Siting Study for European ILC Sites

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Abstract

This report describes the investigation of possible European sites for the construction of the International Linear Collider in the framework of the Global Design Effort activities. The footprint of the ILC is a tunnel with a length of about 30 km in the first stage, a campus site in the center with the experimental hall, damping rings, beam delivery system and the injectors underground and equally distributed service halls at the surface. One deep site near CERN at Geneva has been considered. This is the only European site discussed already in the Reference Report of the International Linear Collider. The tunnel is in bedrock between 100 and 150 m below the surface. Another possibility is a near to surface solution as it was chosen for the European XFEL project in Hamburg which is currently under construction or was proposed for the Linear Collider project TESLA. The big advantage of this design could be the cost savings especially if one would make use of a single tunnel design. For the RDR a twin tunnel solution was considered. One disadvantage of the close to surface solution is the stability of the tunnel typically in soft ground. Thus a second European sample site near DESY in Hamburg is developed for the International Linear Collider. In addition, the Joint Institute for Nuclear Research JINR has also proposed a shallow-tunnel, soft-ground site in the neighborhood of Dubna in the Moscow region of the Russian Federation. The status of siting study and stability considerations for Europe is presented.

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1 Introduction

The International Linear Collider ILC is in the first stage a 500 GeV center-of-mass electron-positron collider, based on 1.3 GHz superconducting radio-frequency accelerating cavities. In addition, the machine must be upgradeable to 1 TeV. The primary cost drivers are the SCRF Main Linac technology and the Conventional Facilities (including civil engineering).

For the Reference Design Report RDR three sample sites, one in each region, were developed. All sites are deep at about 100 m or more below the surface. The design of this solution was used for the costing in the RDR. The European site is located close to the CERN campus and runs parallel to the Jura mountain range. Figure **1** shows the simplified geology. The majority of the underground construction is in the 'Molasse' (a local impermeable sedimentary rock). The American and Asian sites are very similar. These tunnels too are in impermeable rock namely dolomite rock in Northern Illinois near Fermilab and granite somewhere in Japan in the mountains respectively.

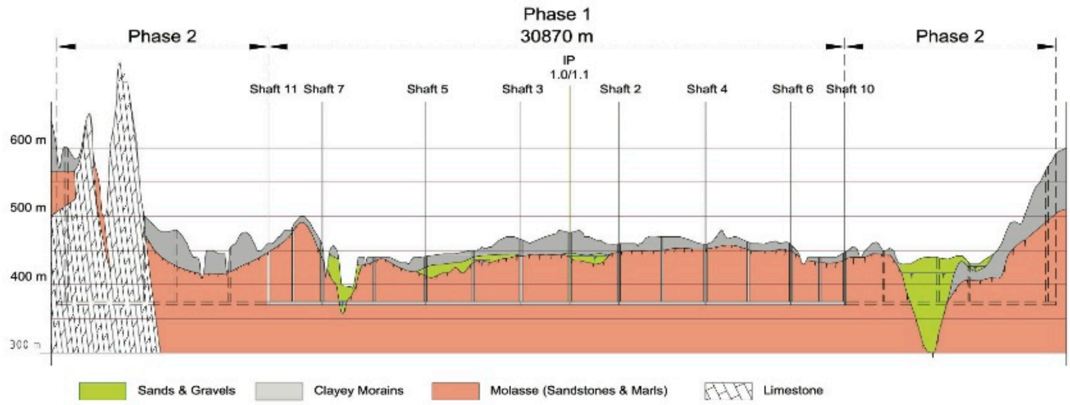


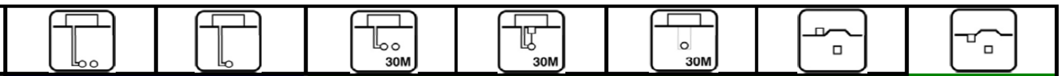
Figure 1: Geology and tunnel profiles for the European sample site close to CERN.

In the RDR two near surface European sites were mentioned: "A second European sample site near DESY, Hamburg, Germany, has also been developed. This site is significantly different from the three reported sites, both in geology and depth (25 m deep), and requires further study. In addition, the Joint Institute for Nuclear Research has submitted a proposal to site the ILC in the neighborhood of Dubna, Russian Federation." and "The DESY and Dubna sites are examples of 'shallow' sites. A more complete study of shallow sites – shallow tunnel or cut-and-cover – will be made in the future as part of the Engineering Design phase."

The general Conventional Facilities layout of the ILC is described as follows:

- Underground tunnels, about 31 km long, house the main accelerators and the Beam Delivery Systems (Beam Tunnel), and their associated support hardware.
- Shafts along the length of the machine provide access to the tunnels. They primarily support the large cryogenics plants at the surface required for the superconducting linacs.
- A single collider hall at the Interaction Region (IR) is large enough to support two physics detectors in a push-pull configuration.
- An approximately circular tunnel located around the central IR region houses both the electron and positron Damping Rings in a stacked configuration.
- Several additional tunnels and service shafts house the electron and positron sources and injector linacs (injection into the Damping Ring), and connect the damping ring to the main accelerator housing.

In general seven different tunnel configurations are possible: single and twin shallow or deep tunnels with service buildings located only at the shafts, cut and cover construction for all or only for the service buildings or a gallery for the services at the surface. Figure **2** shows a comparison matrix of all seven tunnel configurations. The twin deep tunnel configuration was chosen for all three sample sites in the TDR.



	DEEP		NEAR SURFACE				
	Twin Deep Tunnels	Single Deep Tunnel	Twin Near Surface Tunnels	Near Surface Tunnel, at Surface Gallery	Single near Surface Tunnel	Enclosure in Open Cut, Cont. Gallery	Enclosure & Cont. Gallery in Open Cut
EXCAVATION	TBM	TBM	TBM	TBM & OPEN CUT	TBM	OPEN CUT	OPEN CUT
No of TUNNELS	TWO-TUNNEL	ONE-TUNNEL	TWO-TUNNEL	TWO-TUNNELS	ONE-TUNNEL	ONE-TUNNEL	TWO-TUNNELS
SHAFT SOIL	VARIES	VARIES	VARIES	VARIES	SOFT / SLURRY	NA	NA
TUNNEL SOIL	ROCK	ROCK	COHESIVE SOIL or ROCK	COHESIVE SOIL -Low permeability	Saturated Sand & Gravel	SOILS VARIES	SOILS VARIES
SERVICE SPACE	SECOND TUNNEL	SURFACE BUILDINGS	SECOND TUNNEL	CONTINOUS SERVICE GALLERY	AT CAMPUSES	CONTINOUS SERVICE GALLERY	CONTINOUS SERVICE GALLERY
ILC Technology	DISTRIBUED RF	CLUSTERED RF	DISTRIBUED RF	DISTRIBUED RF	CLUSTERED RF	DISTRIBUED RF	DISTRIBUED RF
SIMILAR TO	RDR Sample Sites	RDR & CLIC	RDR	Dubna ILC	XFEL	Project X	Project X
ACCESS	Vertical Shaft	Vertical Shaft	Vertical Shaft	Vertical Shaft	Vertical Shaft	Hatch	Hatch

Figure 2: Tunnel configuration comparison matrix.

A possible alternative for the ongoing Technical Design Phase TDP is the single deep tunnel. The near surface solutions are options for the DESY and the Dubna site. But the design of a tunnel in soil has to be optimized to save cost and to get a realistic comparison with tunnels in rock. In urban areas like the DESY site only tunnel construction with a tunnel boring machine and several shafts in comparable large distances is possible. Other underground elements like caverns or penetration between two tunnels should be avoided in any case. One could decrease the costs significantly if one makes use of these simple rules. The situation is at least partially different for the Russian site at Dubna where open cut and gallery solutions are conceivable. Making use of this advantage could save additional costs.

In the first stage Work Package 5 of ILC-HiGrade investigates possible European sites for the construction of the International Linear Collider. The work in the first period was concentrated on the further investigation of the deep CERN site and the shallow DESY and Dubna sites in the framework of the GDE activities.

2 Siting Study for European ILC Sites

2.1 CERN Site

Overview

One deep site near CERN at Geneva has been considered. This is the only European site discussed in the Reference Design Report of the International Linear Collider. The tunnel is in bedrock between 100 and 150 m below the surface. Ambient ground motion is the main advantage of rock tunnels compared to tunnels in soil; it is about one order of magnitude smaller than in soil. The other two RDR sample sites in Asia and the Americas are also about 100 m below the surface in bedrock similar to the Geneva site.

Single tunnel solution

As part of a cost reduction exercise, several ideas have been developed in order to reduce the civil engineering costs. The single tunnel solution concept has been studied at CERN as part of the GDE effort. Machine models have been integrated into 3d modeling software to understand the underground volume required to house the ILC machine and its services. An example of the 3d modeling produced is shown below in Figure **3**.

