The American Physical Society · Snowmass 2001 · The Future of the High Energy Physics · July 1 to July 20, 2001

Optimal Tunneling for Future Colliders

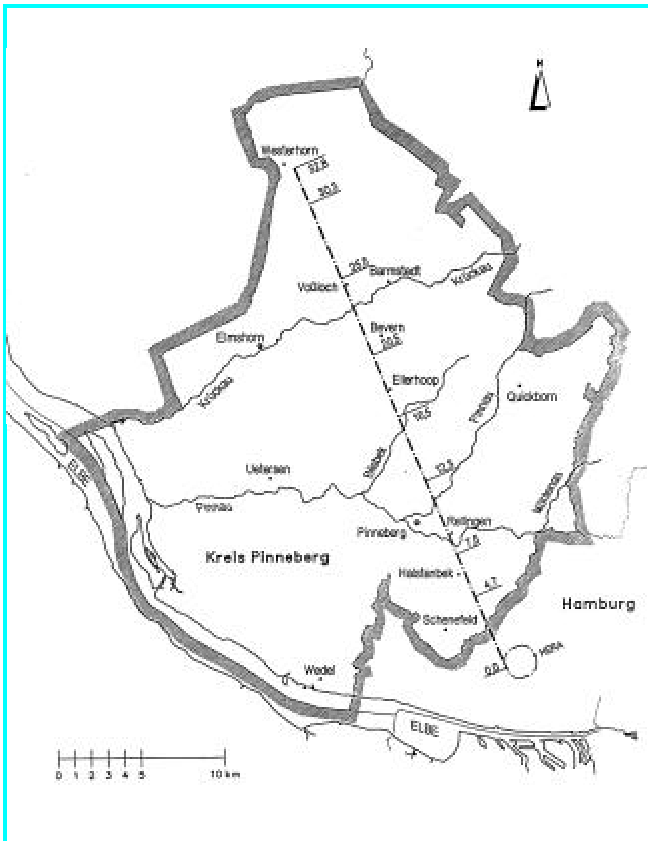
Part 1: Tunnel Requirements

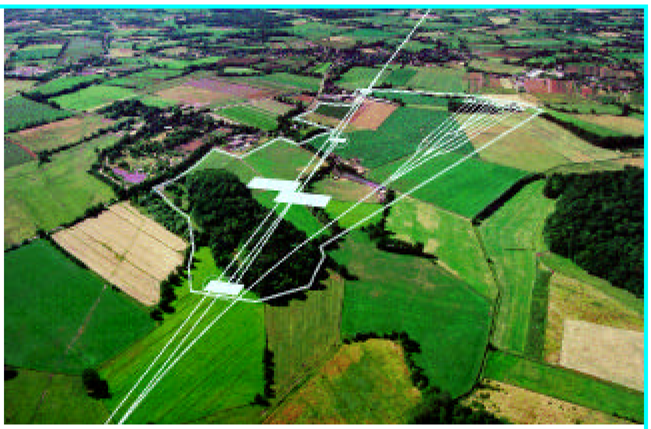
Wilhelm Bialowons

Deutsches **E**lektronen-**SY**nchrotron DESY · Hamburg

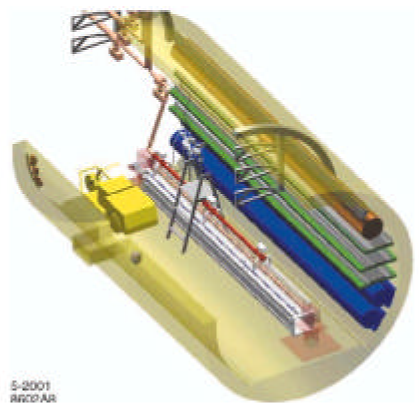
July 17, 2001

TESLA campus area.



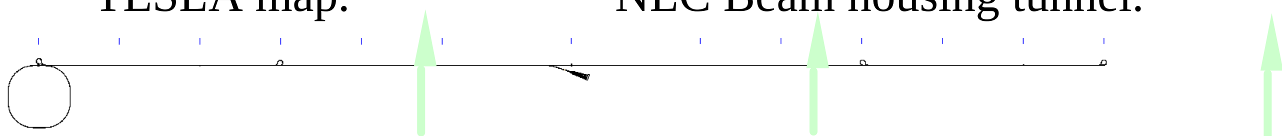


Air photo by Manfred Schulze-Alex, Hamburg, July 9, 1999, 4:30 pm.



TESLA map.

NLC Beam housing tunnel.



Overview

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  - Hadron Collider (VLHC)
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  - Cut-and-cover versus tunnel
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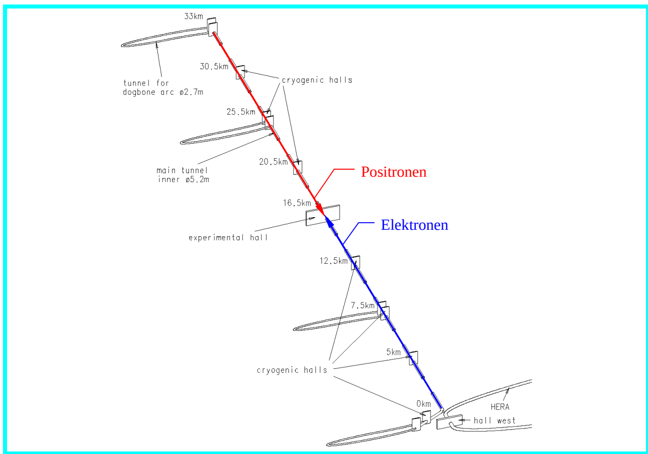
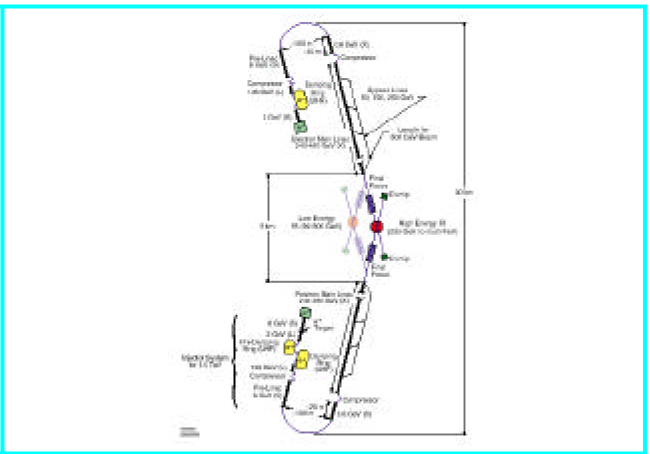
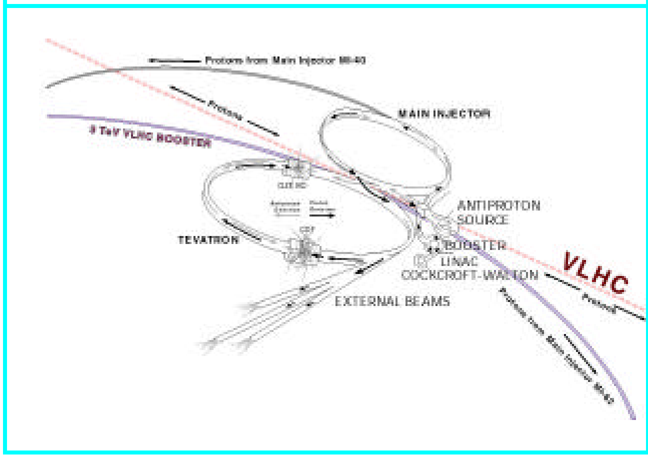
Over view of TESLA

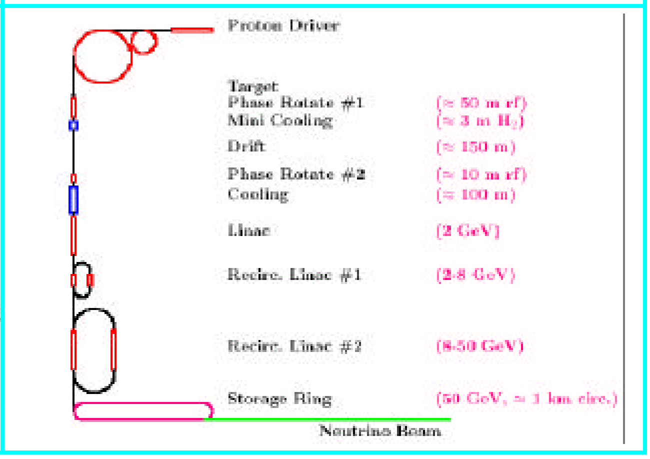


NLC configuration





Injection scheme for the VLHC



A schematic of a neutrino factory.

Different future High Energy Physics projects.

linacs that minimizes the bend angle needed to transport high-energy beams to one of the interaction regions, the high energy IR. The beam delivery system is sufficiently long to allow the high energy IR to be ultimately upgraded to energies in excess of 3 TeV. A synopsis of staging scenarios for the NLC is given in Table 1.1.

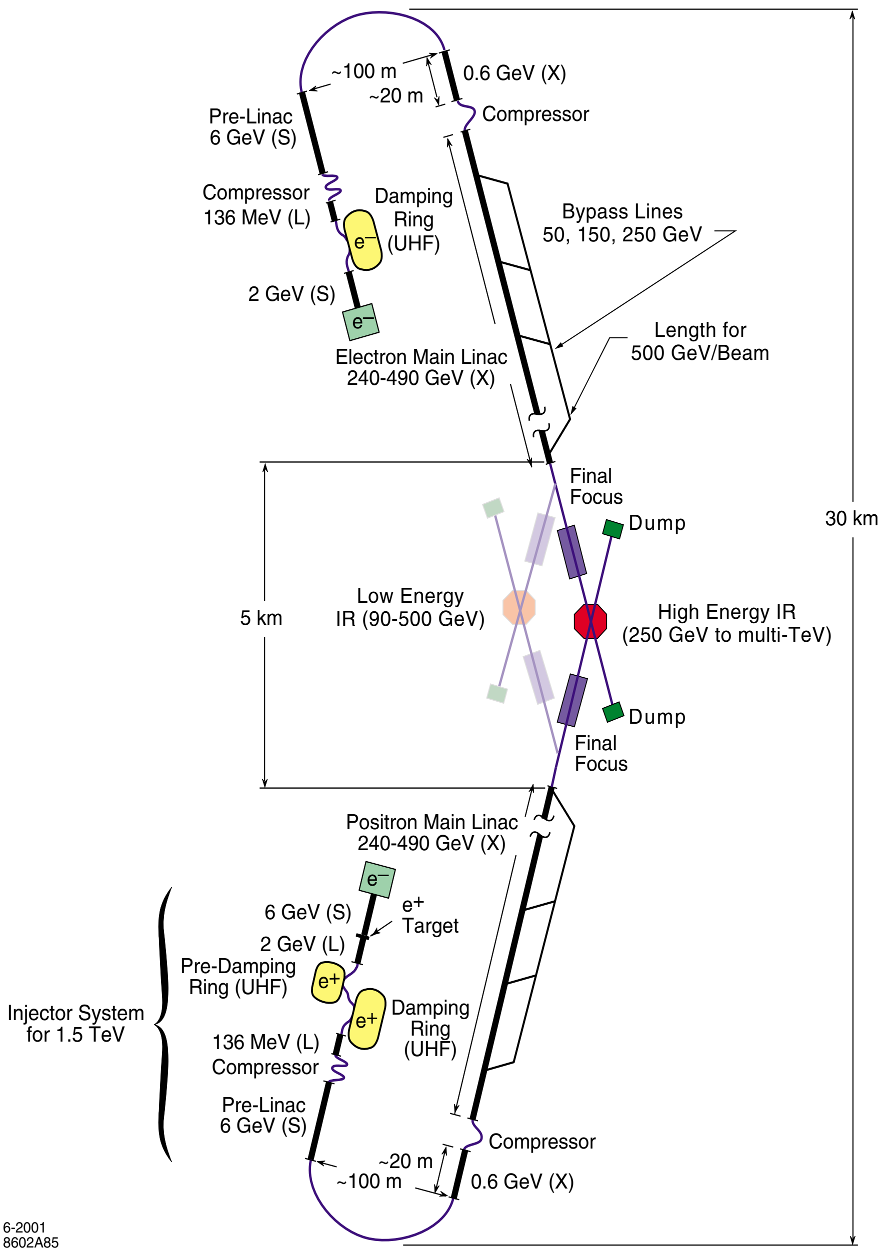
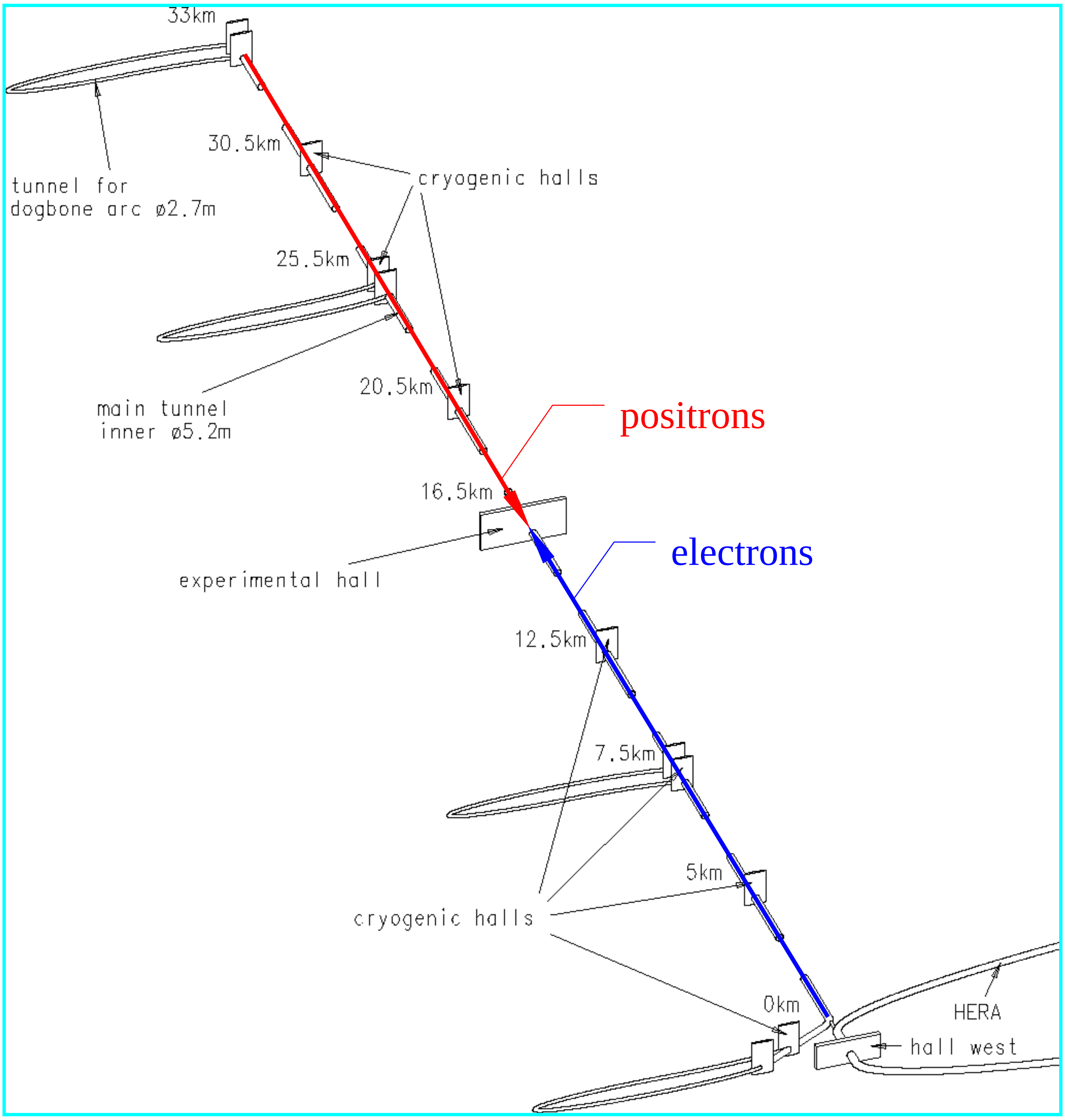
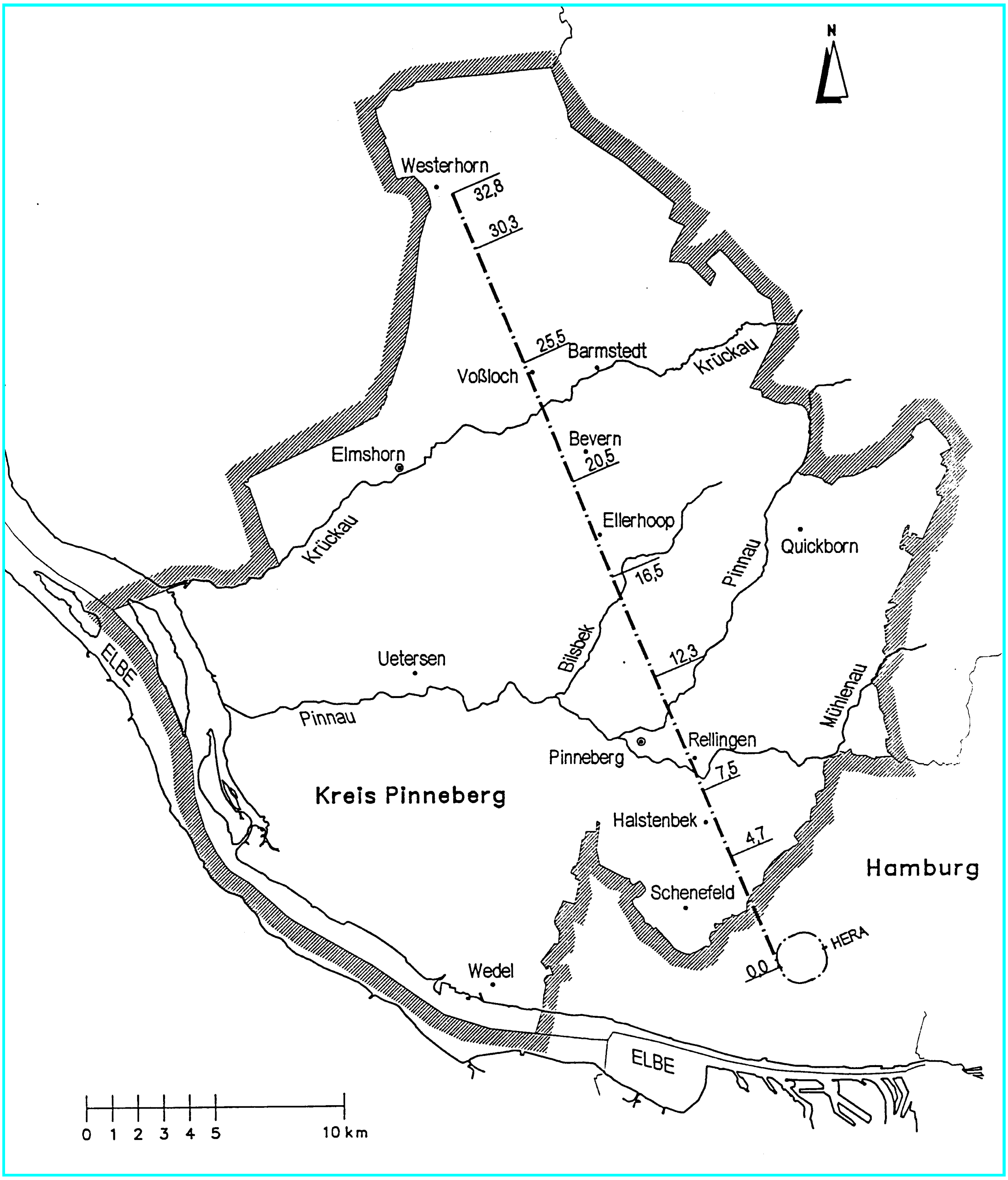


