-band Linac	30	screen monitor/wire
		$10\%(\sigma_y < 5\mu m)$	av.	Damping Ring	6	synchrotron radiation
		$1\%(\approx 1\mu m)$	av.	Bunch Compressor	20	wire scan/synchrotron
		$1\%(\approx 1\mu m)$	av.	Pre Linac	20	wire scanner
	Transverse	10%	av.	Beam Transport	50	screen monitor/wire
	Spread	$1\%(\approx 1\mu m)$	av./each	Main Linac	250	wire scan/synchrotron
		$\pm 1\mu m$	av.	Final Focus	20	wire scanner
		$\pm 30nm$	av.	Final Focus	2	Compton scattering
		$\pm 3nm$	av.	Final Focus	1	Compton scattering
σ_z	Longitudinal	0.5mm(1.7ps)	each	Injector S-band Linac	4	streak camera
	Spread	0.5mm(1.7ps)	each	Damping Ring	3	streak camera
		0.01mm(0.03ps)	each	Bunch Compressor	8	streak camera
		0.0mm(0.03ps)	each	Main Lina	20	streak camera
		0.01mm(0.03ps)	each	Final Focus	2	streak camera
N_b		1%	each	Injector S-band Linac	30	wall current
		1%	each	Damping Ring	12	wall current
	Charge	1%	each	Bunch Compressor	16	wall current
	of	1%	each	Pre Linac	20	wall current
	each bunch	1%	each	Beam Transport	30	wall current
		1%	each	Main Linac	250	wall current
		1%	each	Final Focus	10	wall current

These requirements will be attainable by using the following methods and techniques.

Transverse Position (X, Y)

The transverse position of the beam will be measured by the stripline BPM (Beam Position Monitor), the button BPM, and the microwave cavity BPM. These monitors can distinguish the position of each bunch in the bunch train using a window gate in front of processing circuits. In most cases, only the average signal is needed for the beam orbit control.

Strip Line BPM The strip line beam position monitors will be installed in the injector linac, beam transport, bunch compressor, main linac, and the final focus beam line. The resolution has to be better than about 1μm. To achieve this resolution, the inner diameter of the strip line should be as small as possible and the width as wide as possible. The strip line length should be short enough to avoid the problem of supporting a long strip. The low noise electronics which is an extension of SLC's will be used. A resolution of several tenths of a micron is expected for the average over the bunches in a train.

Button BPM The button beam position monitors will be used in the damping rings because of the limited space and the relatively low resistive-wall impedance. It is an extension of TRISTAN BPM which uses pickup multiplexing method for the low cost. A few μm resolution will be attainable.

Cavity BPM In order to condense a position sensitive signal, a microwave cavity is used for high resolution beam position monitor. This cavity monitor uses 12GHz TM_{110} mode which is sensitive to the transverse beam offset. The Q_{L} should be taken down to about 10 to get several nm resolution for the bunch with 1×10^{10} particles. This position monitor will be used at several points in the final focus beam line where an especially high resolution of the relative displacement is needed.

Longitudinal Position (Z)

The longitudinal position of the beam or the bunch spacing in a train will be measured by the intensity distribution of the Cherenkov radiation or synchrotron radiation. This measurement can be achieved by the autocorrelation method or the streak camera system which is now available with a resolution of 0.6ps. These are within a reasonable extension of the currently available technologies.

Transverse Size (σ_x, σ_y)

The transverse size of the beam which is directly related to the emittance can be measured by phosphor screens, wire scanners, synchrotron radiation monitors, or laser-Compton monitors.

Screen Profile Monitor The beam profile measurements around 10μm accuracy will be done by the ordinary phosphor screen method. The screen substrate should be thinner than usual for avoiding multiple scattering of electrons. The optical telescope system which is needed to avoid radiation damages of the screen must have the resolution down to the level of the Rayleigh limit.