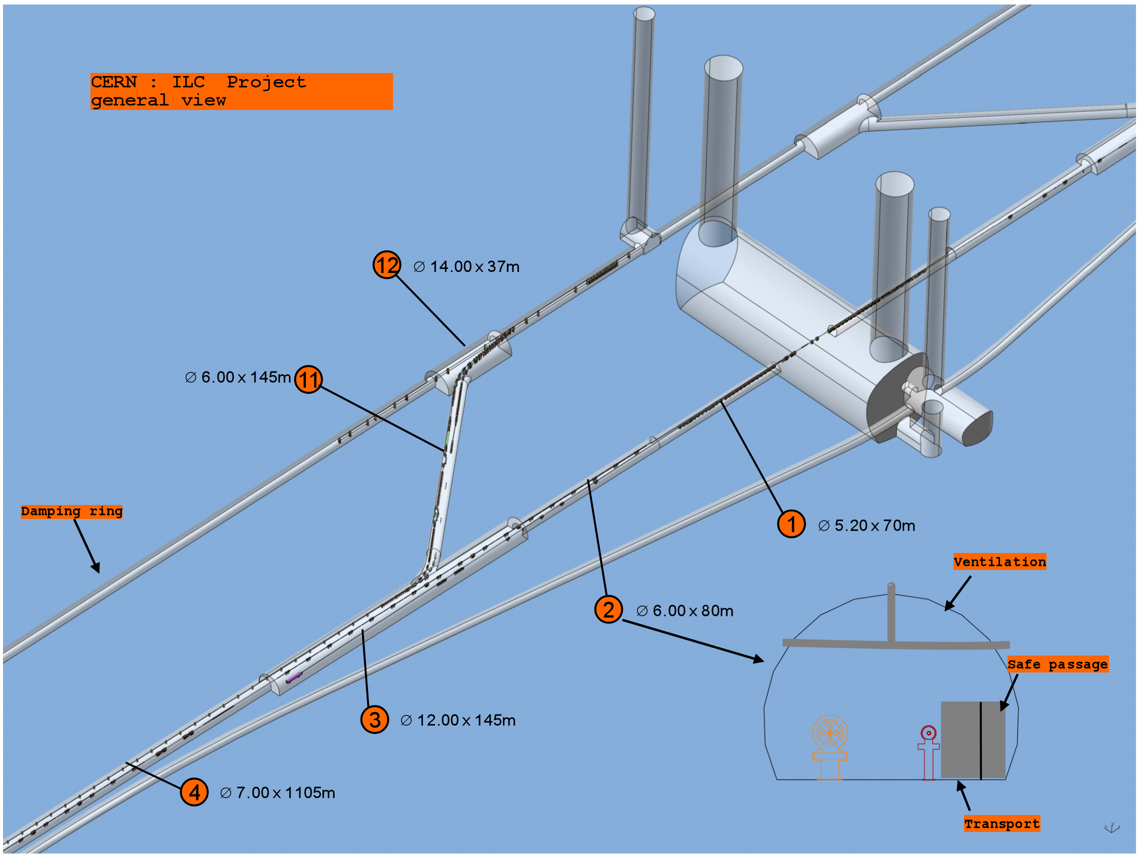


Figure 3: 3d modelling produced at CERN to determine underground space requirements.

These models have been used to fix the typical tunnel cross section at an internal diameter of 5.2 m. One of the driving factors in determining the tunnel size is the ventilation concept adopted for the CERN site. Mainly for safety considerations, the transversal ventilation concept has been proposed. This concept provides efficient cooling for the machine and in conjunction with fire walls, provides a solution for smoke extraction in the event of a fire. Figure **4** shows the typical cross section for the Main Linac at the CERN site.

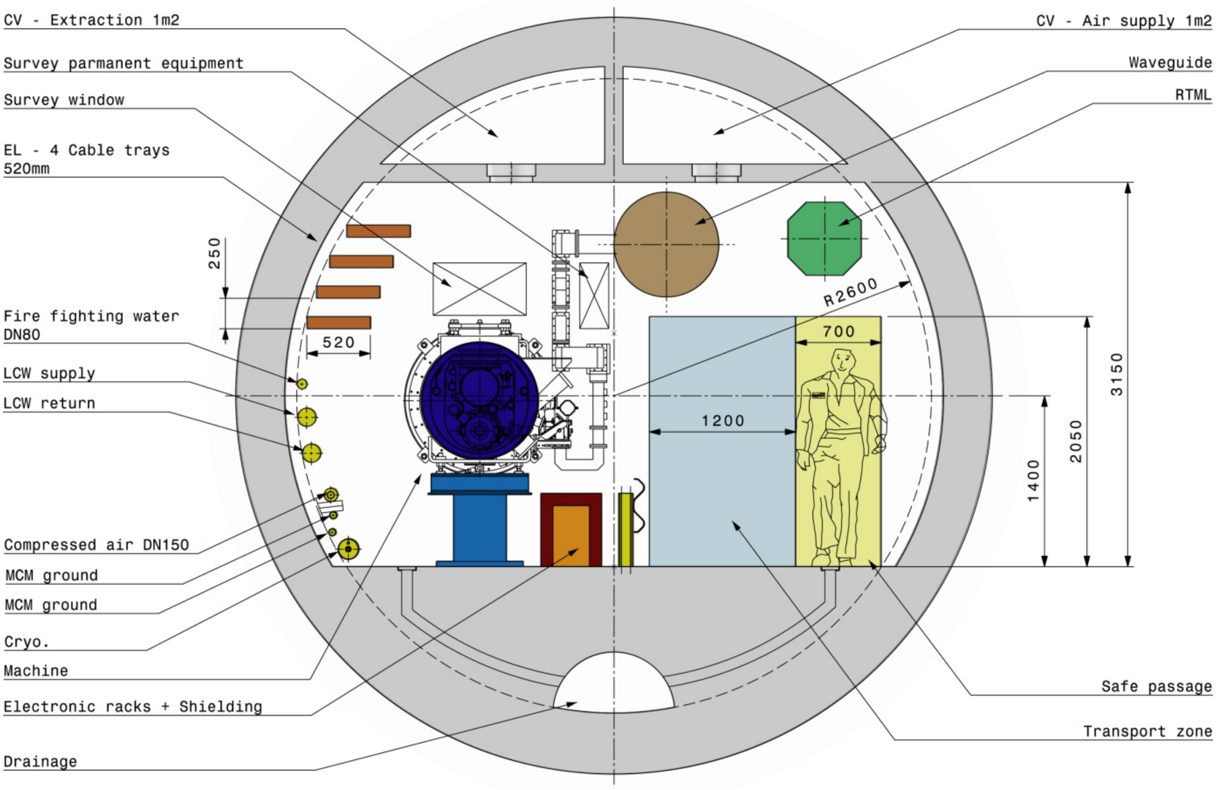


Figure 4: Typical cross section for the Main Linac as the CERN site.

The preferred solution for the installation of the cryo-modules at the CERN site, is to fix them directly onto the tunnel floor (as opposed to the DESY-XFEL solution of suspending the modules from the tunnel crown). The main reasons for this are suspending the modules are:

- This method is not compatible with the transversal ventilation concept
- CERN geology is not conducive to crown mounting, which would most likely induce additional ground movements
- Access for interventions such as alignment are more difficult
- Additional safety risks associated with installation / access for maintenance
- CE construction tolerances significantly greater for segmental lining as opposed to 2nd phase tunnel invert concrete
- Difficult to transfer horizontal forces into tunnel segmental lining

CERN will continue to develop the single tunnel solution as part of the GDE plan, adapted to local conditions. Strong collaboration with the CLIC effort will be maintained during the next stages of the design for ILC.

2.2 DESY Site

Overview

Another possibility is a near-surface solution as it was chosen for the European XFEL project in Hamburg, which is currently under construction. A proposal for a site near Hamburg was also developed for the Linear Collider project TESLA. A proposal for an International Linear Collider site connected to DESY in Hamburg benefits from these detailed TESLA studies, including the pre-investigations for the approval procedure, a hydro-geological study and an environmental impact study, based on a state treaty for the construction and the operation of a Linear Collider. Also a radiation and general safety concept was developed for a single tunnel configuration and shaft distances of about 5 km. The chosen well-proven tunnel and shaft construction method was already used for the construction of HERA, which is in the same geological ground. The documents were complete and no serious problems were detected. This proposal is now further developed to fit to the ILC parameters.

Figure 5: Possible footprint of the ILC site starting at DESY in Hamburg, running in direction North-Northwest and crossing the county of Pinneberg in Schleswig-Holstein.

The big advantage of this design could be the cost savings especially if one would make use of a single tunnel design. For the RDR a twin tunnel solution was considered. One disadvantage of the close to surface solution is the stability of the tunnel typically in soft ground. A second European sample site near DESY in Hamburg is now available for the International Linear Collider. Figure **5** shows a possible overall layout. The tunnel starts at the DESY campus, which is still highly populated and extends into the countryside in Schleswig-Holstein with a very low population.