Figure 1.1: NLC Configuration.

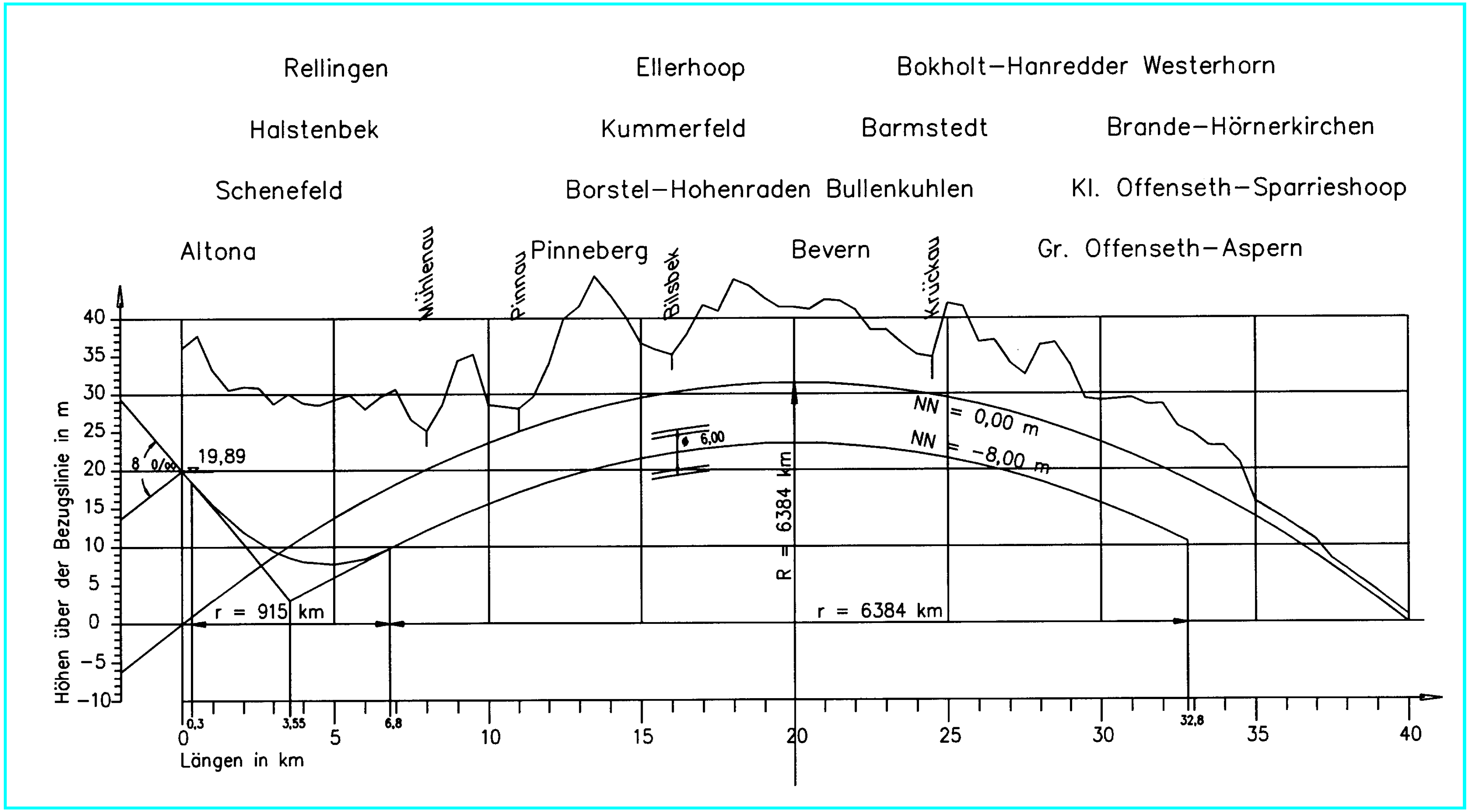


Overview of the TESLA Linear Collider at DESY in Hamburg.



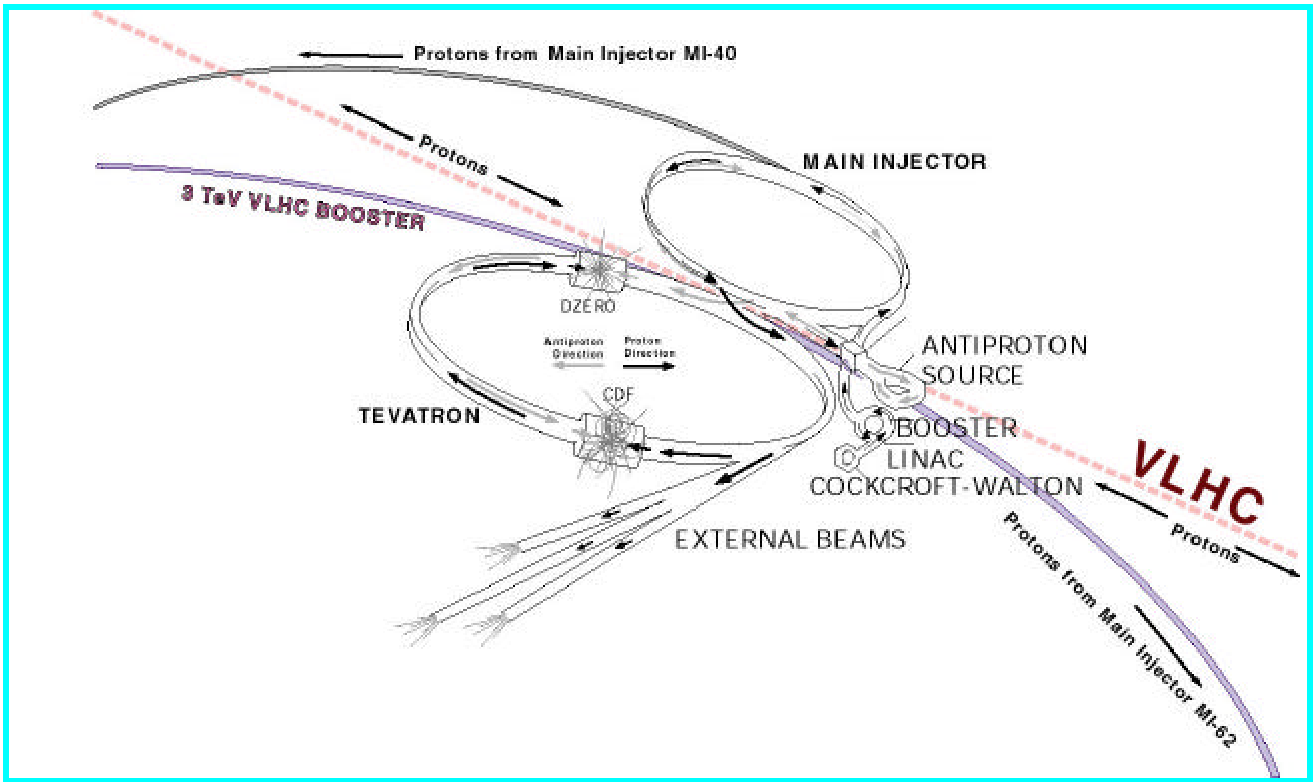
Overall view of the linear collider North-Northwest of DESY.

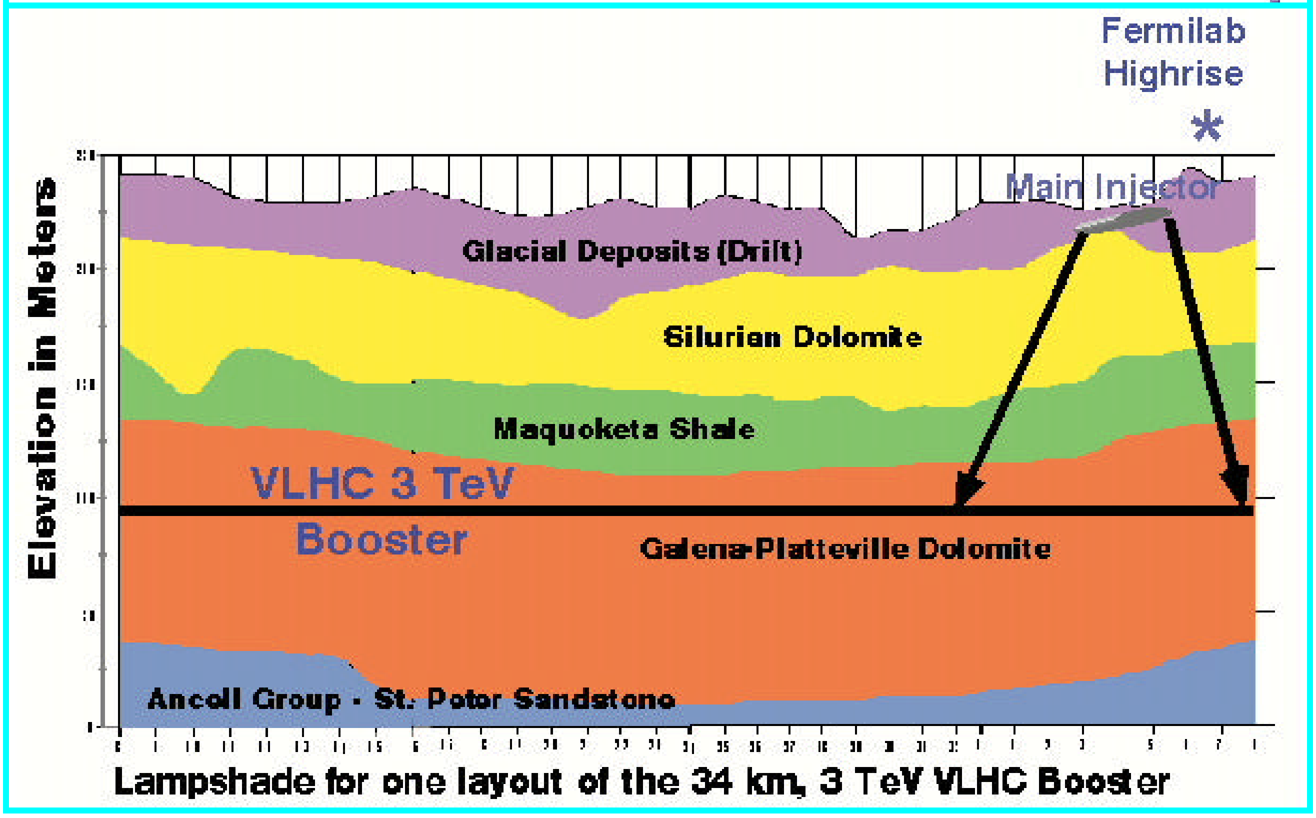
Site map of the Linear Collider and XFEL at DESY in Hamburg.



Expanded profile of the Linear Collider area North-Northwest of DESY.

‘The interaction point HERA West is about 20 m above sea level. The axis of the main part of the linac tunnel lies about 8 m below sea level. The straight section HERA West has a slope of about 8 mrad out of the horizontal. Therefore there is a smooth transition from the initial slope into the horizontal direction with a bending radius of about 1000 km. The depth of the tunnel below ground level of about 8 m in minimum and 12 m in average is more than sufficient to guarantee shielding against radiation. The tunnel is below the ground water level over nearly the entire length.’





The **V**ery **L**arge **H**adron **C**ollider at Fermilab in Illinois.

I. INTRODUCTION

The fascination of the neutrino sector, how it may be explored, and what we might learn in such a venture has been described in the previous *Comment* by Stephen Geer [1]. The need to adequately address this sector puts new, and interesting, burdens upon the accelerator builder. True, accelerators have, through the years, produced neutrinos and certainly one can imagine ever-more-powerful proton accelerators that, combined with horns, can produce ever-more-powerful neutrino beams. Can one design and build a facility directly oriented to this new need? Would such a device be superior to conventional neutrino beams and would it permit one to address new areas? The answer to both questions is "yes," and in this *Comment* I would like to describe what form such a facility, a Neutrino Factory, might take. See Fig. 1 for a schematic of a facility.

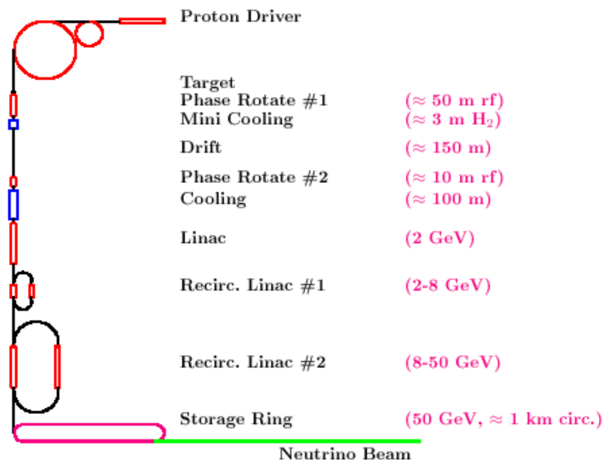


FIGURE 1 A schematic of a neutrino factory. One sees the major components: a proton driver, a target and muon capture region, a phase rotation and cooling section, an acceleration section consisting of a linac and re-circulating linacs, and a storage (decay) ring.