Synchrotron Radiation Profile Monitor The nondestructive beam profile measurements can be done by using the synchrotron radiation with an accuracy better than 1μm. To avoid the diffraction of the synchrotron light, a short wave length has to be used for imaging. This monitor will be installed mainly in the damping rings to monitor the vertical beam size turn by turn.

Wire Scanner Profile Monitor The ordinary beam profile measurements with about 1μm accuracy can be done by the wire scanning method as in the SLC. For a fine resolution, a thin carbon wire of a few μm in diameter is mounted on a mover driven by a stepping motor with 0.5μm step and the repeatability of 0.1μm. The profile is recontructed by measuring the gamma-ray yield synchronizing with the wire movement at the downstream of the wire scanner.

Laser Profile Monitor At the collision point a very precise profile monitor is required for the tuning of the final focus system. The interaction of the beam with laser interference fringe of several nm causes the Compton scattering. The back-scattered gamma-ray is detected at downstream as a function of the steered beam position. The modulation of gamma-ray intensity will bring the information of the beam size. This profile monitor will be installed and tested in FFTB at SLAC.

Longitudinal Size (σ_z)

The longitudinal size of the bunch can be measured by the intensity distribution of the Cherenkov radiation from the beam. This measurement can also be done by the autocorrelation method or by the streak camera system which is the same as the longitudinal position measurement.

Charge of each bunch (N_b)

The charge of each bunch and total charge of the whole train are measured by the wall current monitor. In order to detect each bunch with 1.4ns spacing separately, the pickup and the digitizer must have a fast responce and the cable must be short. The ordinary wall current monitor with several 100ps response is available by using chip resistors, short high-frequency co-axial cables and the sampling oscilloscope.

Other quantities (ϵ_x, ϵ_y, E, δE)

The quantities like transverse emittance ϵ_x, ϵ_y, beam energy E, and energy spread σ_E can be derived by combinations of the above monitors. For example, the emittances can be estimated from the transverse beam size using optics parameters and the beam energy and the spread from the beam position and profile using a bending field.

The estimated numbers of beam instrumentation units for whole JLC are listed in Table 4.30.

4.9.2 Control

The control system for JLC will consist of two levels of computers. The lower level computers interface to the devices directly, take the beam information and device status, and control the devices. The roles of the lower level computers are to be a device driver which can communicate

Table 4.30: Numbers of instrumentation units.

	(two beams)
BPMs	9100
Profile Monitor	399
Streak Camera System	65
Wall Current Monitor	368

with other tasks and the upper level computers, and to be a carrier of the fast feedback for beam stabilization. Each of these computers takes charge of the devices in a small region in the collider complex, such as one for the Injector linac, one for the damping ring, one for 20 klystrons in the main linac, and so on. Each computer has to drive at least 10 crates of CAMAC or VME for the interface boards.

The upper level computers which communicate with operators and the lower level computers, manage the accelerator operations as a whole. For these computers, the collider complex will be divided into five parts, the region from the gun to the entrance of the main linac for electrons, that for positrons, electron main linac, positron main linac, and the final focus region. These five upper level computers should be capable of fast communication with the lower level computers and with the workstations for operator console and should have a capacity for many tasks such as control tasks for many devices and monitoring tasks and so on. The workstation will be used as an operator console instead of console hardware and many TV monitors. The environment of operation will be build easily with flexibility using X-window and TV windows. The idea of workstation console has a great advantage of flexibility.

The modeling of accelerator will be done on an independent calculation server. The program SAD and other tracking and orbit correction programs on the server simulate the beam in the actual accelerator. This server must be capable of very fast calculation. The estimated numbers of various units for this control system are listed in Tab. 4.31

Table 4.31: Numbers of units of the control system.

Large Operation Computer	6
Workstation for console	50
Medium device driver computer	210
Interface Crate (assuming CAMAC)	2100

4.10 Civil Engineering

4.10.1 Technical Site Criteria

An appropriate site for JLC-I should satisfy the following technical criteria.