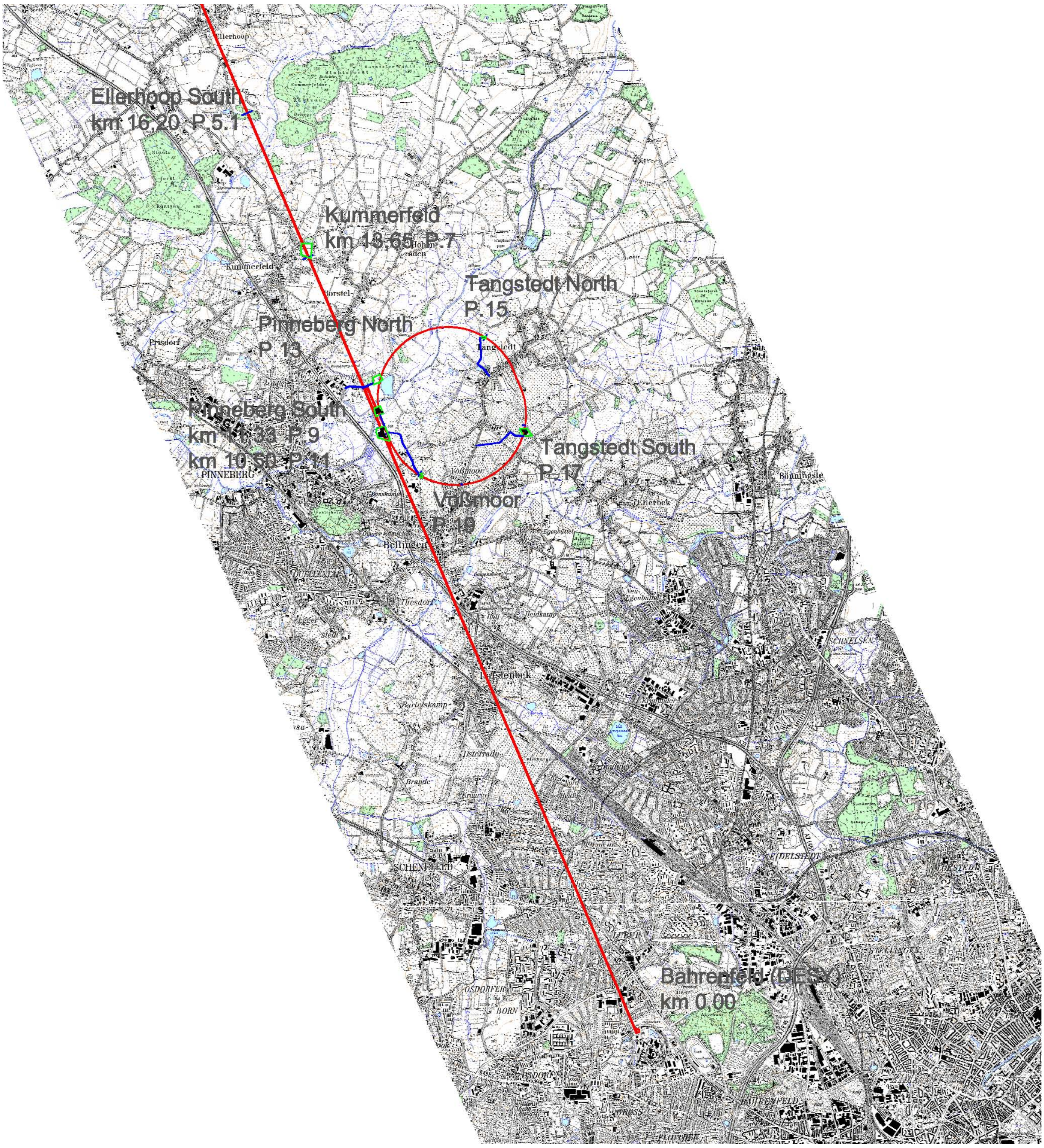


Figure 6: Partial footprint of the ILC site starting at DESY in Hamburg.

This site is significantly different from the RDR sites. The tunnel is about 15 m below surface and extends some 50 km (for the 1 TeV upgrade) in direction North-Northwest from DESY. Figure **6** shows the ILC footprint partially beginning on the existing campus. Figure **7** shows the elevation of the main tunnel following the curvature of the earth with the exception of the Beam Delivery System, which is laser-straight. The tunnel is positioned in the water table nearly over the total length. The sagitta of a laser straight tunnel over the total length (maximum difference in reference to the curvature of earth) is to large (about 50 m). It is very difficult to construct a laser straight tunnel in the water table because the water pressure in the watertight compartment of the tunnel-boring machine has to be limited during maintenance. The ground consists of about 70 % sand and the rest marl with blocks as it was formed by the glacial periods. A tunnel in this ground conditions has to be reinforced by watertight precast concrete blocks. But the surrounding water absorbs one order of magnitude more heat losses compared to a tunnel in bedrock, which is thermally insulating for practical purposes. Therefore a tunnel in the water needs no additional air conditioning that could induce additional vibration (floor motion). Another advantage is that the tunnel ventilation can be switched off during operation, which results in a better longtime stability.

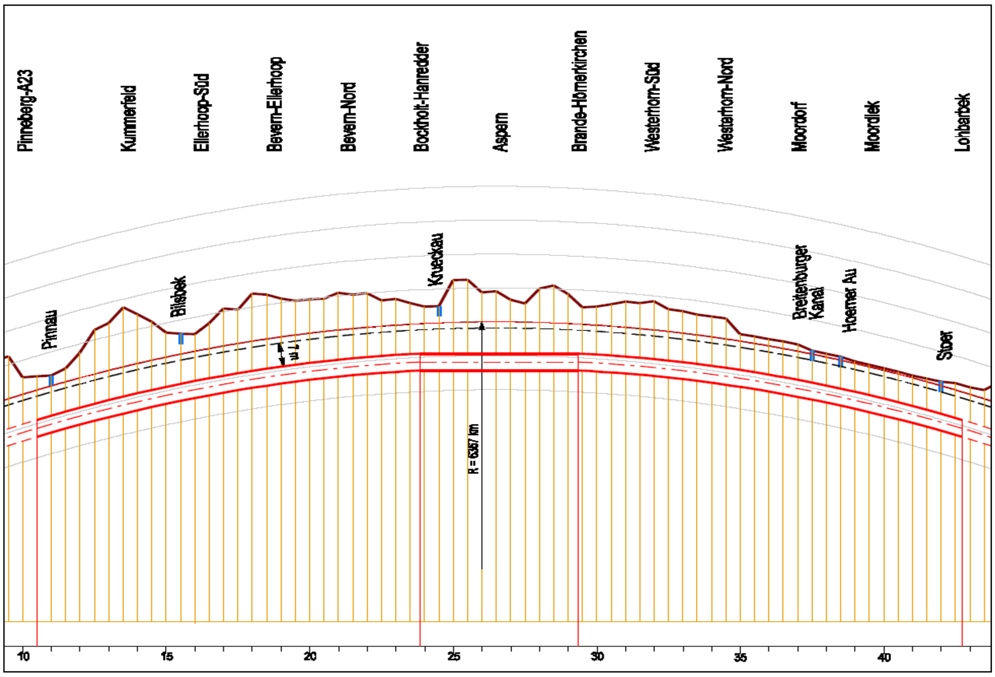


Figure 7: Elevation of the main tunnel at the potential ILC site at DESY in Hamburg.

Main Linac Tunnel

A possible tunnel layout is shown in Figure **8**. The inner diameter of the main Linac tunnel is about 5 m. The achievable precision of a bored tunnel with this diameter is about 10 cm in the transverse directions. This must be taken into account for the installation of the machine and beam lines. The tunnel must be bored with a tunnel-boring machine (TBM) and lined with precast watertight concrete segments called tubbings. The TBM will be similar to the HERA boring machine. A cutting head rotates in a compartment filled with a pressured liquid called bentonite. The bentonite suspension resists the soil and hydraulic pressure to avoid displacements on the surface above the tunnel. The liquid also stabilizes the sand in front of the boring machine and transports the soil, which is removed by the rotating cutting wheel. Above ground the soil is separated from the bentonite. The regenerated suspension is pumped back to the machine. In the steel cylinder behind the milling wheel (called the shield) a complete tunnel ring is assembled from tubbings, which could be 30 cm thick and 1.20 m long. A ring could consist of seven tubbings and has then a weight of 15 t. The diameter of the wheel is for the given tunnel diameter about 6 m. The remaining slit between the soil and the tubbings will be filled with concrete. Minimal settings on ground are not avoidable but are below 1 cm.