I will go into some detail, in this *Comment*, in describing the components of such a facility, the demands upon each component, the required R&D before undertaking construction of such a facility, and the expected performance of a Neutrino Factory. I shall, also, describe possibilities for up-grade in flux and energy.

The concept of a neutrino factory was proposed, in the mid-seventies, independently, by Kushkarev, Wojcicki, and Collins. It

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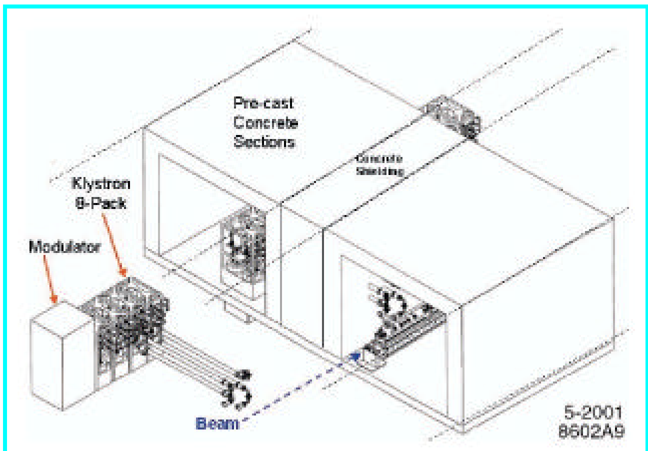
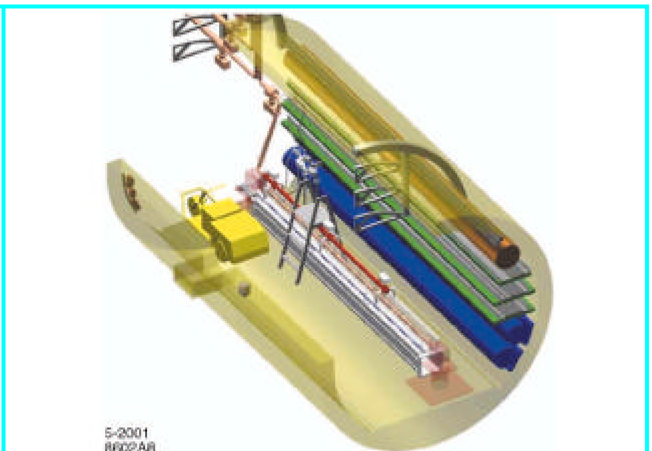
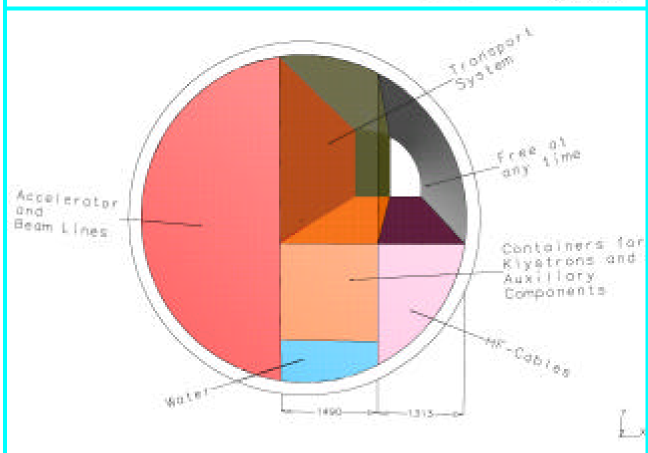
NLC near surface precst section

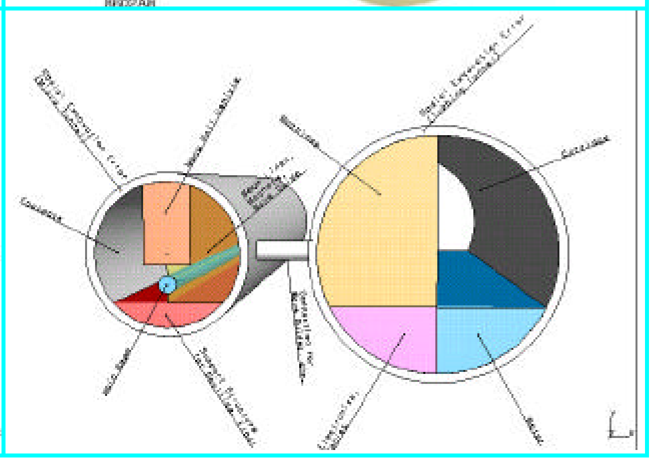


NLC beam housing tunnel





Single tunnel for TESLA



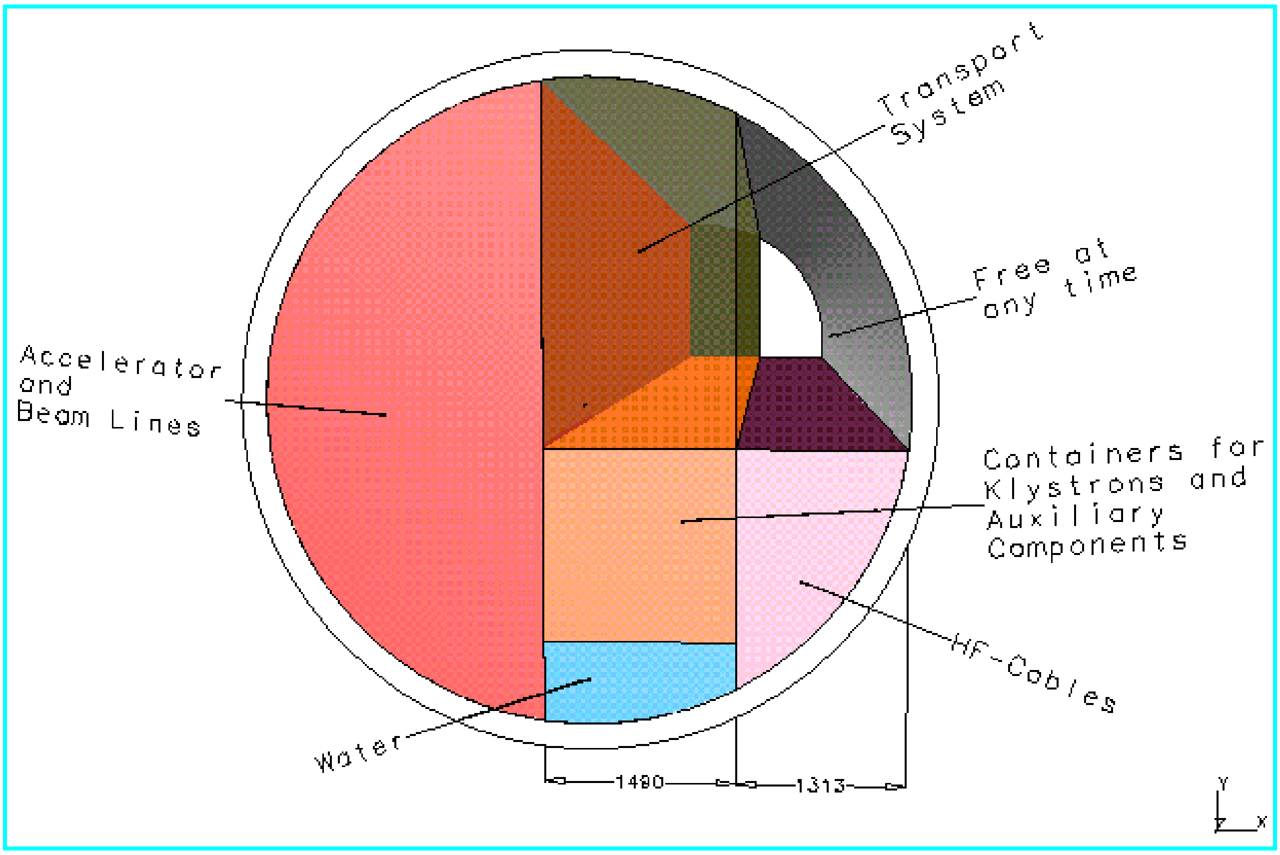
Twin tunnel for S-Band

Different Linear Collider tunnels designs.

	TESLA
Radio frequency f_{rf} /GHz	1.3
Accelerating gradient E / MV / m	23.4
Active cavity length L / m	1.038
Rf pulse length T / ms	1.370
Repetition rate f_{rep} /Hz	5
Number of bunches n_b	2820
Charge per bunch N_e / 10^{10}	2.0
Bunch spacing T_b /ns	337
Peak rf power per cavity $P_{\max}$ / MW	0.23
Number of cavities per klystron	36
Peak rf power per klystron $P_{\max}$ / MW	8.7
Average rf power P / kW	68
Overall efficiency / %	60
Power reserve $P_{\max}$ / P	1.1
Solenoid power P / kW	4
Number of klystrons	584
Klystron lifetime T / h	40 000
Klystron failure T / h	68
Total beam power P_{beam} / MW	22.6
Total rf power P_{rf} / MW	65
Cooling water $V_{\max}$ /m^3/h @ delta$T$ = 50 K	1120

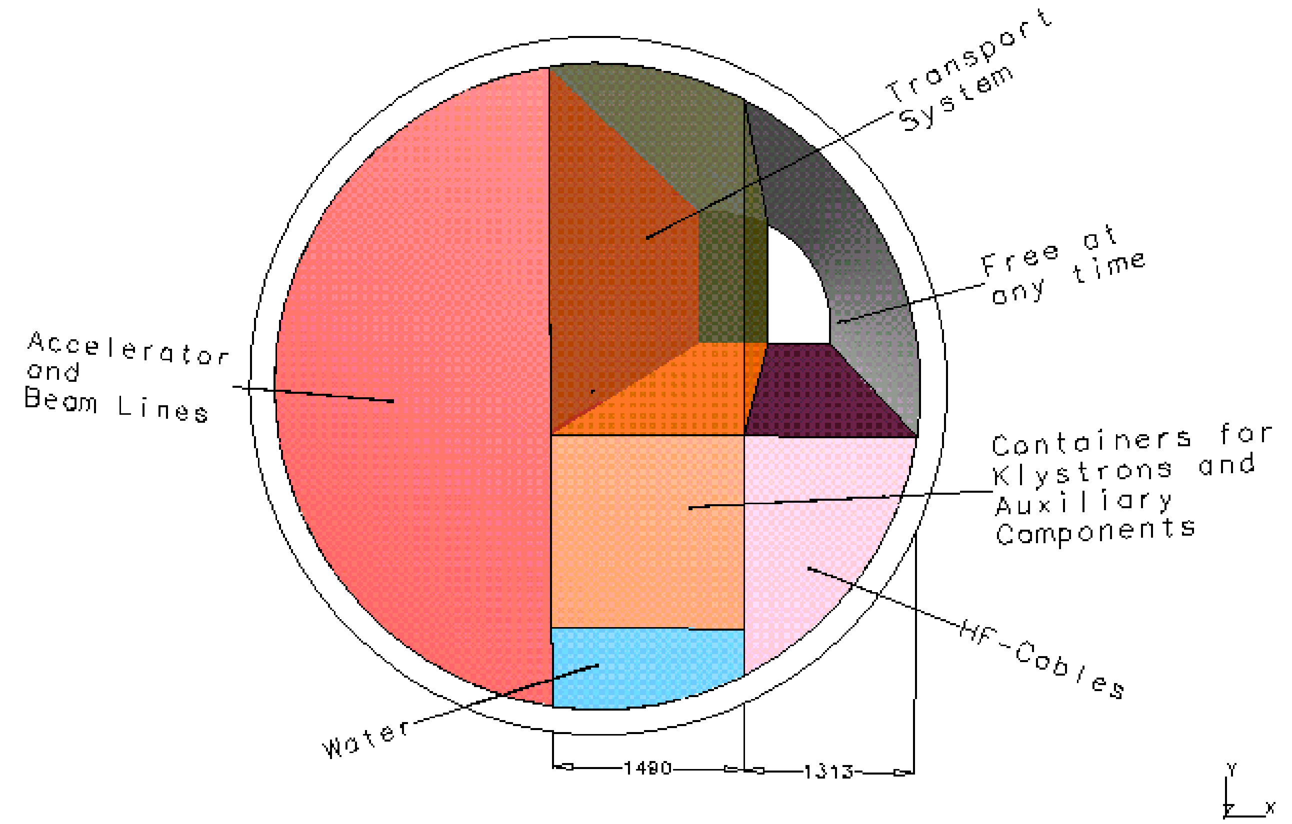
TESLA rf parameters for the E_{cm} = 500 GeV baseline design.

The machine length includes a 2 % overhead for energy management. The primary elecrtic power quoted include a 10 % regulation reserve.

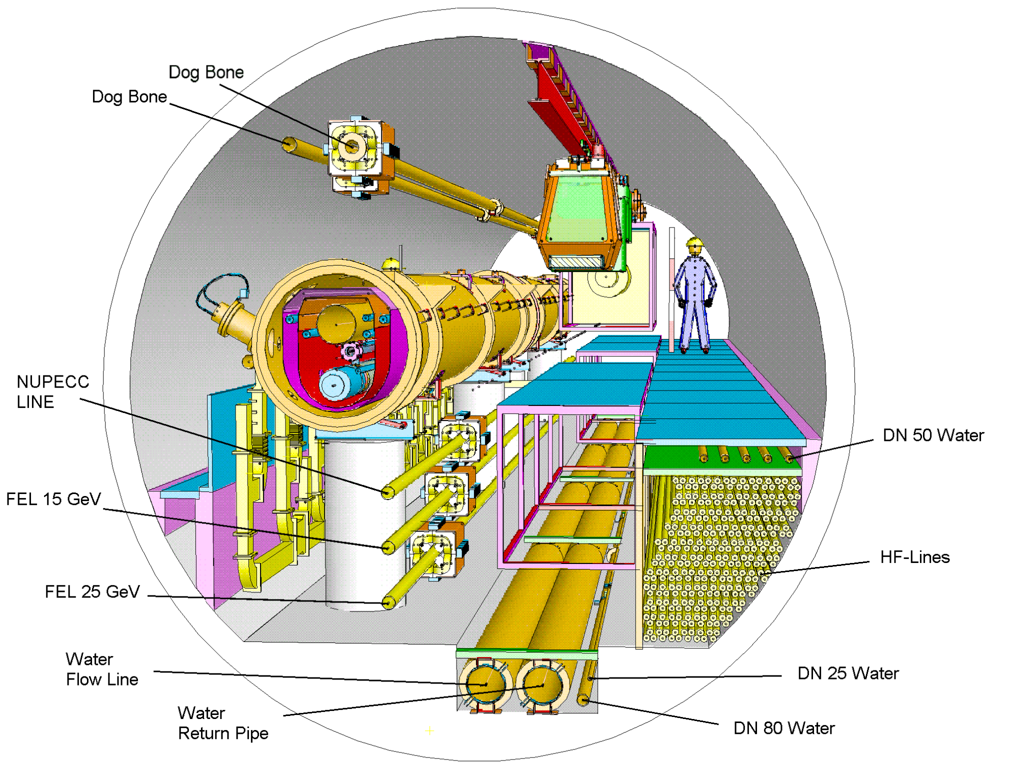


Concept for the TESLA tunnel layout.

'The main tunnel of the TESLA Linear Collider has a minimum inner diameter of 5 m (5.20 m minus construction tolerances). The main components installed in the tunnel are the cryomodules for the superconducting linac and the beam lines for the dog-bone damping rings, for the FEL laboratory and for the ELFE@DESY (Nuclear Physics) option. In addition there are numerous auxiliary components. The cross section is divided vertically into three parts. One third is for sensitive accelerator and beam line components and for the rf distribution. A walk path is located on the outer side for installation and maintenance. The place for the transport system is in the center above the place for components which need easy access. On the bottom the hot and cold water pipes are installed in a small channel; this channel serves for the collection and detection of leakage water. The klystrons, electronics and vacuum pumps are mounted in special containers, the center of mass of which are just below the hook of the transport system. This allows for easy installation and exchange of components with a relative short lifetime. The transport system is a so-called monorail, utilizing an I-beam fixed at the top of the tunnel. The vehicle is used to transport equipment and persons. The last part is the main walk path. The space above the grids is free at all times and the space below is reserved mainly for the cable connection between modulators and klystrons. The free space is for an escape route and for lines-of-sight for optical survey.