1) A geologically and geohydrologically stable area for the constructions of a long linac tunnel and a large detector-hall. The low level of seismic and microseismic activity for the alignment of the final focus system, the main linacs, and the damping rings.

2) Availability of large electric power ($\sim$ 300 MW) and enough water cooling capacity for linear collider operation. An area close to the existing AC power line from a power station to industrial cities is favorable in this respect.

3) Easy access to the site from a highway, a Shinkansen, and an airport.

Keeping these criteria in mind, possible main tunnel designs are studied. In this section, we describe the main tunnel design based on the blasting method, after a short histroical review of the design based on the shield method.

4.10.2 Construction Methods of Main Tunnel and Detector-Hall

The construction methods for the main tunnel and detector-hall have been investigated for the following two cases, shield method and blasting method. In early stage of the JLC project design, the shield method seemed the most appropriate to reduce the land cost. At that time utilization of deep underground was attracting peopole's attention as a solution to obtain the lands for public use during the inflation period of the land price triggered by the rapid ecnomical growth. The Ministries started the preparation of the draft of a law for the utilization of deep underground in the metropolitan area. The objective of the draft was to allow constructions of public facilities at a depth deeper than 50 m underground without distinction of superficies. Assuming that the law will be concluded in a few years, we have elaborated a plan to construct main tunnels and a detector-hall at a depth of 100 m underground of Tsukuba area, so that the detector-hall could fit in the present KEK site. This could also allow the construction of the injector complex, including damping rings, injector linacs, and a positron production linac, on the ground in the KEK site. Outside the present KEK site, several spot sites were required to construct the pits dug in the ground for the access to the main tunnels as with LEP and HERA. The accelerator and detector components could then be transported through the pits by lifts.

If we use shield machines, the cross section of the main tunnel should be a circle and its diameter should be constant over the full length of the main tunnel. In deep underground, the wall of the tunnel should be strong eneough to sustain high earth pressure and it should also be made water-tight by the chemical processing to put up with high water pressure. The construction cost depends on the depth of the tunnel. The cost has been estimated to be approximately 20–30 MYens/m, referring to the Trans-Tokyo Bay Tunnel to connect Chiba and Kawasaki by a highway under construction. The technical difficulty lies in the construction of the access pits of 100 m in depth. There remains a subtle problem with the interpretation of the word "metropolitan area": whether the law can be applicable to Tsukuba area or not. The sudden collapse of so-called bubble economy in 1990 induced a recession and caused the drop of land price, which diminished the interest in the utilization of deep underground.

The second construction method is the blasting method. The main tunnel can be excavated along a ridge of mountains. Several approach tunnels can then be excavated in horizontal direction from outside the mountains in order to facilitate the transportation of accelerator and detector components by weight cargo carriers. This construction method does not restrict the shape of the tunnels and allows us to excavte them with an optimum cross section along the accelerator: a large diameter for the main linac, a small diameter for the beam transport line and side rooms for storage. The blasting method is the standard technology to construct highway tunnels. The construction cost can therefore be minimized by matching the specification of the main tunnel to that of a standard highway tunnel. The basic design of the tunnels and the detector-hall has been completed.