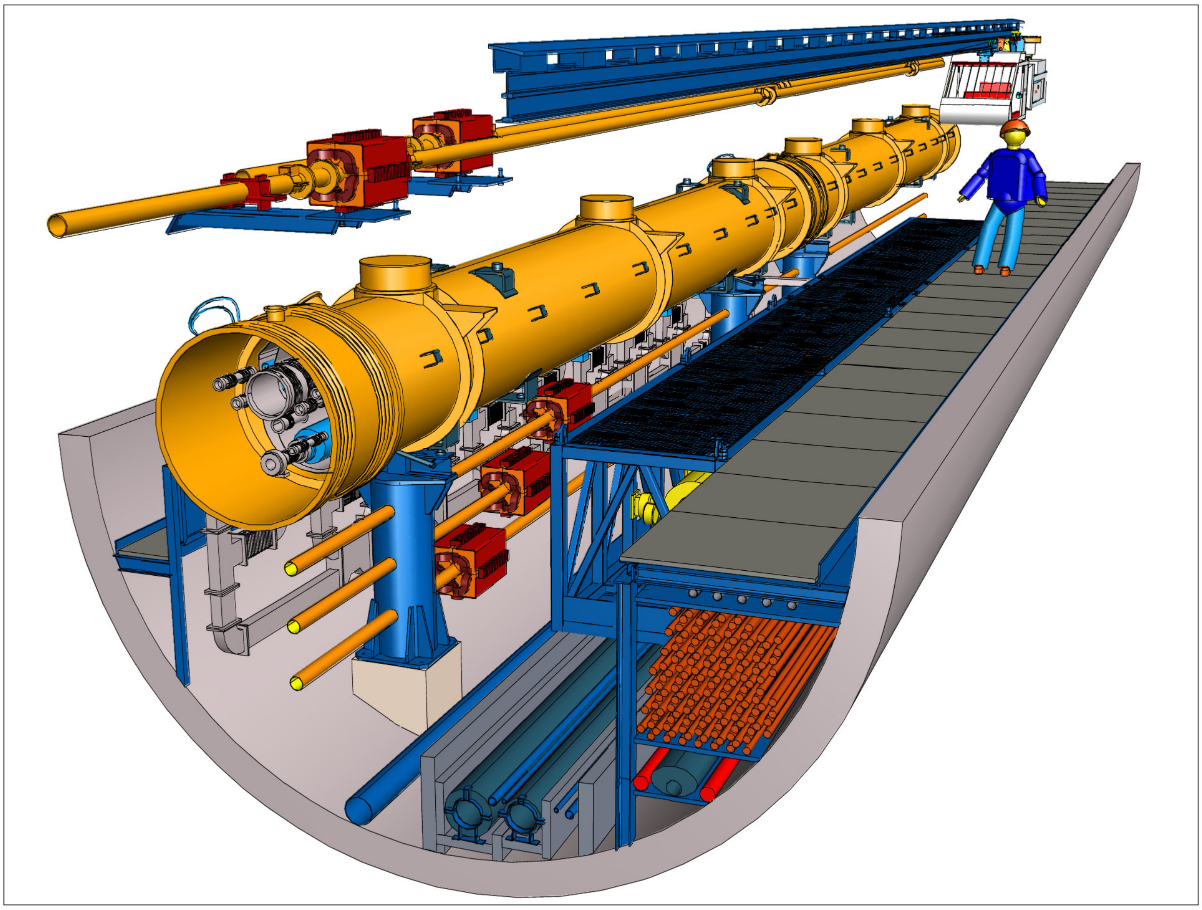


Figure 8: Artist view of one possible tunnel layout for a superconducting linear accelerator.

Based on the HERA experience the TBM speed is estimated to be 10 m per day on average and 14 m per day maximum. The machine will run 24 hours a day, five days a week, 250 days a year: hence one TBM will bore 2.5 km of tunnel per year. Twenty trucks per day per access shaft will be required to transport the earth away; eight trucks per day are required to deliver the tubbings.

During the installation time and the shut down periods the whole tunnel will be ventilated with dried air. The ventilation will be stopped during accelerator operation. For smoke exhaust the ventilation can be sped up, reversed and exhausted at the next shaft or hall. The northern and southern tunnel sections form separate fire compartments. The longest escape route has a length of about 5 km. Fire protection walls shield the shafts. The fire load in the tunnel will be minimized. Unavoidable fire loads will be shielded by small fire compartments or protected by a fire extinguishing system, if necessary. Smoke and fire detection systems are installed in all tunnels.

The lifetime of the electronic components is limited by radiation background. The selected electronics are operable up to an integrated radiation dose of 100 Gy. The radiation background is mainly determined by the dark current of the cavities, which is limited by the additional heat load of the 2 K helium circuit. Most of the power of the lost electrons is absorbed in the cold mass, namely the cavity, the 2 K helium and the Infrastructure and Auxiliary Systems helium container. A value for the required shielding to suppress radiation damage was calculated. The result is that the lifetime of the electronics components is about 10 years without any additional shielding. However, space for additional radiation shielding is reserved.

Safety of personnel and equipment in the tunnel has to be provided during construction, shutdown, maintenance, and operation of the Linear Collider. The tunnel has segments between access shafts with a longest distance of 5 km. The resulting escape and access times largely determine the organizational and technical means for rescue as well as for fire protection.

2.3 Dubna Site

Overview

In addition, the Joint Institute for Nuclear Research JINR has also proposed a shallow tunnel soft ground site in the neighborhood of Dubna in the Russian Federation. Figure **9** shows the general layout of the potential ILC site near Dubna. The tunnel starts near the JINR Institute in Dubna and runs in a depth of about 20 m south of the Volga River. Close to surface buildings are constructed by an open pit method and the tunnel by a boring machine. Here a single tunnel solution is also possible where most of the infrastructure will be installed at the surface. This choice promises a significant cost savings for the ILC CFS cost which are currently the largest fraction of the total costs (Ref. 12, 13 and 21).

The site investigations for Dubna are at an earlier stage than the others two sites (near CERN and DESY). Already at this stage it becomes clear that this site is an interesting alternative largely because of the high number of degrees of freedom for construction.

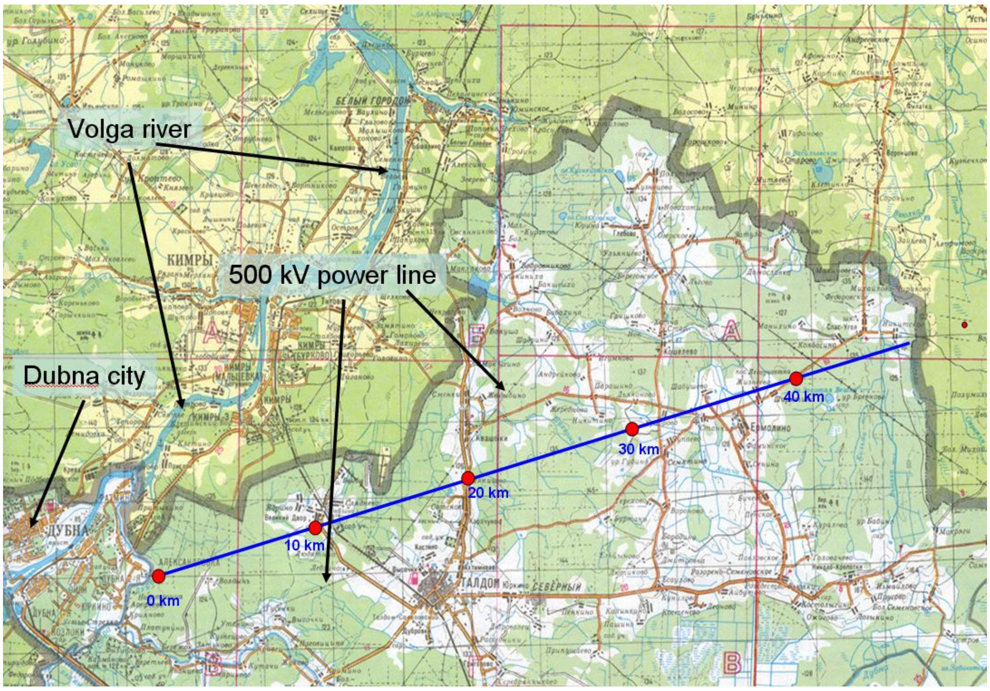


Figure 9: General layout of the potential ILC site near Dubna.

Current Dubna Site Design

In this layout the International Linear Collider ILC, with a total length of about 50 km in the second stage, is placed in the northern part of the Moscow region. The tunnel starts at the Joint Institute for Nuclear Research JINR in Dubna and runs into Northeast direction (see Figure **9**). There are several advantages for the ILC in Dubna:

- The presence of JINR as a basic scientific and organizational body is a considerable advantage. The Joint Institute is an international intergovernmental organization, which includes eighteen member and five associated member states. A Federal Law has put the agreement between the Russian Federation and JINR on the special status of the scientific organization into effect.
- The proposed territory is thinly populated and practically free of industry, rivers and roads. There are no nature reserves and monuments at the site. The site does not affect

national parks. The proposed position of the accelerator tunnels is in relatively dry drift clay, which excludes the influence of the groundwater distribution.
- The area is seismically quiet and has stable geological characteristics.
- A flat relief and unique geological conditions allows to place the ILC close to the surface (at a depth of about 20 m) and to construct the tunnels, experimental halls and other underground buildings at low cost. Even cut-and-cover construction is possible over nearly the whole length.
- An additional attractive feature of placing the ILC complex on this territory is the opportunity of using the land without additional cost. Prevalent legal practice makes it possible to get the land at the ILC location for permanent free use just as it has been done for JINR, according to an agreement with the Russian Federation government.
- There are sources of the electric power of sufficient capacity in this area, i.e. a 500 kV power line and two power stations.
- There is a developed system of transport and communication services, highways, railways and a waterway (the Volga river) with good connections to central Europe.
- Presence of a modern communication infrastructure, including one of the largest satellite communication centers in Europe.
- A special economic zone established in Dubna in December 2005 provides preferential terms for development and manufacture of high technology technical production.