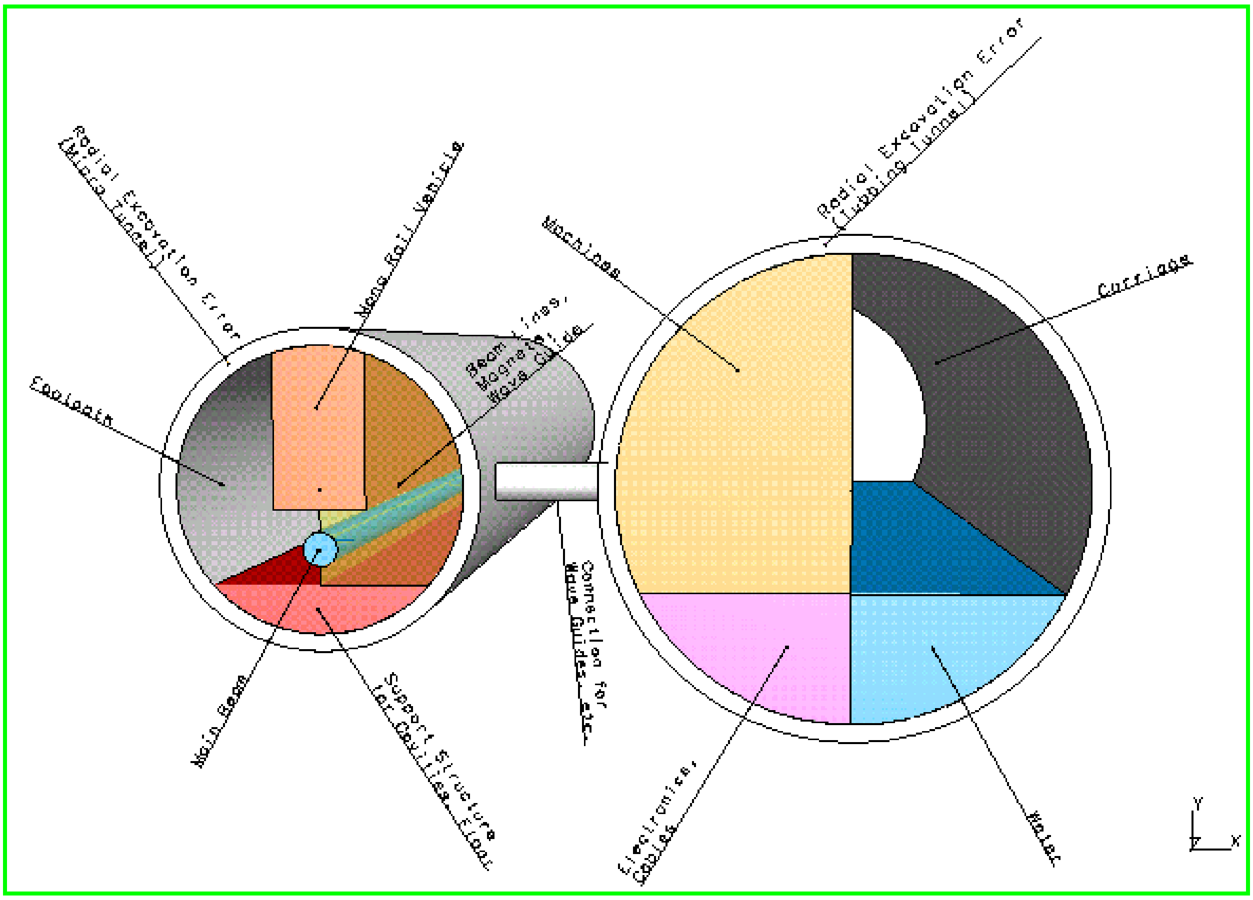
Concept for the TESLA tunnel layout.



TESLA tunnel layout.

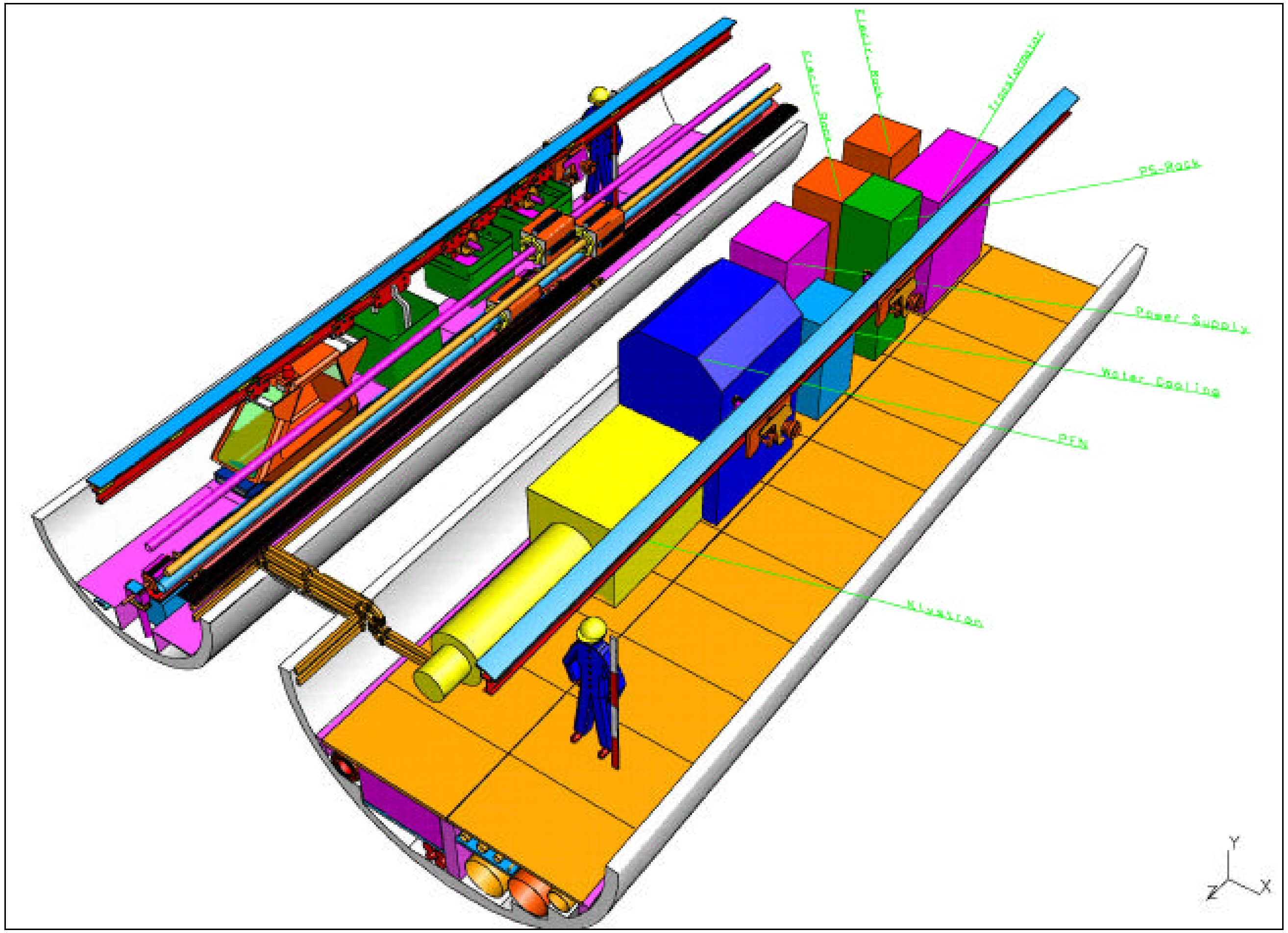
	NLC
Radio frequency f_{rf} /GHz	
Accelerating gradient E / MV / m	
Active cavity length L / m	
Rf pulse length T / ms	
Repetition rate f_{rep} /Hz	
Number of bunches n_b	
Charge per bunch N_e / 10^{10}	
Bunch spacing T_b /ns	
Peak rf power per cavity $P_{\max}$ / MW	
Number of cavities per klystron	
Peak rf power per klystron $P_{\max}$ / MW	
Average rf power P / kW	
Overall efficiency / %	
Power reserve $P_{\max} / P$	
Solenoid power P / kW	
Number of klystrons	2022
Klystron lifetime T / h	20 000
Klystron failure T / h	10
Total beam power P_{beam} / MW	
Total rf power P_{rf} / MW	
Cooling water $V_{\max}$ /m^3/h @ delta$T$ = 50 K	

NLC rf parameters for the E_{cm} = 500 GeV baseline design.

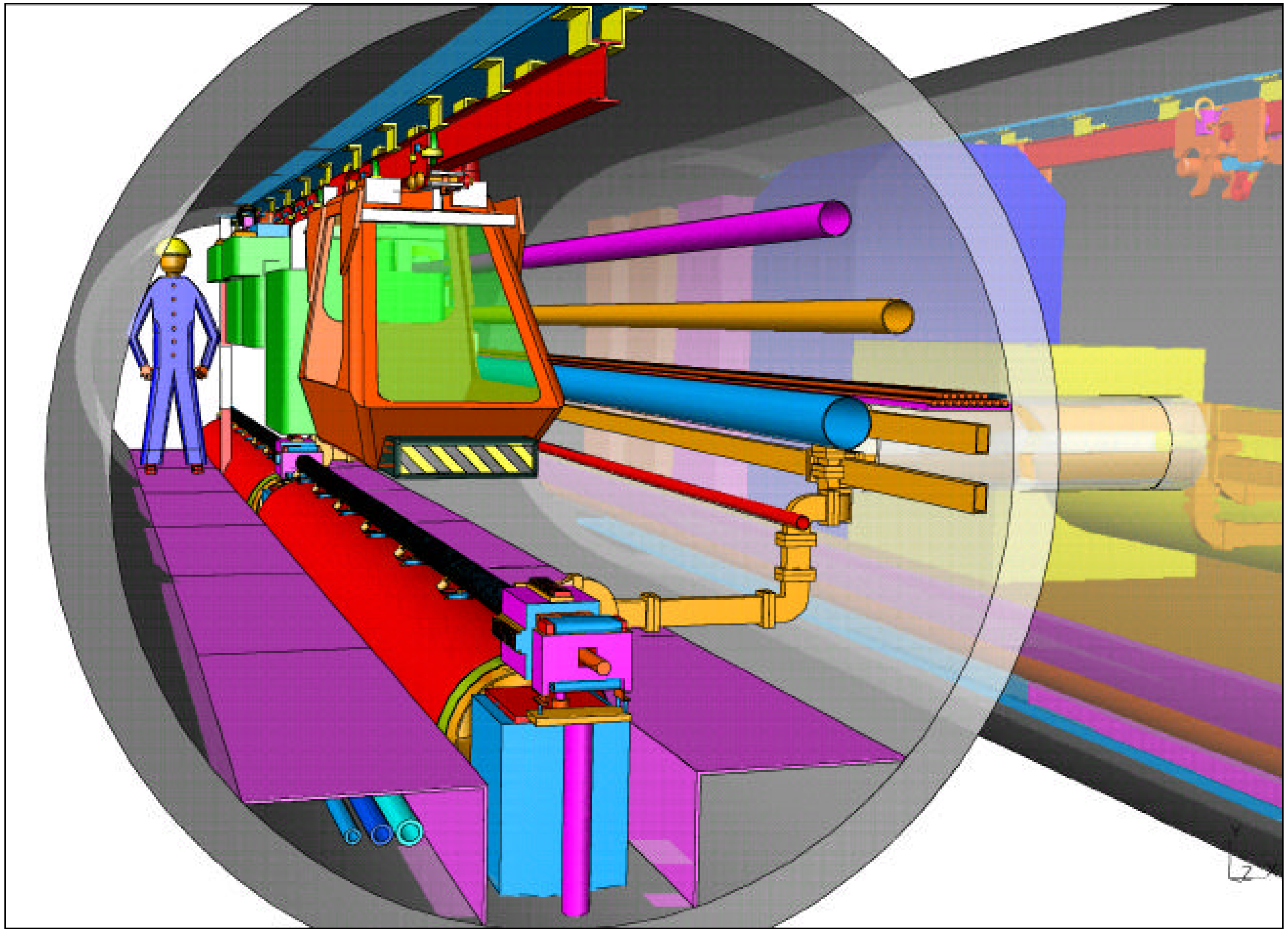


Concept for the S-Band double tunnel layout.

The main components installed in the collider tunnels are the S-band accelerating sections mounted on girders, the beam lines for the low emittance and low energy electron and positron beams and the beam lines for the FEL Laboratory and the ELFE@DESY (Nuclear Physics) operation. In addition there are numerous auxiliary components including klystrons and modulators. During beam operation access is necessary to these components. For example the klystrons and modulators have to be repaired quasi continuously due to the large number and their relatively short lifetime. Thus for the S-Band Linear Collider a double tunnel solution was chosen. A small tunnel with an inner diameter of 2.5 m houses the S-band linear accelerator and the beam lines. A larger tunnel with an inner diameter of 4 m houses the auxiliary components. The tunnels are connected every 25 m by pipes of 300 mm inner diameter. The cross section is vertically divided into two parts. One part is for the linear accelerator and the beam lines. The center of mass of an S-band section is just below the hook of the transport system. This allows an easier installation of most of the components. The transport system is a so-called monorail, utilizing an I-beam fixed at the top of the tunnel. The vehicle is used to transport equipment and persons. The other part is the main walk path, which is free at all times for emergency exit and for the lines-of-sight for optical survey. The auxiliary tunnel is divided horizontally and vertically into two parts. The lower part is reserved for cable connections and cooling pipes. The upper part is reserved for the horizontally oriented klystrons , modulators, electronics, power supplies and distribution, the transport system, similar to that in the other tunnel and for the emergency walk path. The two tunnels are connected by pipes housing the wave guides, which connect the klystrons and accelerating structures.



View into the S-Band Linear Collider tunnel.



View into the S-Band Linear Collider tunnel.