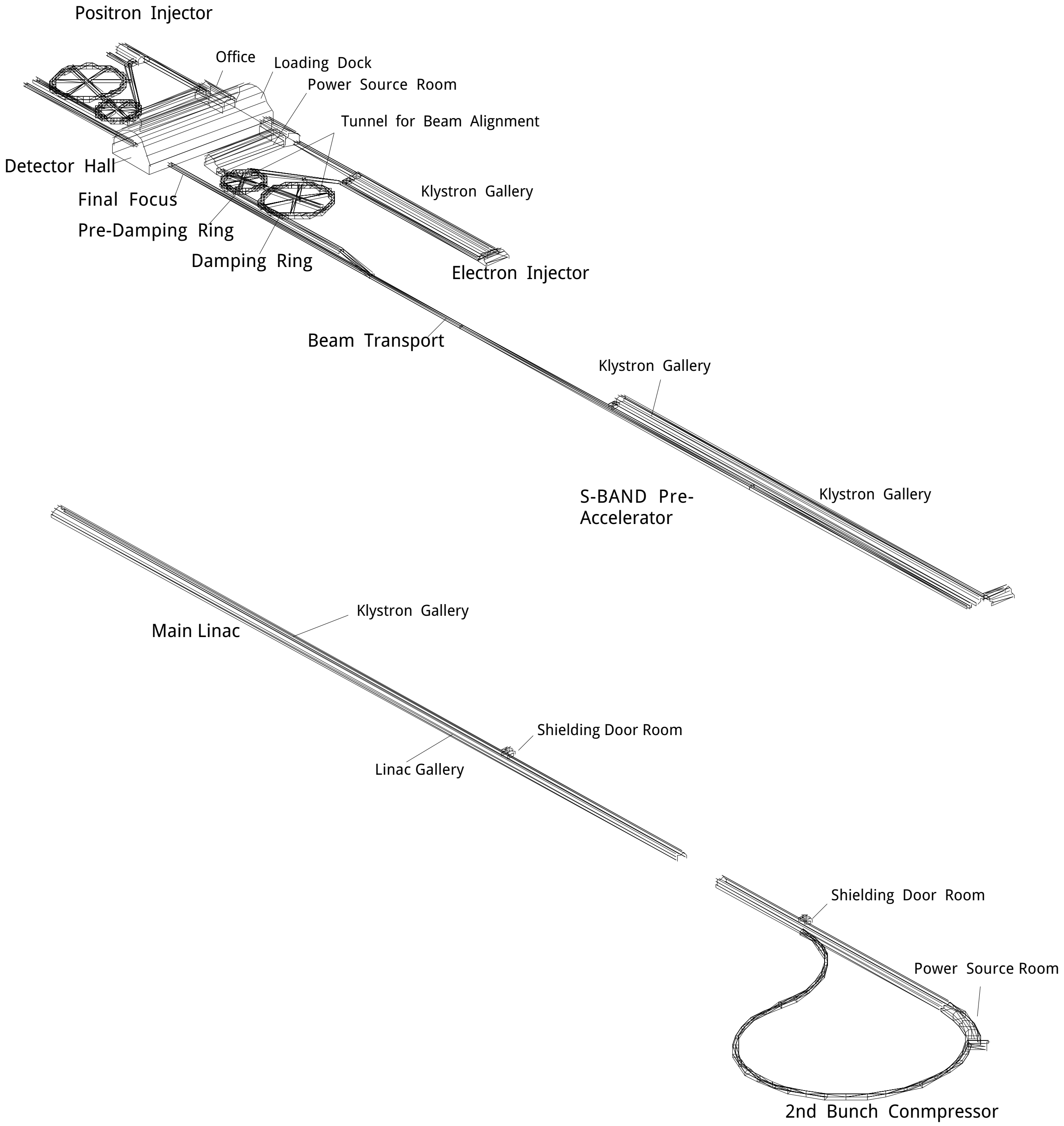

Figure 4.74: Three dimensional schematic drawing of JLC.

Figure 4.74 is a three-dimensional drawing of the JLC-I tunnel. The injector complex including the injector linacs, the positron production linac, the pre-damping and damping rings, and the pre-accelerators will be constructed near the detector-hall. These facilities have a common access tunnel from the outside of the mountain and are connected with short access tunnels to provide an easy mutual access between the facilities. The straight tunnels across the damping ring tunnels ease the alignment of the damping ring components.