Currently no further projects are planned in this territory. The ground is available for the ILC. The site is located within one administrative area, the Moscow region. The regional government has approved the JINR initiative to locate the ILC there.

Site Description

The area is thinly populated. The path of the accelerator traverses two small settlements and a railway between the towns Taldom and Kimry with low frequency. The region around the accelerator path is mainly covered with forest and a small proportion of agricultural lands. The Elevation is nearly flat with some surface swamping. Tertiary soil is stable. This has been confirmed by the geological survey carried out during the site selection for the U-70 accelerator.

Geological characteristics of the territory allow tunnel construction in a stable geological layer at a relatively small depth of about 20 meters. JINR and Dubna have all necessary infrastructure to accommodate specialists for the period of the accelerator construction, to accumulate the equipment, to provide for the project production support during manufacturing of the special purpose equipment. The international airport Sheremetyevo is at a distance of about 100 kilometers from Dubna. It is connected with Dubna by means of the highway. Besides, there is a small aerodrome Borki in the immediate vicinity. The electricity supply network located in the vicinity of Dubna makes it possible to provide the needed power supply for the accelerator (about 330 MW). The reserved area for the accelerator complex is 50 km times 1 km. This gives the opportunity to adjust the orientation. The accelerator tunnel is in a homogeneous geological layer following the curvature of the earth.

The present baseline design at Dubna presupposes the construction of an underground accelerator tunnel and a surface klystron gallery (see Figure **2**). The inner diameter of the tunnel is about 5 m. The distance to the surface is large enough to meet the structural stability and the requirements of the radiation safety when the staff is in the gallery during accelerator operation. The tunnel is connected to the surface by vertical shafts, which are at a distance of about 5 km and provide for access, for loading the necessary services into the tunnel like electricity, ventilation and cooling water. The RF units in the accelerator tunnel are supplied from the klystron gallery by small cross penetrations at intervals of approximately 12 m.

A Tunnel Boring Machine will construct the tunnels in a depth of about 20 m. The TBM average speed in the chosen geological structure can reach 30 meters per day. The underground halls and shafts are constructed in an open pit method and connected directly to the tunnels. The site is also well suited for second stage of the research facility with a center-of-mass energy of 1000 GeV.

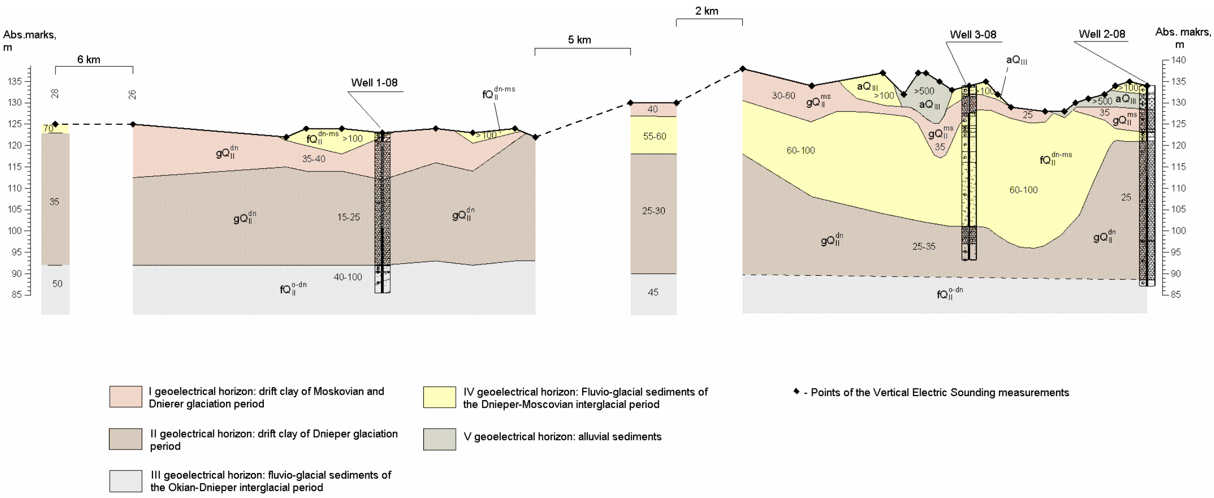


Figure 10: Detail of the geological cut for the Dubna sample site together with the soil boring profiles.

Results from a Soil Boring Report

Figure **10** shows a detail of the geological cut for the Dubna sample site together with soil boring profiles. This area is within the Russian plate, a part of the Eastern European ancient platform. This is a stable, steady structural element of the earth's crust. The characteristic feature of this territory is the uniform and monolithic character of the surface. The surface deviation from the curvature of earth, like single hills and ridges, have smooth shapes, soft outlines and small peaks. The absolute surface marks range from 125 to 135 m with regard to the Baltic Sea level. The whole area is waterlogged.

The proposed ILC site is located in the southern part of a very gently sloping saucer-shaped structure, the Moscow syncline. Alluvial deposits, i.e. fine water-saturated sands, 1 to 5 m of thickness, are bedded above. Below one can find semisolid drift clay from the Moscow glacial period with inclusions of detritus and igneous rocks. The thickness of moraine deposits is 30 to 40 m. Under the moraine from the Moscow glacial period fluvioglacial water-saturated sands and loams of the Dnieper glacial period are bedded. Jurassic clays and carboniferous limestone of the platform mantle are spread under the overburdens at the depth of 50 to 60 m. The depth of the International Linear Collider at Dubna is proposed in the drift clay 20 m below the surface, at 100 m above the sea level. Watertight soil below should prevent the tunnel from groundwater inrush. This makes a tunneling method possible using tunnel shields with simultaneous wall construction by tubbings (precast concrete blocks) or shotcrete. Standard boring machines provide a more than sufficient tunneling speed in drift clay. Vertical shafts, experimental and service halls, and other underground volumes could be constructed by cut-and-cover. This could reduce the civil engineering additionally.

A GSPI team examined the ground at several points along the tunnel route between October and December 2008. This investigation includes:

- Boring of 3 wells in depth of 36 to 47 m with full core extraction,

- Selection of 40 soil monoliths and 16 disturbed soil samples for investigations of their physical-mechanical properties,
- Selection of 10 ground water probes for chemical analysis,
- 35 points of vertical electric sounding,
- Gamma-ray logging, thermometry and vertical seismic profiling in boreholes and
- High-resolution surface seismic survey using shear wave reflection method.

The obtained data (geological structure and hydro-geological conditions, geotechnical soil properties, weak development or absence of adverse natural and engineering-geological processes) are favorable for placing the linear collider in the investigated territory. The results contained in the GSPI Soil Boring Report supports the positioning of a site that is compatible with the current ILC criteria in the Dubna area and supports a near surface design solution.

Figure **11** shows the log file of one borehole together with the (surface) wave velocity measurement. The file indicates clearly the permeable and non-permeable layers. The water is pressurized. The pressure is proportional to the water column difference in the borehole. The measured wave velocity increases slightly with the deeps starting with 300 m/s at the surface.