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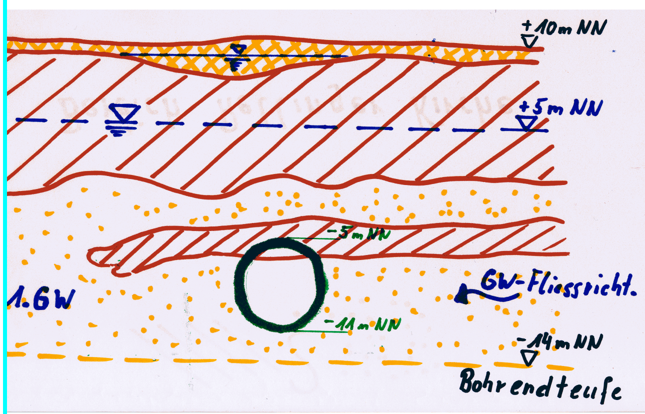
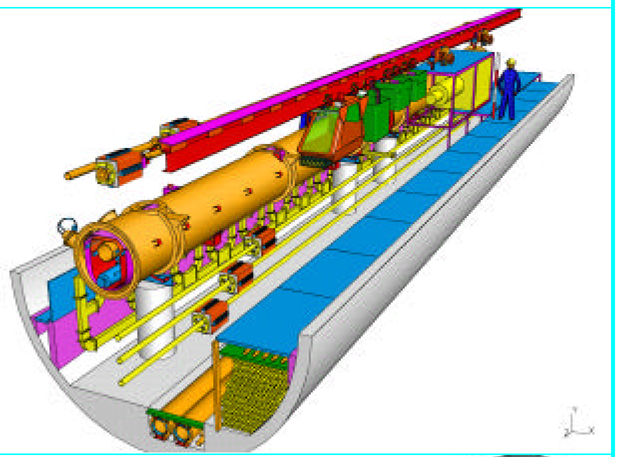
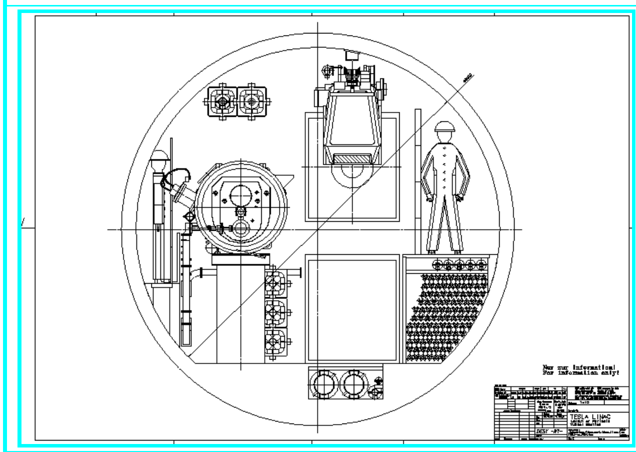
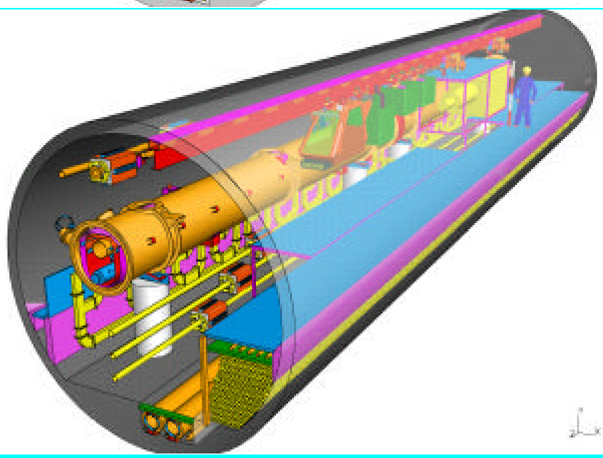
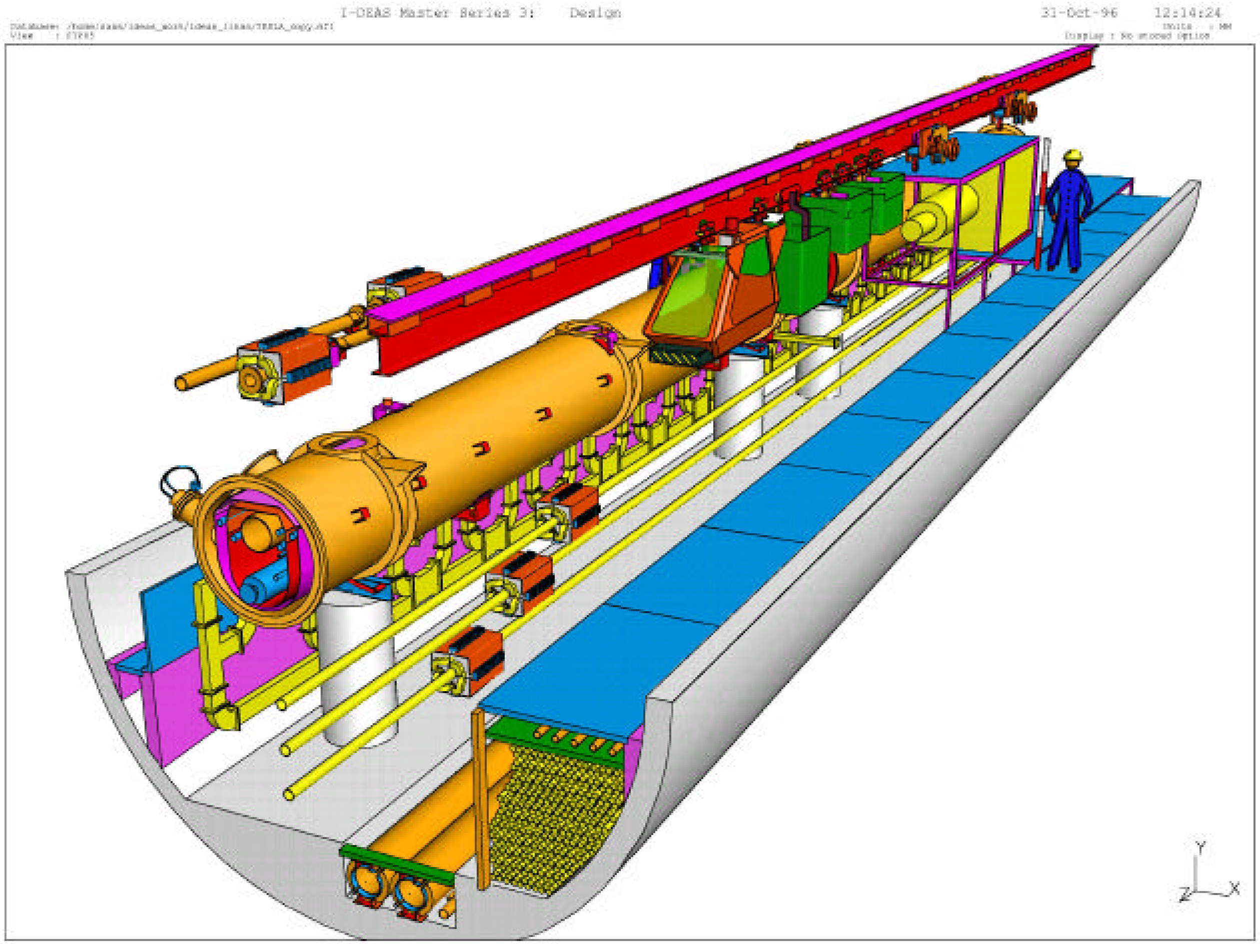
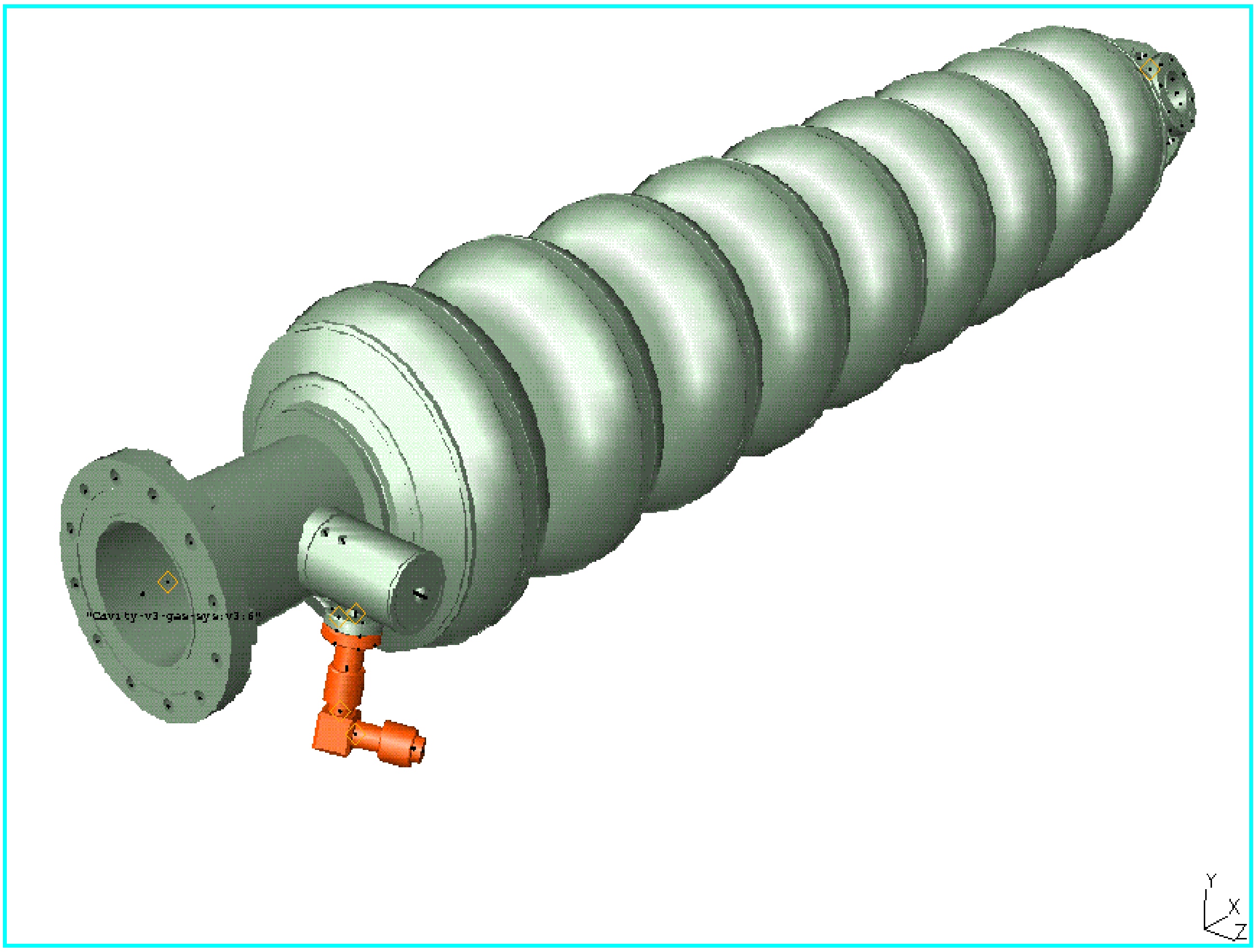
Typical geological properties.	
	
	

Tunnel layout for the Linear Collider TESLA.



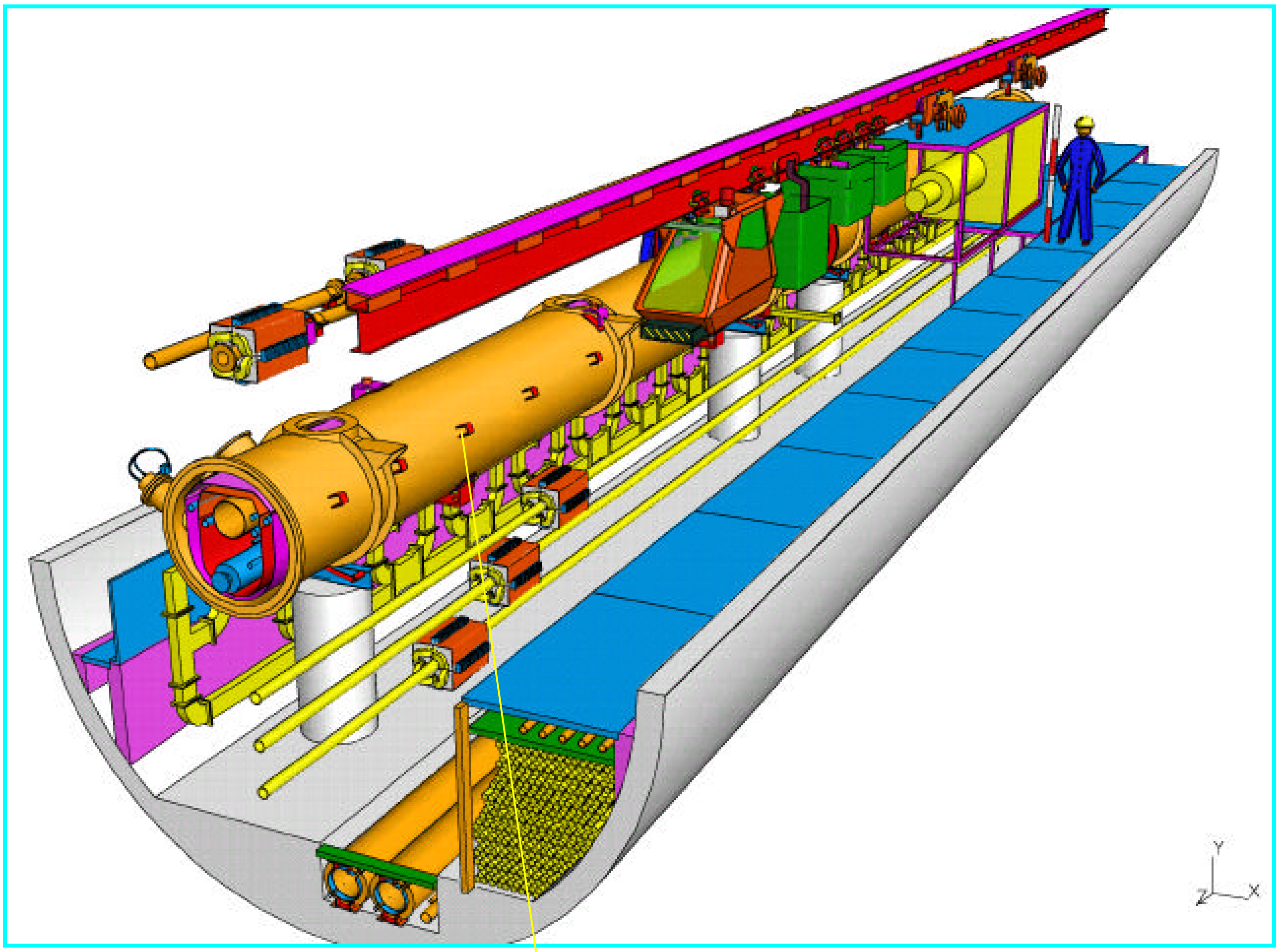
View into the TESLA Linear Collider tunnel.



TESLA nine cell superconducting cavity.

	Subsections	Strings	Modules	Cavities	Klystrons	Length L / m
Modules				12		16.604
Strings			10			
Subsections						
Linacs	12		1 752	21 024	584 (1 168)	29 090.2

Number of main components for the TESLA linear collider.



View into the TESLA Linear Collider tunnel.

	Subsections	Strings	Modules	Cavities	Klystrons	Length L / m
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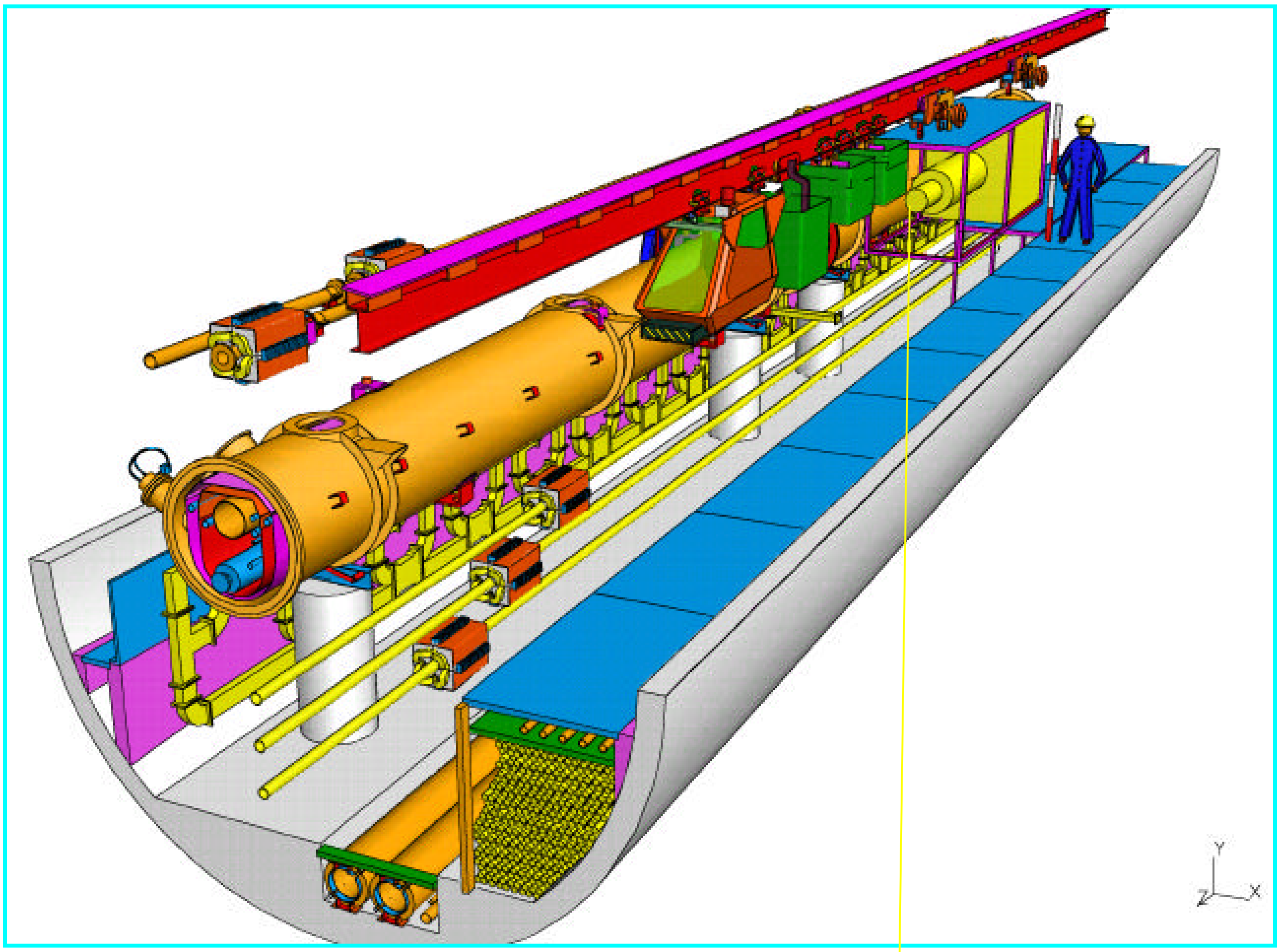

View into the TESLA Linear Collider tunnel.