Figure 4.75 gives a cross-sectional view of the tunnel for the main linac. The main linac

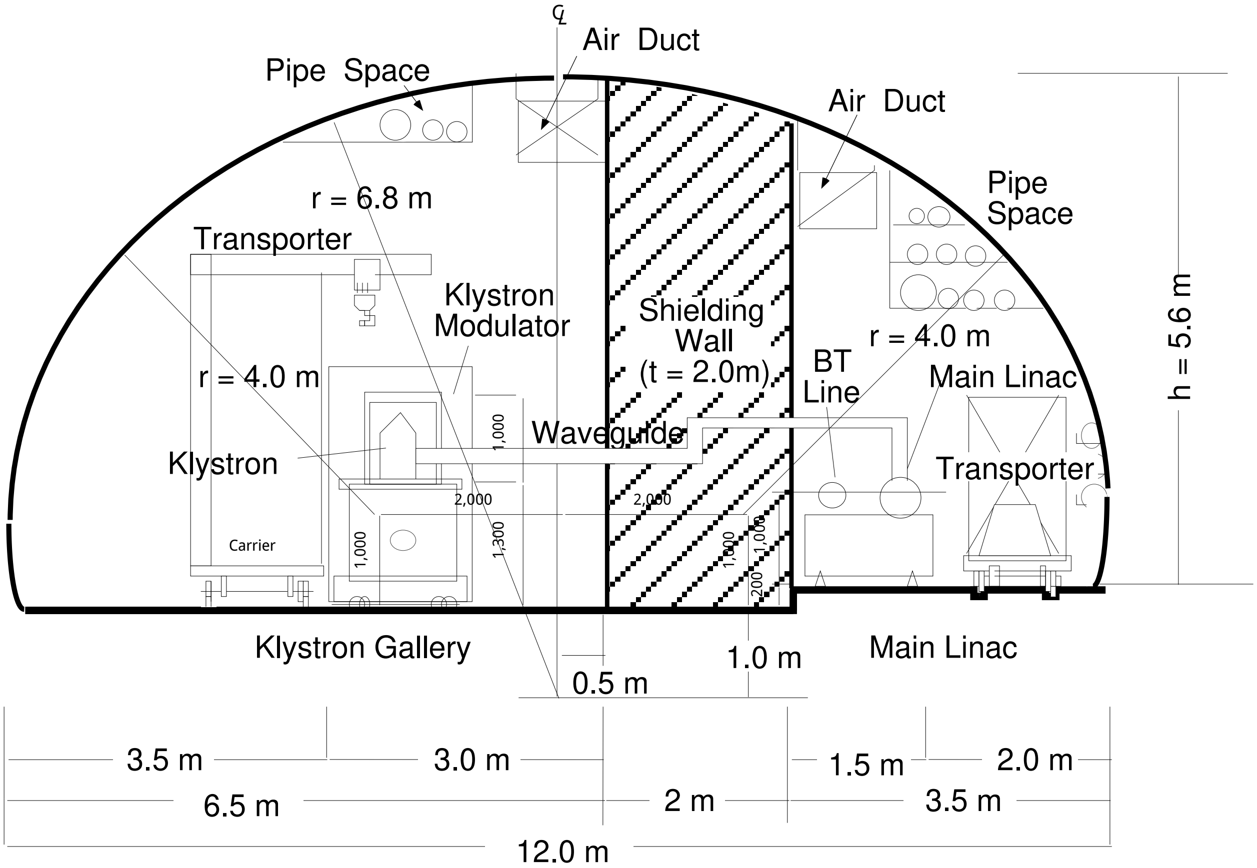

Figure 4.75: Main linac tunnel.

tunnel has a semi-cylindrical shape like a quonset hat, which is 12 m in width and 5.6 m in height. The size of the tunnel is similar to that of a standard highway tunnel for two traffic lanes. A 2 m thick shielding wall divides the tunnel into two galleries. The wider one houses the klystrons and their modulators, while the remaining one is occupied by the accelerating structures and the beam transport line. The klystron tubes and the accelerating structures are connected with RF waveguides through the shielding wall. As shown in Figs. 4.76 and 4.77, the access doors for maintenance are prepared at every 500 m. The cross section of the tunnel for the collimator and the final focus system is shown in Fig. 4.78. The damping ring tunnel is shown in Fig. 4.79 and the detector-hall is shown in Fig. 4.80.