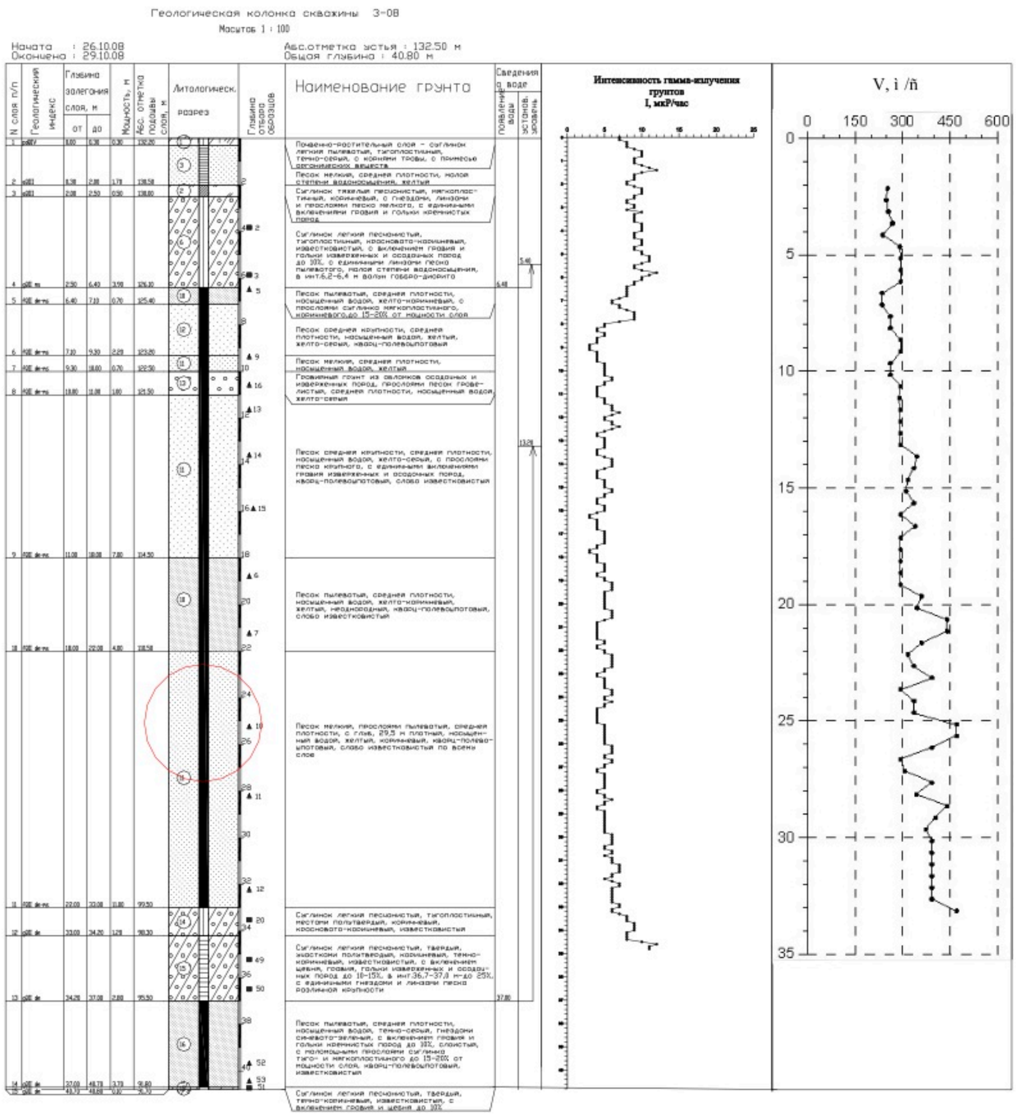


Figure 11: Profile of one bore hole at Dubna together with the (surface) wave velocity measurements.

3 Stability Investigations

Special problems investigated in the Work Package 5 are the ground stability at different tunnel locations. Vibrating quadrupoles in the Main Linac could increase the beam emittance (beam size at the Interaction Point) and vibrations in the Final Focus could disturb the pointing stability of the colliding beams. The ambient noise, the floor motion, the transfer function of the support and the tunnel temperature stability has an influence on the position stability of the machine elements.

Measurement of the Ambient Noise and the Floor Motion at Different Location

Beam size and pointing stability requirements of current and next generation machines approach a range where ground motion may decrease performance. The ground motion has different sources. The earth itself vibrates randomly with a white noise acceleration spectrum. The so called Spectral Power Density p_y versus the frequency ν characterizes the noise and is defined by:

$$p_y : \int_{\nu_1}^{\nu_2} p_y(\nu)d\nu := \left\langle y^2 \right\rangle_{\nu_1}^{\nu_2},$$

where ν_1 to ν_2 is the frequency range of the Root Mean Square value and y is either the horizontal (x) or vertical machine plane (z). Then the Spectral Power Density is inversely proportional to ν^4 for the background noise from the earth. The low noise spectrum in Figure **12**, measured at the German seismic station Moxa operated by University of Jena, shows this general behavior over a wide frequency range. The strong signal below 1 Hz comes from ocean waves and can be seen all over the world even in large distances from the coast. The second curve was taken in the HERA tunnel about 20 m below the surface. HERA is located in Hamburg. It shows a typical high noise spectrum, which is shifted by four orders of magnitudes above one Hertz. The high excitation is the ambient noise mainly from local traffic and other human activities. The broad 10 Hz signal comes from public busses. The sharper lines at higher frequencies are the vibration from floor motion mainly by electrical motors.

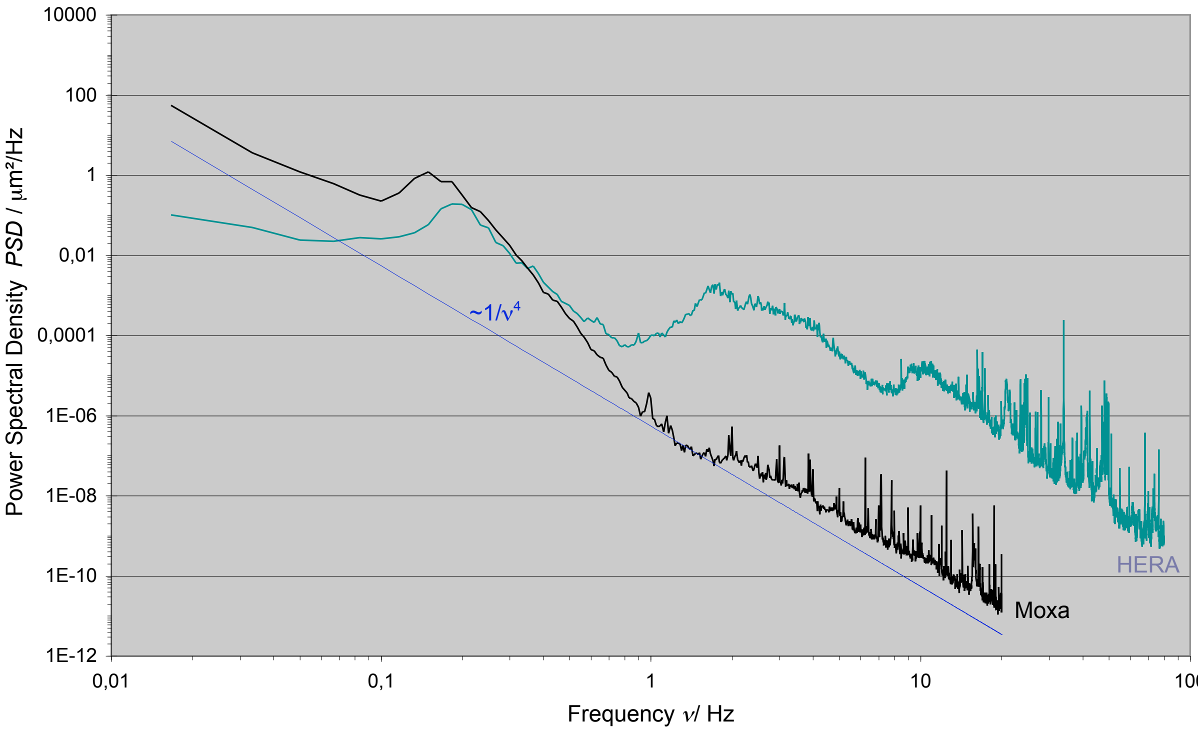


Figure 12: Power Spectral Densities of two sites measured with a broadband seismic sensor.

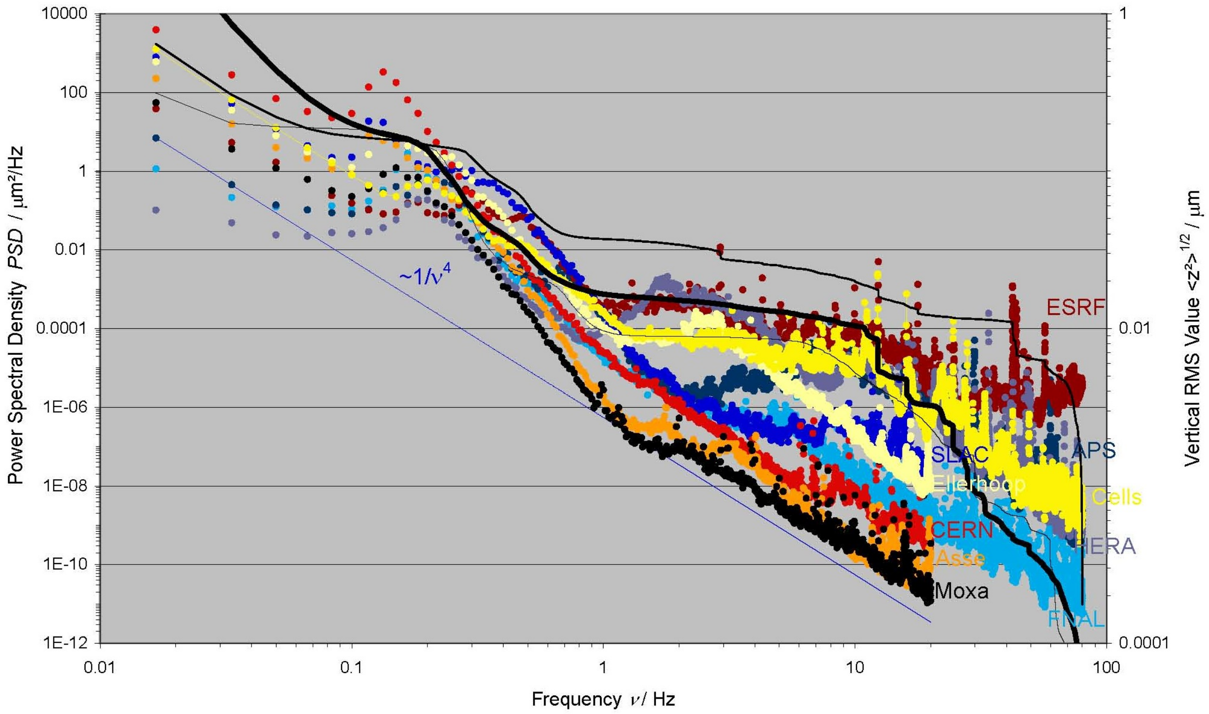


Figure 13: Spectral Power Density averaged over one hour versus frequency measured at different accelerator and reference sites.