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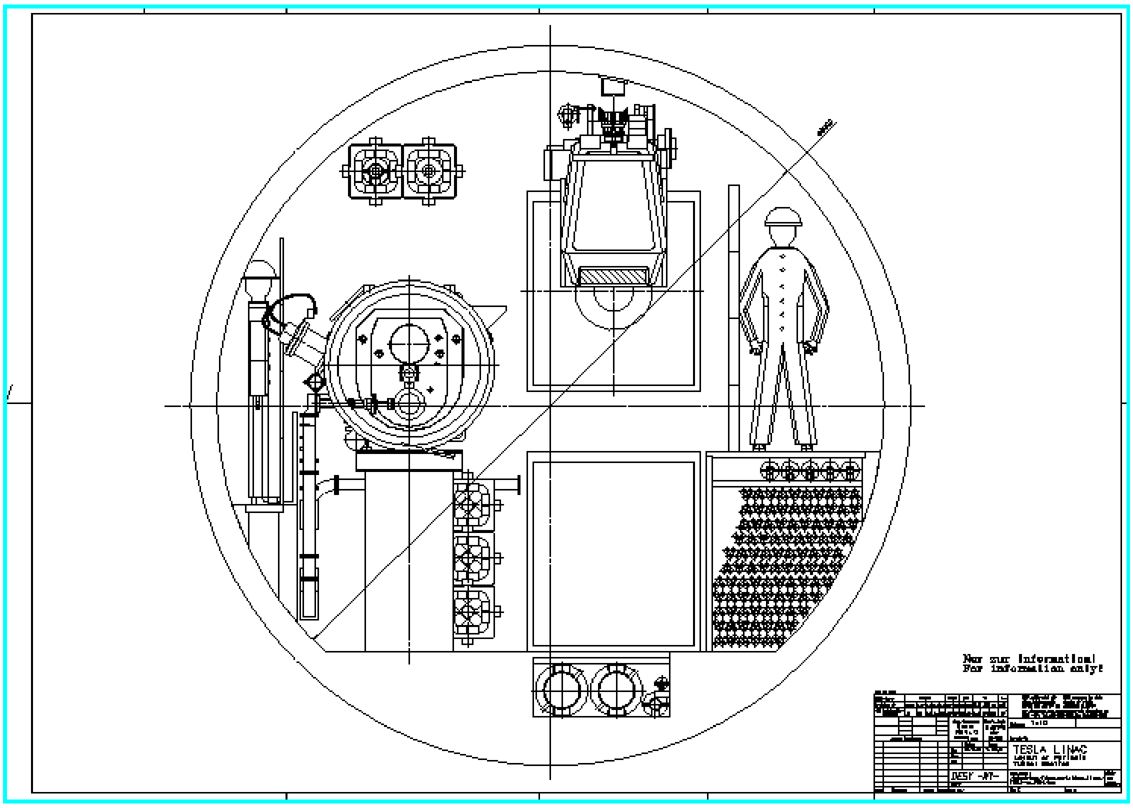


Source: http://www.desy.de/ftp/pub/w1/linac/tesla01dxf.gif

Cross section of the TESLA tunnel.

Construction Costs for the TESLA tunnel

	HERA	TESLA
Inner tunnel diameter d / m	5.2	5.2
Tunnel length L / km	6.236	33
Normalized price P / DM / m	12 300[*]	20 000
Price index P_{2000} / P_{1981}	1.6[**]	
Scaling law: P / DM / m = 8 500 + 2 500 d / m		

[*] The tunnel construction costs of HERA were 76.3 Mill. DM with the purchasing power of January 1, 1981. In the HERA-Proposal the cost estimate of the tunnel construction was 92.5 Mill. DM. The total cost estimate was 654 Mill. DM.

[**] Statistisches Bundesamt.

4 Project Cost Estimate and Schedule

The costs for the TESLA project are given separately for the 500 GeV electron–positron linear collider, the X-ray Free Electron Laser (incremental cost for accelerator, beam delivery and the X–ray laboratory), and one detector for particle physics. All costs are given in Euro and in year 2000 prices.

4.1 The Linear Collider

The cost for the 500 GeV linear collider baseline design with one interaction region is

- 3136 million EUR.

The cost for the major subsystems is detailed in Fig. 4.1.1, Fig. 4.1.2 and table 4.1.1.

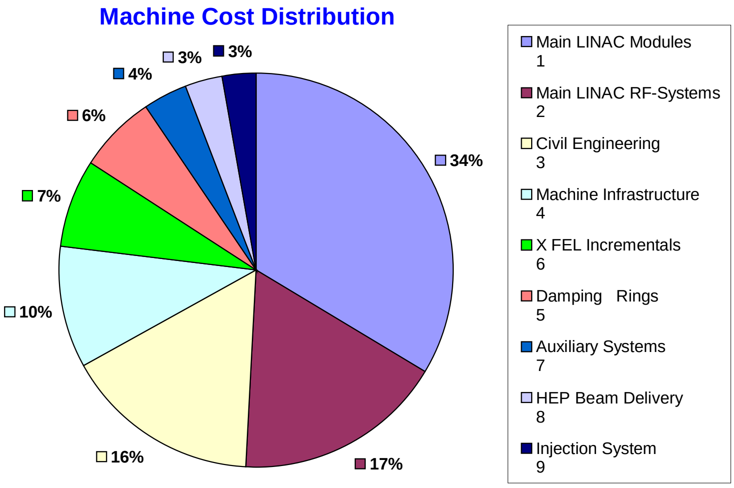
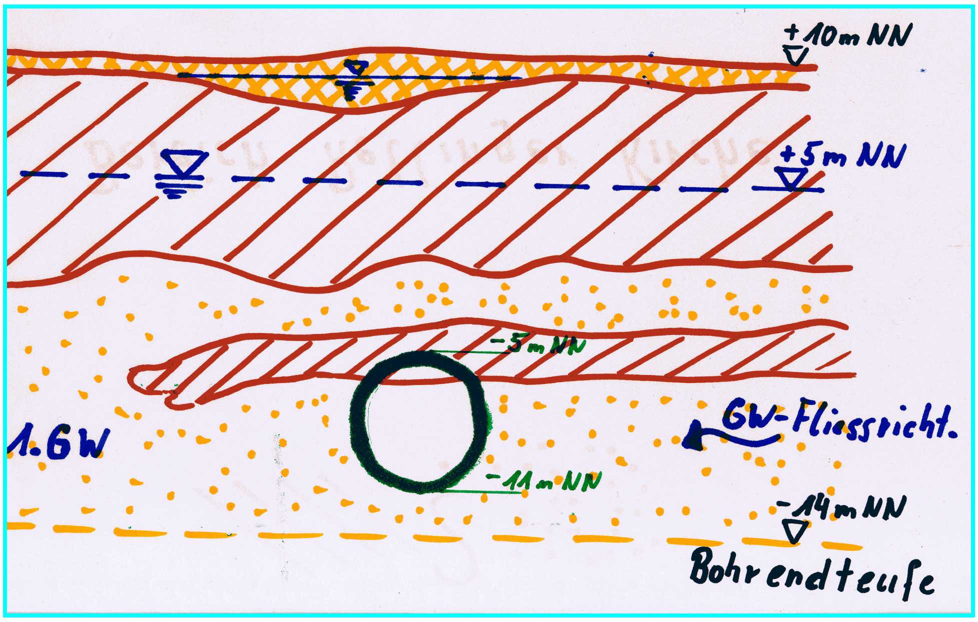


Figure 4.1.1: *Distribution of the accelerator sub–systems in percent of the total cost. The costs of the X–ray FEL laboratory and the detector for particle physics are not included here.*

Radiation safety of the tunnel



Position of TESLA tunnel and typical geological properties.

Assumption for a beam loss:

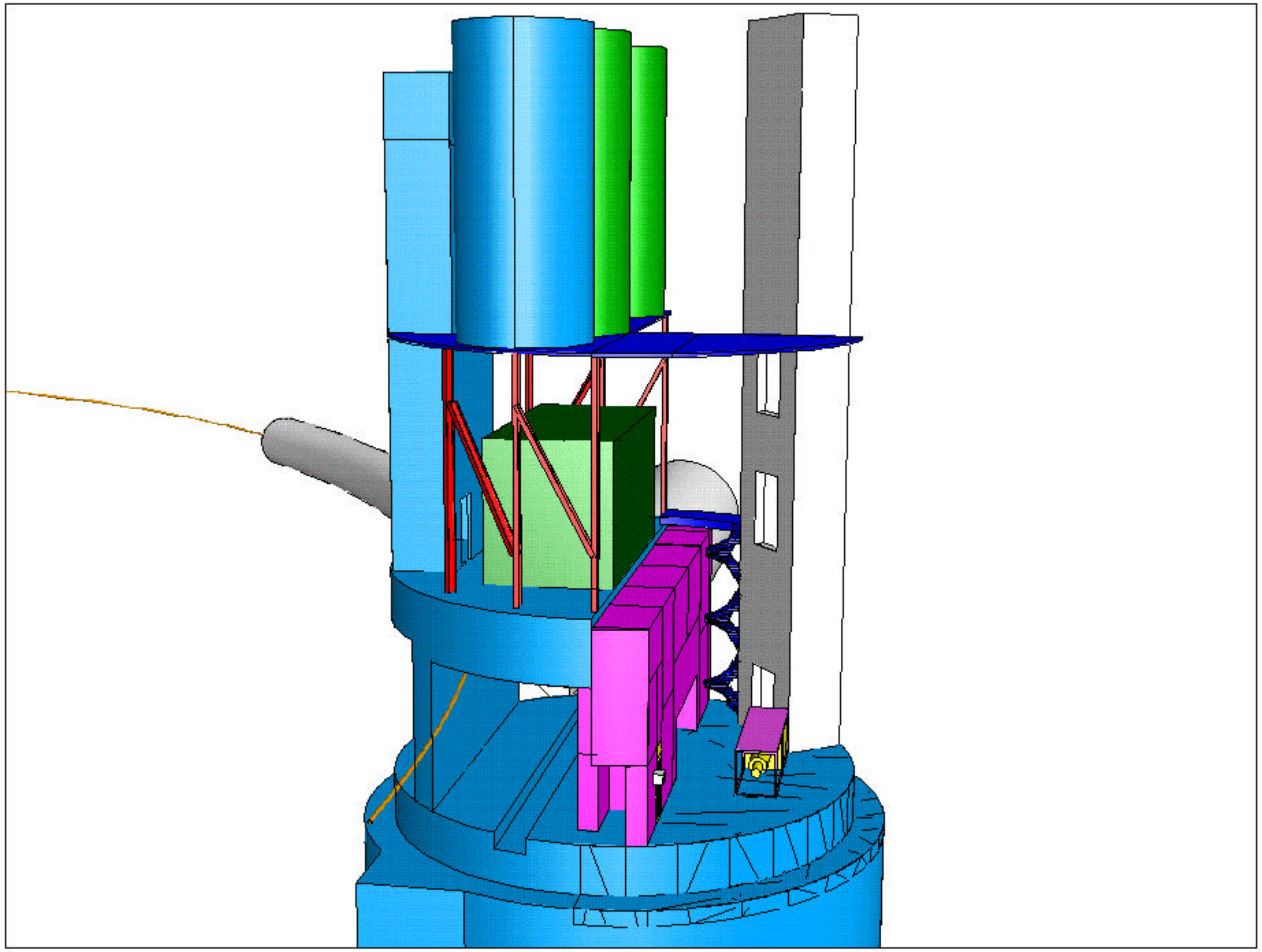
Linear loss of 100 W/m (The average cooling power is 3 W/m!).
During 100 h per year.

This is a relative loss power of 0.1 % at 125 GeV over 56 m!

For these assumptions one can calculate the doses per year on ground:

	Distance between tunnel and ground in m	Doses per year in µSv
Minimal covering	8.0	0.6
Average covering	14.0	$5\ 10^{-6} = 0$
Natural radiation dose		1 000 to 2 000

A power loss of 0.1 W/m over 5000 h/year leads to a value of a factor of 20 less.



View into a TESLA shaft.

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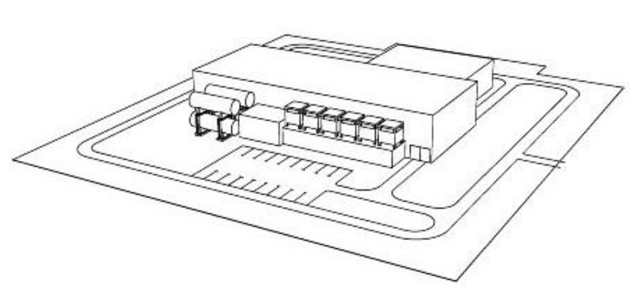
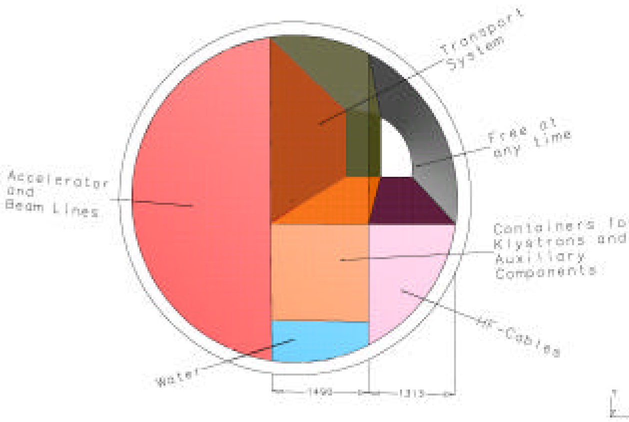
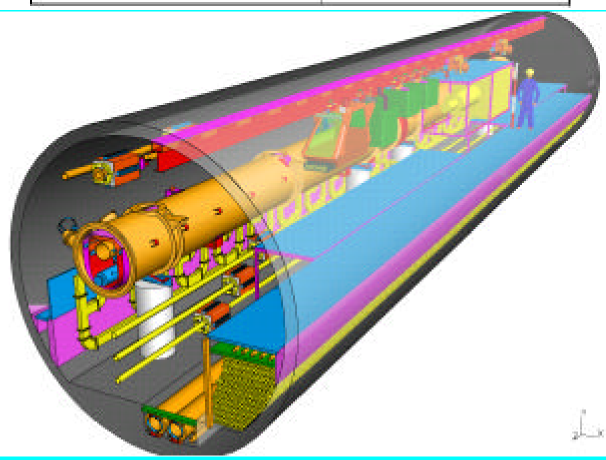


Tunnel			
DESY 0.0	[illegible]	4.8	4.4 MW
	[illegible]	58.8	51.8 m³/h
	[illegible]	78.0	77.4 m³/h
Halstenbek-Süd 5.0	[illegible]	4.8	4.4 MW
	[illegible]	58.8	51.8 m³/h
	[illegible]	78.0	77.4 m³/h
Halstenbek-Nord 7.5	[illegible]	9.6	MW
	[illegible]	117.6	m³/h
	[illegible]	156.0	m³/h
Borstel 12.5	[illegible]	9.6	MW
	[illegible]	117.6	m³/h
	[illegible]	156.0	m³/h
Ellerhoop 16.5	[illegible]	282.6	48.7 m³/h
Bevern 20.5	[illegible]	9.6	MW
	[illegible]	117.6	m³/h
	[illegible]	156.0	m³/h
Voßloch 25.5	[illegible]	9.6	MW
	[illegible]	117.6	m³/h
	[illegible]	156.0	m³/h
Bokelseß 30.5	[illegible]	9.6	MW
	[illegible]	117.6	m³/h
	[illegible]	156.0	m³/h
Westerhorn 33.0			





Cooling and tunnel ventilation considerations.

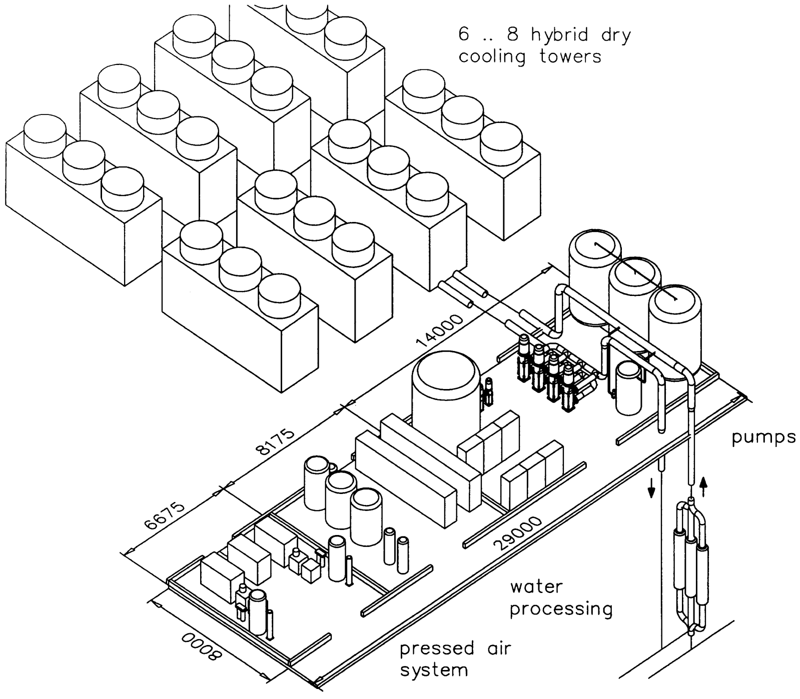


Figure 8.5.1: *Sketch of the cooling station for one service hall.*

keeps the pressure of the return pipe as low as required by some of the RF system components. The diameter of the tubes, installed on the tunnel floor (figure 8.5.4), is 200 mm over the whole length of the linac tunnel. For operation at 500 GeV the pressure in the supply water pipe is approximately 7.5 bar and goes up to 10 bar at 800 GeV.