The cost of the tunnels and the detector-hall has been estimated for the following two candidate sites as shown in Table 4.32. Type A mountain consists of a single geological formation with granite of class $B - C_H$, which provides a good geological stability in the tunnels. Type B mountain has a complicated geological formation with peridotite, diabase tuff, and andesite lava of class $C_M - C_L(D)$. The volume to be dug out depends on the thickness of the tunnel

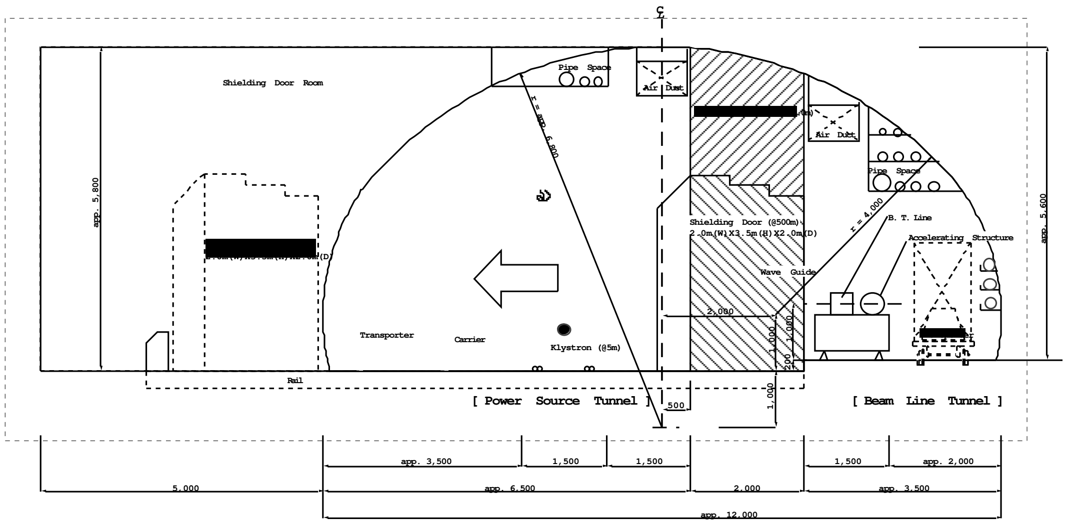

Figure 4.76: Side view of the access door between klystron gallery and accelerator tunnel.