Site	Minimal RMS-Value / nm	RMS-Rise / nm
Moxa (seismic station)	0.6	0.9
Asse (salt mine NDL[4] -900 m)	0.8	1.0
DESY campus	40	134
DESY HERA tunnel	40	113
Ellerhoop	15	48
CERN campus	5	14
CERN LHC tunnel	2	3.5
ESRF	40	155
SLAC	5	9
FNAL campus	7	7
FNAL NuMI target hall	3	5
APS	15	8
Minimal noise above 1 Hz	< 0.5 nm	

Table 1: Minimal RMS-Values and RMS-Rise above 1 Hz at different accelerator and reference sites.

The ground motion was measured at several accelerator and reference sites all over the world in all three regions. Figure **13** is a compressed presentation of these measurements with a focus on European sites. An additional reference curve was taken at Asse, a former German salt mine, about 900 m below sea level (National Datum Level – 900 m). The result is similar to the seismic station, which is above the sea level in the bedrock of a mountain. In general these two curves represent minimum ground motion. The other spectra are in a wide range up

[4] National Datum Level respectively Sea Level

to five orders of magnitude higher than the reference value. The differences are mainly above 1 Hz. Therefore the RMS-Value above this frequency can be used as single value for the assessment of the different sites. Table **1** shows these values for the different sites. The Root Mean Square is divided in the minimal value and in the typical night to day rise for a more differentiated view. The result of this investigation is that the ground motion measurement is one tool and the RMS-Values above 1 Hz a set of parameters for the site selection process.

Measurement of the Transfer Function of Quadrupole Supports

The tunnel layout, the design of the civil construction and the machine could have strong influence on the stability of the machine. For example the services and activities in the service tunnel of a twin tunnel design can increase the ambient noise and the floor motion. There are also complex dependencies, i.e. if the Beam Delivery System needs a service tunnel due to the fact that heat losses to air from the high current cables are limited or air conditioning is necessary. The stability of the quadrupole supports is another design problem. The design of the supports depends on the geology and tunnel layout in a certain sense and is therefore site dependent. Resonances can increase the ground vibration significantly if the layout is not stiff enough. The quality of the design can be characterized be the transfer function T_y:

$$T(\nu)_y = \sqrt{\frac{p_{y\,\mathrm{Magnet}}}{p_{y\,\mathrm{Floor}}}},$$

which is the frequency dependent amplification (or damping) of the ground vibration.

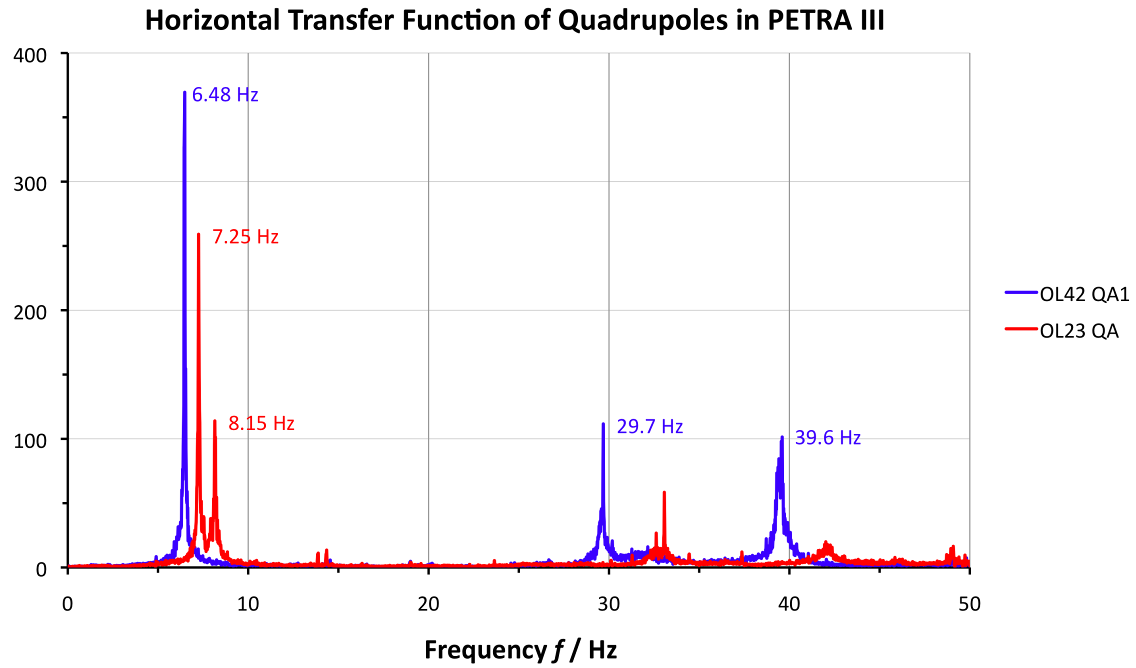


Figure 14: Horizontal transfer function of two quadrupoles in PETRA III.

Figure **14** shows an example measured at two different PETRA III magnets at DESY in Hamburg. There are several resonances below 50 Hz with a quality of 100 or even much higher. The splitting of one line into two frequencies comes from the unequal distribution of the magnet load on the bolts of the tripod. Simple design rules for getting the stability of the ground for the focusing elements are:

- No resonance frequencies below 25 Hz better 50 Hz (i.e. low beam position and stable adjustment elements),

- the center of mass above center of tripod and
- the quadrupoles should be always at the fix points of the construction.

If this cannot be guaranteed the implications must be taken into account for the comparison of the different sites. The possible stability of the quadrupole supports is an additional parameter for the site selection process.

A Simple Model for the Heat Flow of a Tunnel into the Water Table

Another important parameter for the stability of an accelerator is the temperature (stability). The only heat sink for a tunnel without air conditioning is the ground water. Figure 15 shows a model for analytical heat flow calculation of a tunnel in bedrock below (above) the water table. With the result of the calculation the limit of heat losses without additional air conditioning is straighforward to estimate.

A mirror tunnel model for the heat flow calculation of a tunnel in bedrock below a water table as shown in Figure **15** is the method to get the following analytic solution for the heat flow $\dot{Q}$ per unit length l:

$$\frac{\dot{Q}}{l} = \frac{2\pi\lambda\left(\vartheta_1 - \vartheta_0\right)}{\ln\left(1 + \frac{D}{r_0 + D} \Big/ 1 - \frac{D}{r_0 + D}\right)},$$

where r_0 is the inner tunnel radius, D the distance to the water table, λ the conductivity of the bed rock, ϑ_1 the tunnel temperature and ϑ_0 the water temperature. For a conductivity of 5 W/K m, a tunnel radius of 2.5 m, a distance of 7 m and a temperature difference of 10 K the resulting heat flow is 166 W/m. The thin blue curve in Figure **16** shows the heat losses per unit length with these assumptions for different distances to the water table but without heat convection from the tunnel air to the rock. This is taken into account for the calculation of the thick blue curve with circles by convection constant of 5 W/m^2.

The red curves are the corresponding curves for a coaxial arrangement, which could be assumed for a tunnel in water-saturated soil. Then the heat flow $\dot{Q}$ per unit length l is:

$$\frac{\dot{Q}}{l} = \frac{2\pi\lambda\left(\vartheta_1 - \vartheta_0\right)}{\ln\left(\frac{r_0 + \Delta}{r_0}\right)},$$

where r_0 is the inner tunnel radius, Δ the thickness of the tunnel lining and the concrete filling of the remaining bore slit, λ the conductivity of the tunnel tube, ϑ_1 the tunnel temperature and ϑ_0 the water temperature. For a conductivity of 5 W/K m, an inner tunnel radius of 2.5 m, a thickness of 0.4 m and a temperature difference of 10 K the resulting heat flow is about 2.1 kW/m.