The temperature of the return water is 70 °C . Therefore the return water tube will be insulated with mineral wool of 70 mm thickness, which reduces the heat loss into the tunnel to about 30 W/m. To minimise the mechanical stress in the tubes due to thermal expansion there are compensators in the tubes. Every six metres is a sliding support and between pairs of compensators a fixed support. The last or direct connections to all elements (e.g. magnets, klystrons etc.) are done by EPDM-rubber tubes. The advantages are: resistance against radiation, high flexibility for the connections, quick installation, direct connection between elements at high electrical potential and grounded tubes.

8.5.2 Air conditioning

A ventilation and exhaust system is foreseen for each of the 9 halls along the TESLA site (two end stations, 6 service halls, central site), see figure 8.5.5. Each of the tunnel sections between two halls is operated independently and with 100 % fresh air (no recycling). It is also possible to bypass a hall and feed the air from one tunnel sec-

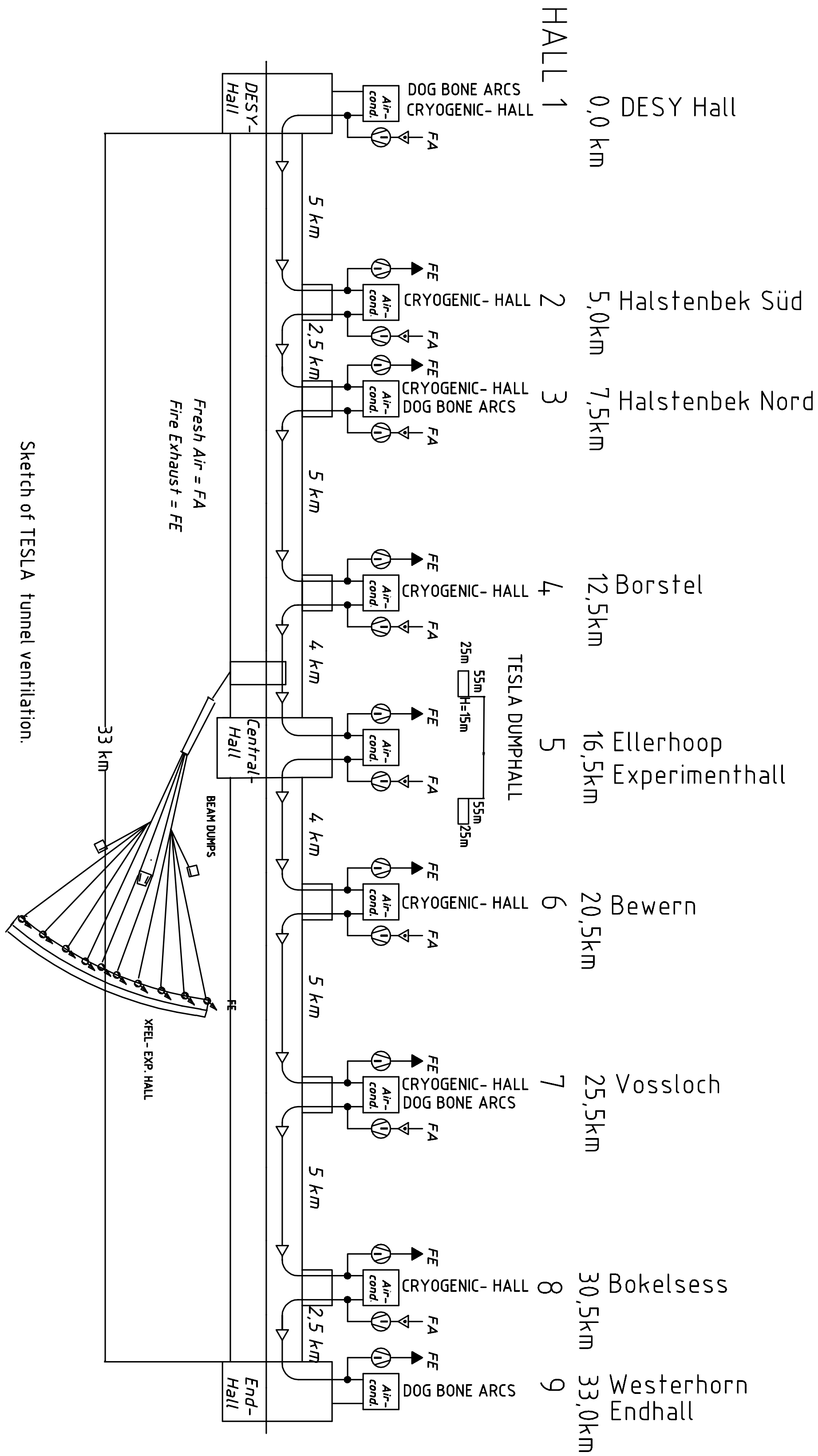
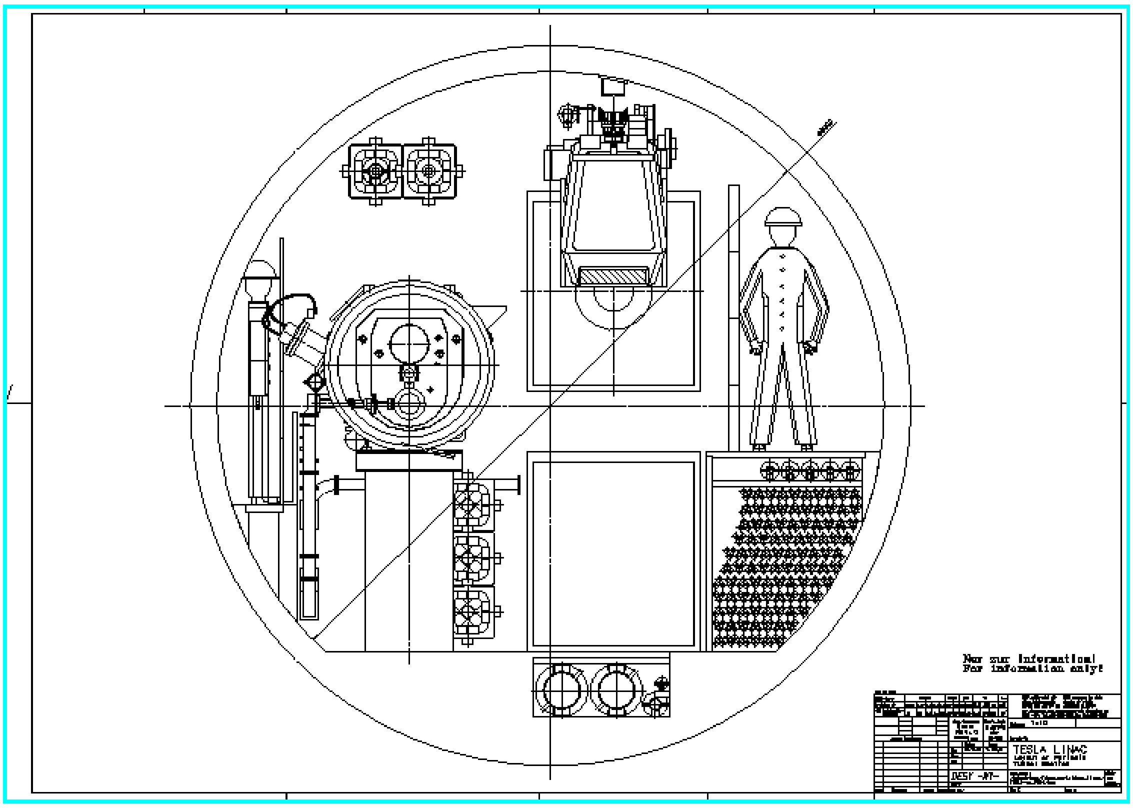


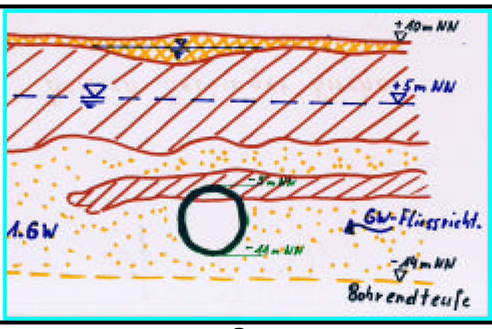
Figure 8.5.5: *Overview of the ventilation system.*



Source: http://www.desy.de/ftp/pub/w1/linac/tesla01dxf.gif

Cross section of the TESLA tunnel.

Heat properties of air and concrete

	Air	Concrete
Density / kg / m^3	1.128	2 300
Heat capacity c_p / kJ/kg K	1.01	
Heat conductivity W / K m		1.0
Velocity of air v / m / s	0.5	
Heat transport / W / K m @ 5 km	2.2	52.3

Temperature stabilization of a tunnel in an aquifer is much easier than of an tunnel in dry bedrock.

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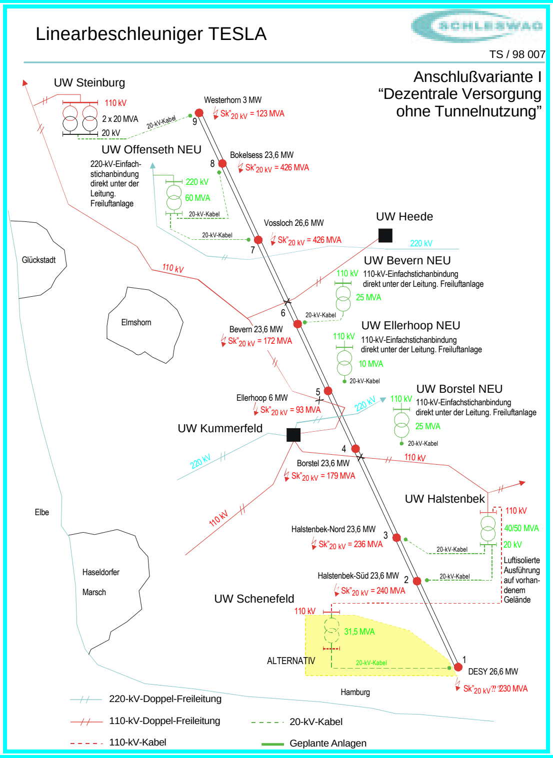
		TESLA	Superstuctur	FEL	Superstructure	
Center of mass energy	E_{cm}	500	500	50	50	GeV
Radio frequency	ν_{rf}	1.3	1.3	1.3	1.3	GHz
Accelerating gradient	E	24.60	21.50	14.76	12.90	MeV/m
Maximum accelerating gradient	$\hat{E}$	25.00	25.00	18.00	18.00	MeV/m
Number of cells	n	9	7	9	7	
Empty cells between cavity	n'	3	1			
Empty cells between modules	n''	3	2			
Number of cavities per module	$n_{cy/mod}$	8	12			
Number of modules	n_{mod}	2448	2400			
Active cavity length	L	1.038	0.807	1.038	0.807	m
Normalized shunt impedance	R_S / Q_0	1036	735	1036	735	Ω
Quality factor	Q_0	0.5	0.5	0.5	0.5	10^{10}
Matched external quality factor	Q_E	3.00	2.48	1.36	1.31	10^6
External quality factor	Q_{ext}	3.00	2.48	3.00	2.48	10^6
Dynamic heat load @ 2 K	P_{dyn}	0.87	0.58	0.35	0.23	W
Helium mass flow @ 2 K	$\dot{m}_{2K}$	0.038	0.025	0.015	0.010	g/s
Rise time	τ_{cav}	764.63	607.72	764.63	764.63	µs
Filling time	T_0	530.00	421.24	286.82	323.54	µs
Rf pulse length	τ_{rf}	1328.98	1371.03	1331.19	1367.91	µs
Repetition rate	ν_{rep}	5	5	5	5	Hz
Number of bunches	n_b	1130	2820	11315	11315	
Charge per bunch	N_e	3.630	2.000	0.624	0.624	10^{10}
Average current	$\langle I \rangle$	32.86	45.18	56.58	56.58	µA
Bunch spacing	τ_b	707.69	336.92	92.31	92.31	ns
Bunch train length	τ_t	798.98	949.79	1044.37	1044.37	µs
Peak current	$\hat{I}$	8.22	9.51	10.83	10.83	mA
Peak rf power per cavity	$\hat{P}$	0.2098	0.1651	0.1930	0.1248	MW
Without current	$\hat{P}(I=0)$	0.0525	0.0243	0.0189	0.0087	MW
Matched rf power per cavity	$\hat{P} = N_e eE / eL / \tau_b$	0.2098	0.1651	0.1660	0.1128	MW
Number of cavities per klystron	n_{cy}	32	48	32	48	
Wave guide losses	η_{wg}	4.00	4.00	4.00	4.00	%
Peak rf power per klystron	$\hat{P}_{kl}$	6.99	8.26	6.43	6.24	MW
Maximum klystron power	$\hat{P}_{kl}$	10.00	10.00	10.00	10.00	MW
Average rf power	$\langle P_{kl} \rangle$	53.62	65.30	49.41	49.26	kW
Maximum rf power	$\langle \hat{P}_{kl} \rangle$	76.67	79.09	76.80	78.91	kW
Electronic klystron efficiency	η_{el}	70.00	70.00	70.00	70.00	%
Rise time efficiency	η_{t}	86.67	86.67	86.67	86.67	%
HV cable losses	η_{HV}	2.00	2.00	2.00	2.00	%
Total klystron efficiency	η_{kl}	59.46	59.46	59.46	59.46	%
Electronic modulator efficiency	η_{mod}	92.00	92.00	92.00	92.00	%
Power reserve	$\hat{P}/P$	1.15	1.15	1.15	1.15	
Auxiliary power	P_{aux}	4	4	4	4	kW
Number of klystrons	n_{kl}	612	600	102	100	
Total beam power	P_{beam}	16.43	22.59	2.83	2.83	MW
Total rf power	P_{rf}	57.5	68.1	8.9	8.7	MW
Maximum rf power	$\hat{P}_{rf}$	70.8	71.6	11.8	11.9	MW
Suply water temperature	T_0	30.0	30.0			°C
Temperature difference	ΔT	50.0	50.0	50.0	50.0	°C
Total cooling water	$\dot{V}_{wc}$	988.34	1170.98	152.33	148.92	m³/h
Maximum cooling water	$\hat{\dot{V}}_{wc}$	1218.58	1231.17	203.42	204.74	m³/h
Modulator losses	P_{mod}	4.78	5.71	0.73	0.72	MW
Maximum modulator losses	$\hat{P}_{mod}$	5.95	6.02	0.99	1.00	MW
Sum total rf power	P_{rf}	62.24	73.79	9.59	9.38	MW
Sum maximum total rf power	$\hat{P}_{rf}$	76.79	77.59	12.82	12.90	MW
Thomson parameter						
Klystron voltage	U_{kl}	110		110		kV
Klystron current	I_{kl}	130		130		A
Klystron power	$\langle P_{kl} \rangle$	126.50		126.71		kW
Klystron cooling water	$\dot{V}_{kl} / P_{kl}$	0.80		0.80		l/min kW
Cooling water	$\dot{V}_{wc}$	6.07		6.08		m³/h
Temperature rise	ΔT	17.92		17.92		K
Water pumps						
Cooling water	$\dot{V}_{wc}$	1050.00				m³/h
Pressure difference	Δp	12.00				bar
Pump efficiency	η_{pump}	0.70				
Motor efficiency	η_{motor}	0.85				
Motor power	P_{motor}	596.03				kW
Cryogenic plant						
Total dynamic heat load @ 2 K	P_{dyn}	17.1	16.8	1.1	1.1	kW
Helium mass flow @ 2 K	$\dot{m}_{2K}$	744.5	728.3	49.2	47.6	g/s
Conversion factor for 2 K	α_{2K}	800.0	800.0	800.0	800.0	
Safety factor	η	1.5	1.5	1.5	1.5	
Total AC power for 2 K	P_{total}	20.5	20.1	1.4	1.3	MW