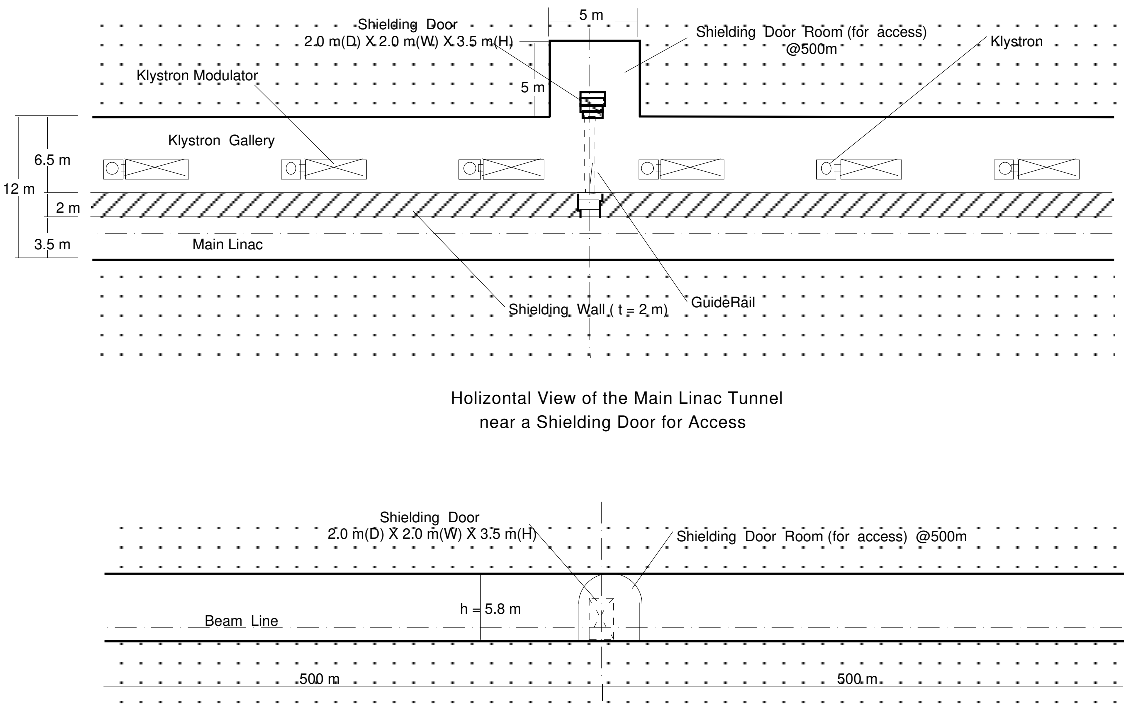

Figure 4.77: Top view of the access door between klystron gallery and accelerator tunnel.

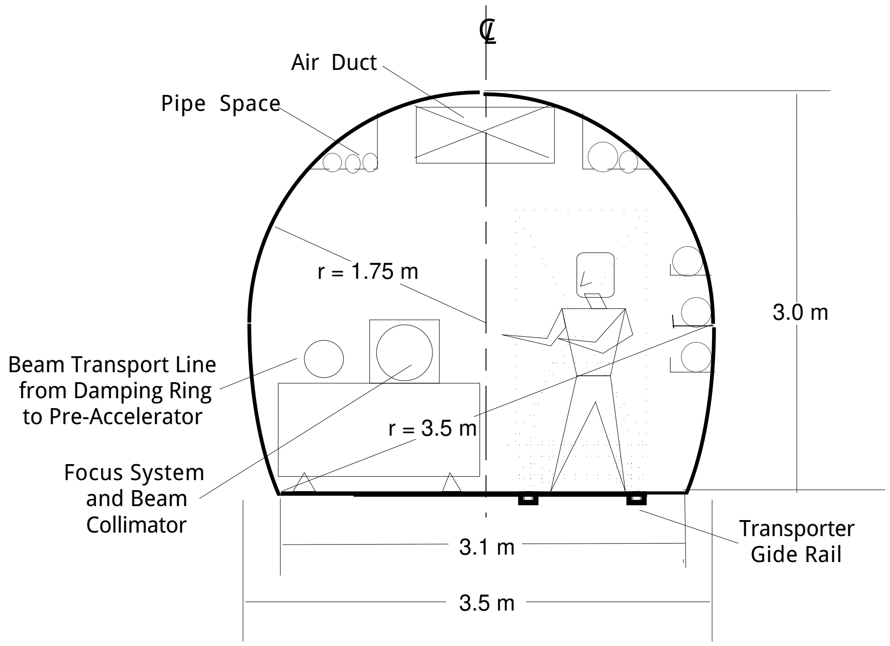

Figure 4.78: Beam line tunnel.