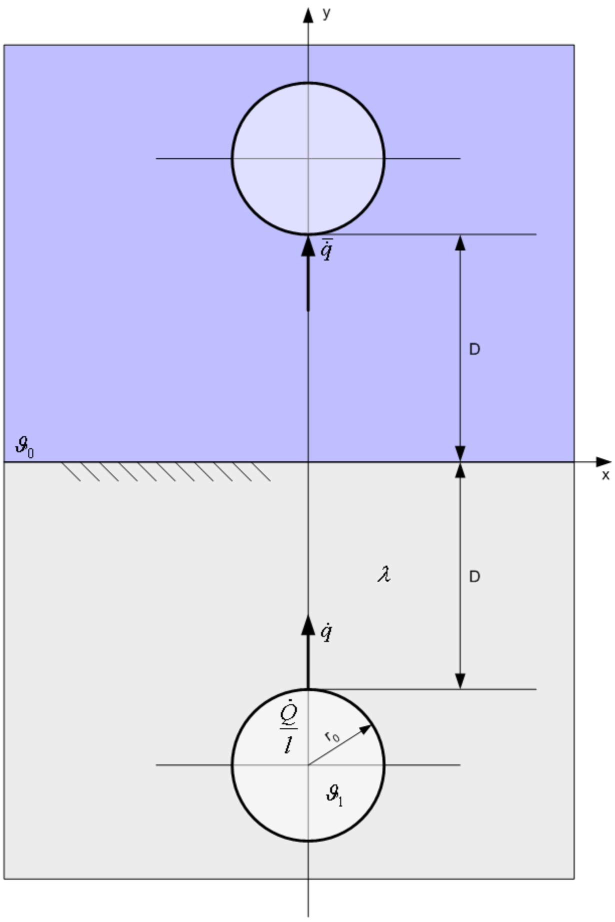


Figure 15: Use of a “Mirror”-tunnel for the heat flow calculation of a tunnel in bedrock below the water table.

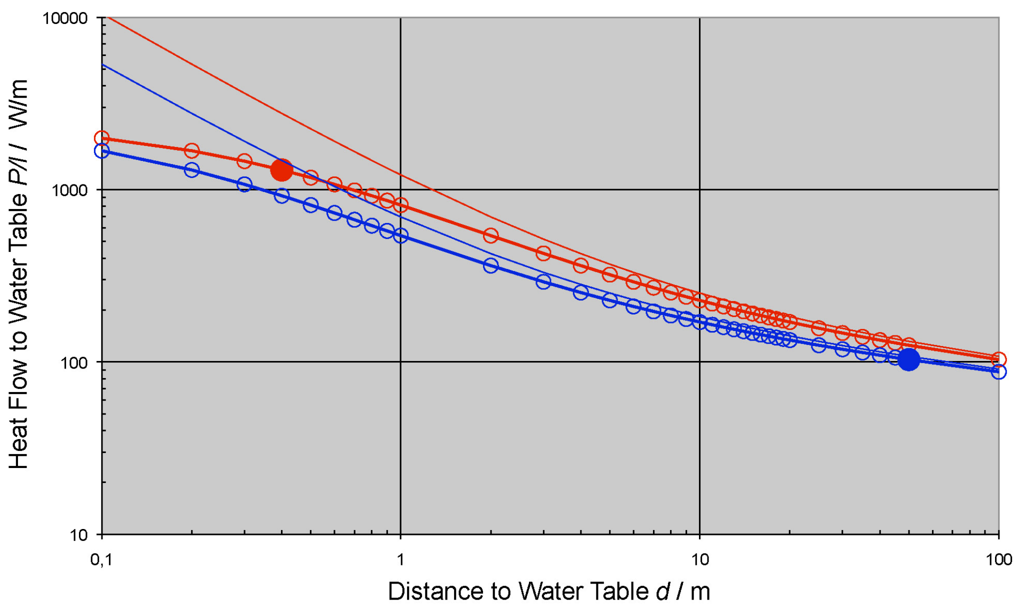


Figure 16: Heat flow to the water table for a tunnel in bedrock (blue) and for a tunnel in water saturated soil (red) at 10 K temperature difference. The filled points are pointing to typical values.

These simple calculation show that the heat losses to air in a tunnel in the water table could be about ten times higher than in a tunnel in bed rock for the same temperature difference. The ground water temperature is about 10 °C and the tunnel air temperature should be limited to 40 °C. Consequently heat losses up to 3 kW/m can absorbed by a tunnel in the water table. This is well above possible heat losses to air. No air condition and ventilation is necessary. The temperature distribution is inherently very stable if the heat losses are approximately constant. On the other hand air condition and turbulent airflow is needed for a tunnel in bedrock with heat losses above some 100 W/m where the temperature distribution is not as stable. Single line fluorescent lamps are producing already 50 W/m heat losses. This behavior compensates the other disadvantages of near surface tunnel if they are in the water-saturated soil. The maximum heat losses to air without air conditioning is a further parameter for the site selection process.

4 Summary

Presently three sites for the International Linear Collider are investigated at established High Energy Physics center in Europe. At CERN in Geneva the tunnel is located deep underground in non-permeable bedrock. At DESY in Hamburg and JINR in Dubna the tunnel is close to the surface in water saturated respectively in non-permeable soil. They have advantages and disadvantages. But all three are more or less well suited for housing a Linear Collider and one has ample choice for a site selection process in Europe. After a decision a well-investigated optimal site can bid to host the International Linear Collider.

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Appendix

Face-to-Face Meetings

InDiCo	Meeting	Location	Date
2432	TILC08 Joint ACFA Physics and Detector Workshop and GDE meeting on International Linear Collider	Tohoku University, Sendai, Japan	March 3 to 6, 2008
3154	TILC09 Joint ACFA Physics and Detector Workshop and GDE Meeting on International Linear Collider and Accelerator Advisory Panel Review Meeting	Tsukuba, Japan	April 17 to 21, 2009
2709	ILC Cost Management Group Workshop	DESY, Hamburg	May 5 to 8, 2008
2321	GDE Meeting - ILC Conventional Facilities and Siting Workshop	JINR, Dubna, Russia	June 4 to 6, 2008
2900	ILC-HiGrade Kick-Off Meeting	DESY, Hamburg	August 29, 2008
	XXI. Russian Particle Accelerator Conference RuPAC 2008	Zvenigorod, Russia	September 29 to October 3, 2008
3646	Joint GDE, ILC-HiGrade and JINR Conventional Facilities and Siting Meeting	DESY, Hamburg	June 25 and 26, 2009
	Visit of Phil Crosby, SKA and University of Manchester	DESY, Hamburg	July 13 and 14, 2009
3461	2009 Linear Collider Workshop of the Americas	Albuquerque, New Mexico, US	September 29 to October 3, 2009
4253	Accelerator Advisory Panel Review Meeting	Oxford Univer-sity, Oxford, UK	January 6 to 8, 2010
4408	ILC-HiGrade Scientific and Annual Meeting	CERN, Geneva	February 25, 2010
4175	International Linear Collider Workshop LCWS10	Beijing, China	March 26 to 30, 2010

Table 2: Face-to-Face meetings.

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3. Wilhelm Bialowons, *Cost Reduction Strategies*, TILC08 Joint ACFA Physics and Detector Workshop and GDE meeting on International Linear Collider (2432), Tohoku University, Sendai, Japan, March 3 to 6, 2008.

4. Wilhelm Bialowons, and Frank Lehner, *Process Cooling Water Cost Reduction Strategies*, ILC Cost Management Group Workshop (2709), Deutsches Elektronen-Synchrotron DESY, Hamburg, May 5 to 8, 2008.

5. Wilhelm Bialowons, *Potential International Linear Collider Site at DESY in Hamburg*, GDE Meeting - ILC Conventional Facilities and Siting Workshop (2321), Joint Institute for Nuclear Research JINR, Dubna, Russia, June 4 to 6, 2008.

6. Wilhelm Bialowons, *Process Cooling Water Cost Reduction Strategies*, GDE Meeting - ILC Conventional Facilities and Siting Workshop (2321), Joint Institute for Nuclear Research JINR, Dubna, Russia, June 4 to 6, 2008.

7. Wilhelm Bialowons, *WP 5 ILC Siting in Europe Work Package Report,* ILC-HiGrade Kick-Off Meeting (2900), Deutsches Elektronen-Synchrotron DESY, Hamburg, August 29, 2008.

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10. Wilhelm Bialowons, *Potential ILC Site at DESY in Hamburg*, Joint GDE, ILC-HiGrade and JINR Conventional Facilities and Siting Meeting (3646), DESY, Hamburg, June 25 and 26, 2009.

11. Victor Kuchler, *Overview of CFS Tunnel Configuration Study and Opportunities for JINR/GSPI Participation*, Joint GDE, ILC-HiGrade and JINR Conventional Facilities and Siting Meeting (3646), DESY, Hamburg, June 25 and 26, 2009.

12. Grigori Shirhov, *A Potential ILC Site at Dubna, Moscow Region,* Joint GDE, ILC-HiGrade and JINR Conventional Facilities and Siting Meeting (3646), DESY, Hamburg, June 25 and 26, 2009.

13. Andrey Dudarev and Valery Sokolov, *The Results of the Preliminary Geological Engineering Surveys Along the Supposed Route of the ILC in Dubna Area of Moscow Region*, Joint GDE, ILC-HiGrade and JINR Conventional Facilities and Siting Meeting (3646), DESY, Hamburg, June 25 and 26, 2009.

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16. John Andrew Osborne, *European Life Safety and Egress*, 2009 Linear Collider Workshop of the Americas (3461), Albuquerque, New Mexico, US, September 29 to October 3, 2009.

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