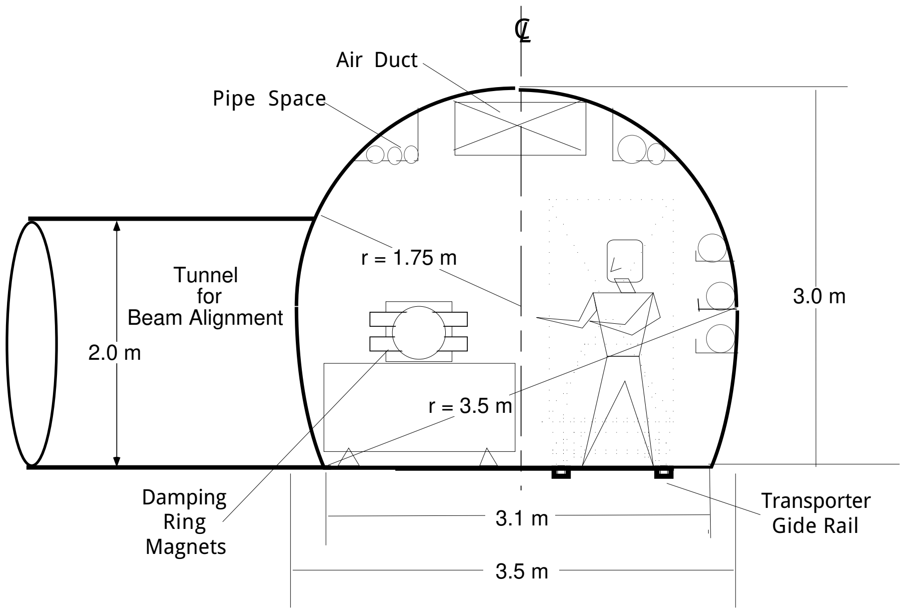

Figure 4.79: Damping Ring Tunnel.

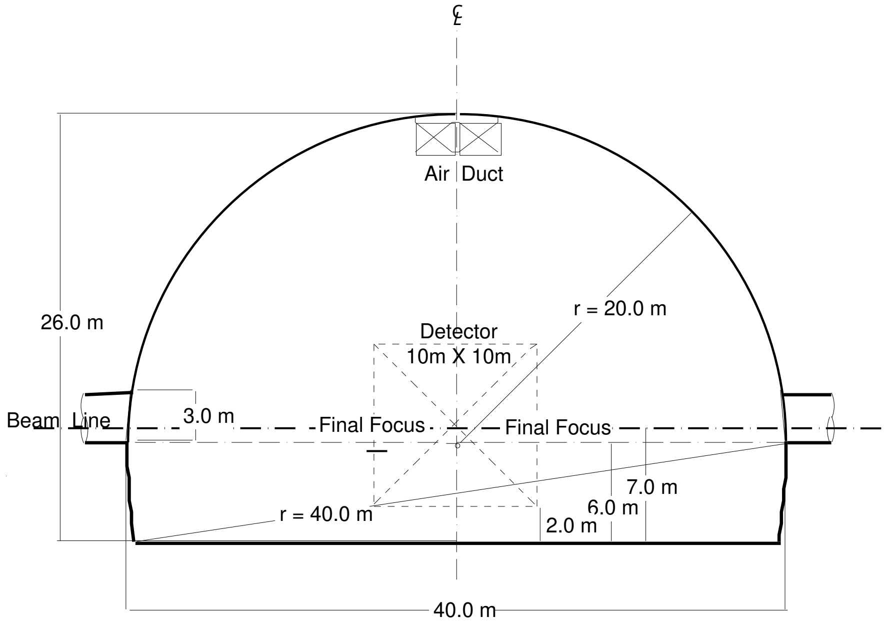

Figure 4.80: Detector-hall.

wall. Type B tunnel requires a thicker primary spray and secondary mask concreate than Type A tunnel. The construction cost of the main tunnel depends on the geological feature but falls in the rage of 2–3 MYens in both cases.

Table 4.32: Cost estimation of the tunnel for main linac

Mountain		A	B
Geological formation		Granite	Periotite, Diabase Tuff, and Andesite Lava
Geological class		$B - C_H$	$C_M - C_L(D)$
Primary spray concreate t_s	mm	100	150
Secondary mask concreate t_c	mm	300	400
Total Thickness of concreate t_t	mm	400	550
Volume to be dug out	m^3/m	69.3	73.0
Cost	MYen/m	2.2	2.7

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