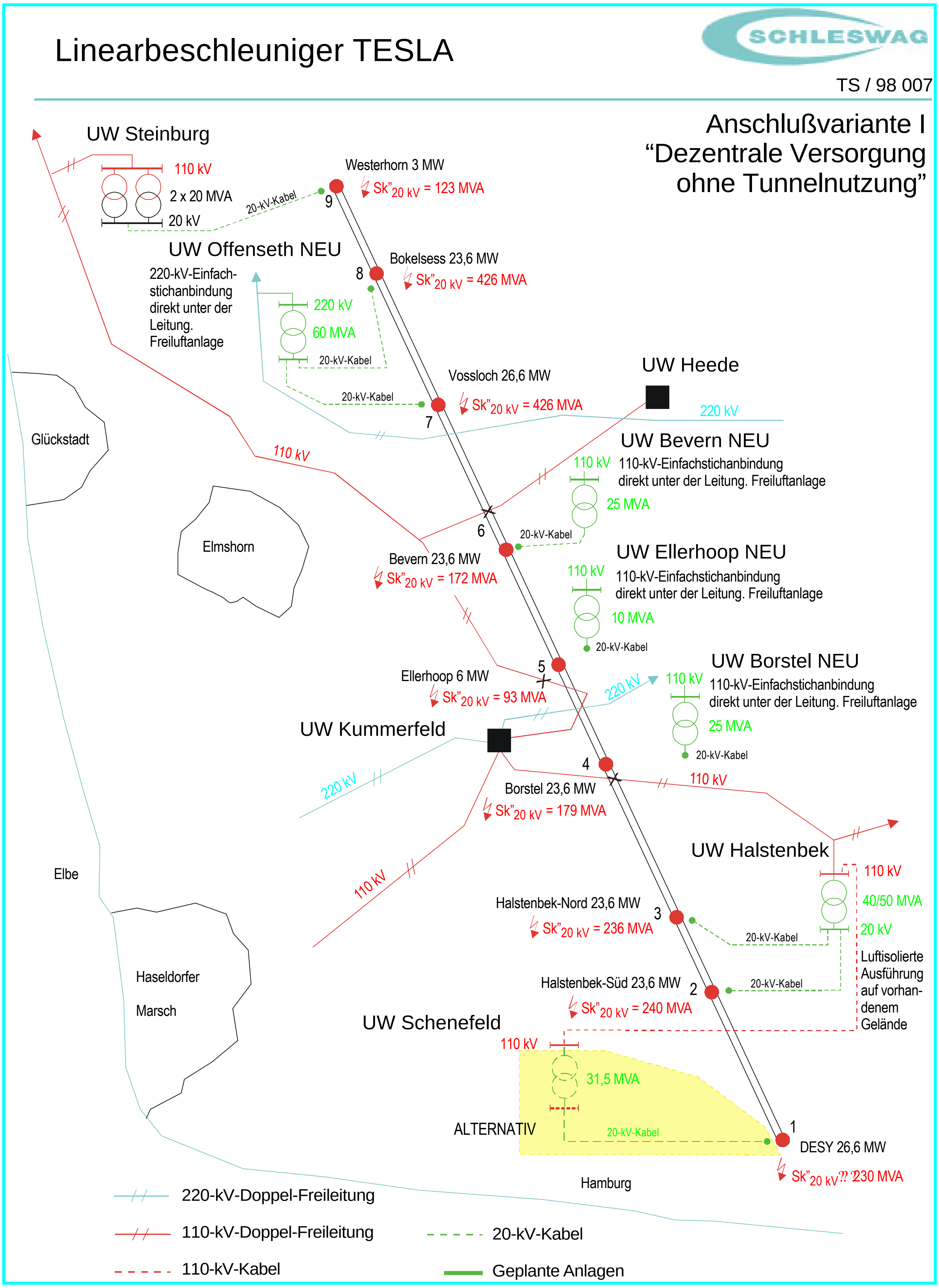


Site	Position L/km		Power S / MVA
DESY	0	Cryogenic plant 1	10.8
		Modulators	12.8
		Damping ring	6.0
Halstenbek-Süd	5	Cryogenic plant 2	10.8
		Modulators	12.8
Halstenbek-Nord	7.5	Cryogenic plant 3	10.8
		Modulators	12.8
Borstel	12.5	Cryogenic plant 4	10.8
		Modulators	12.8
Ellerhoop	16.5	Experiment	3.0
		FEL-Laboratory	3.0
Bevern	10.5	Cryogenic plant 5	10.8
		Modulators	12.8
Voßloch	25.5	Cryogenic plant 6	10.8
		Modulators	12.8
		Damping ring	6.0
Bokelseß	30.5	Cryogenic plant 7	10.8
		Modulators	12.8
Westerhorn	33	End station	3.0
		Sum	186.2

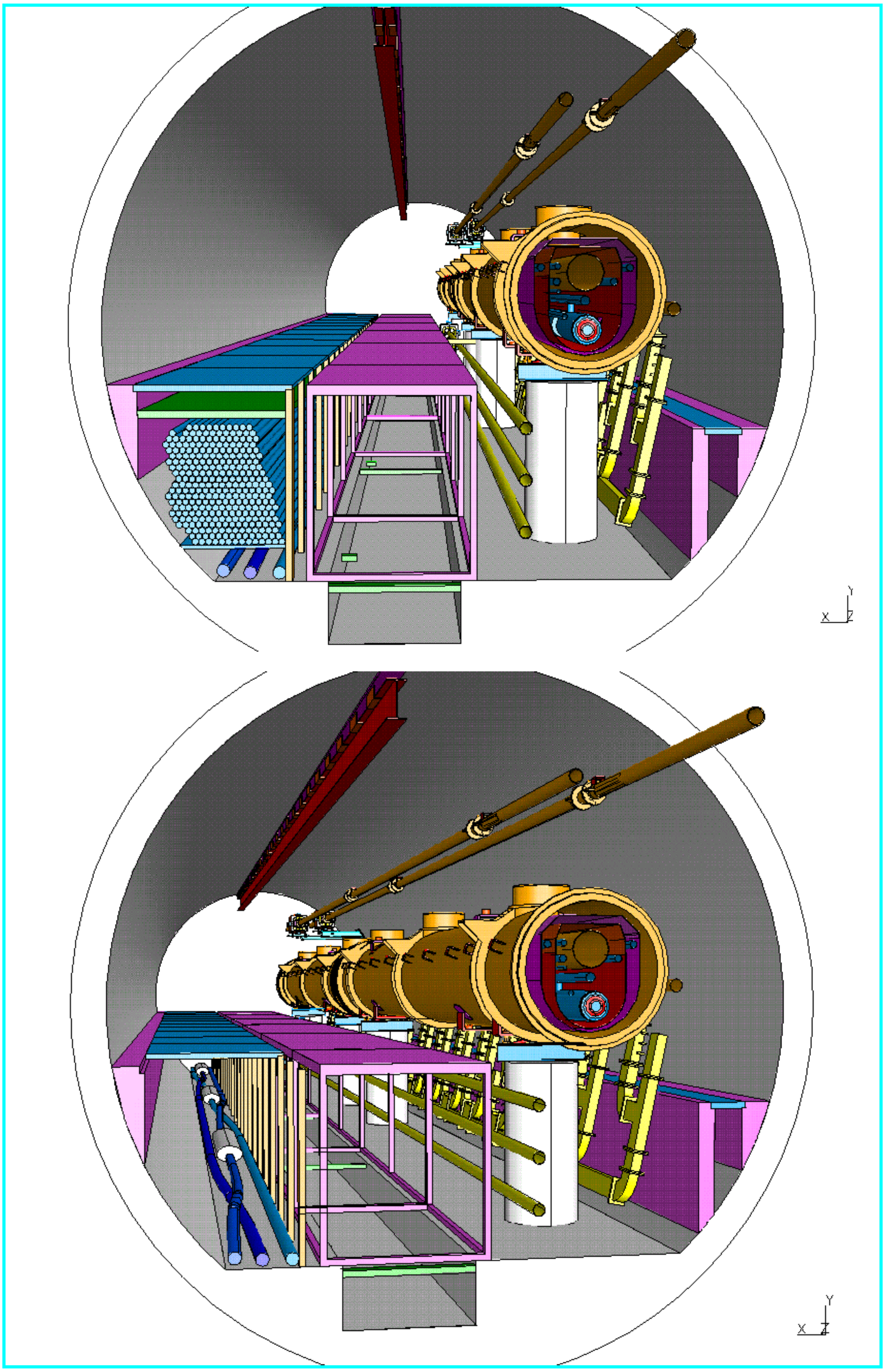
Status: TDR Workshop at Zeuthen, February 3 – 9, 2000.

Installed electrical power S for the TESLA Linear Collider.

This value includes redundancy but no reactive power (cos? ? 1) and allows for an energy upgrade. The nominal power consumption is P ? 140 MW.



External power distribution for the TESLA Linear Collider.



110 kV power cable in the TESLA tunnel.

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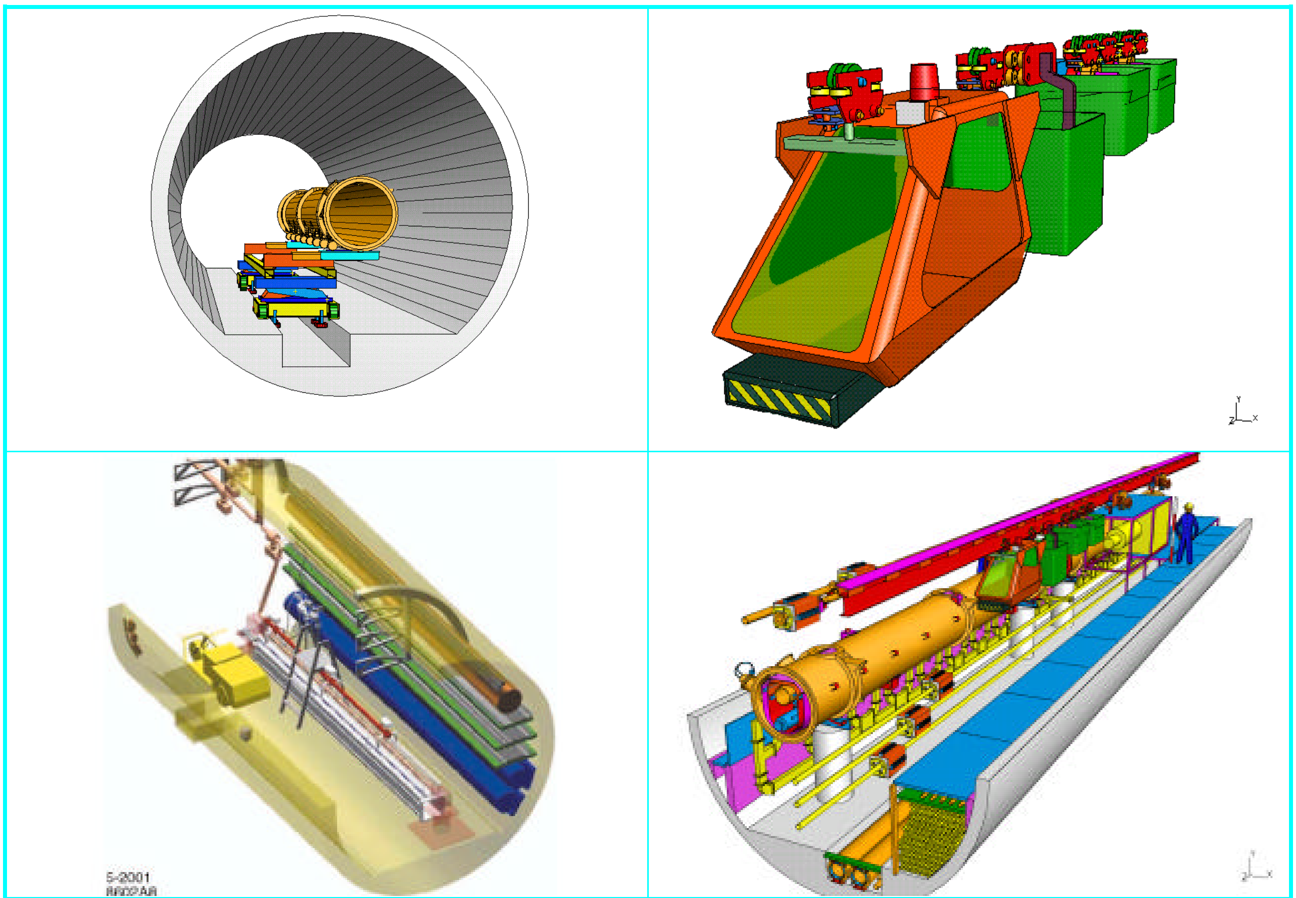
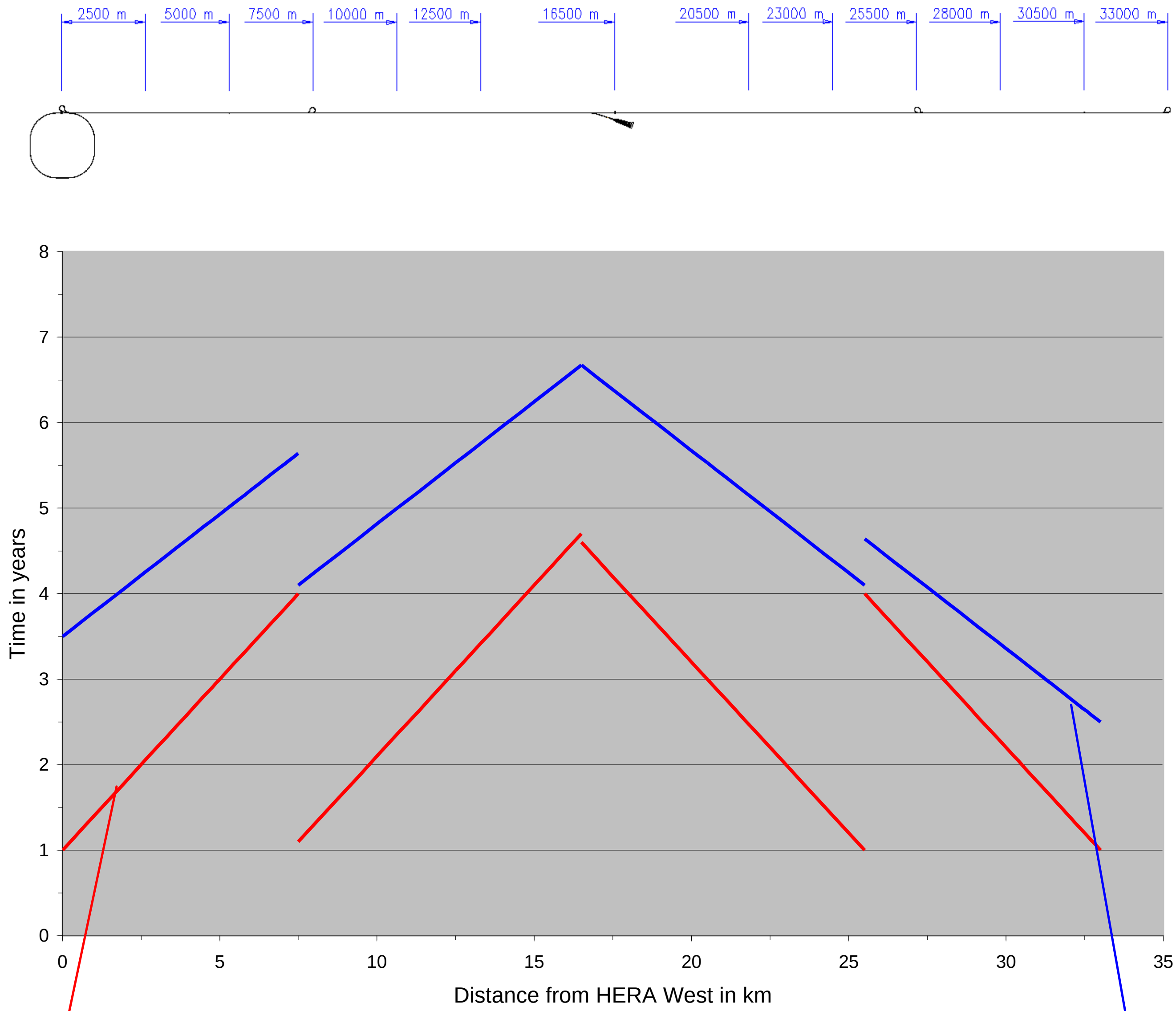


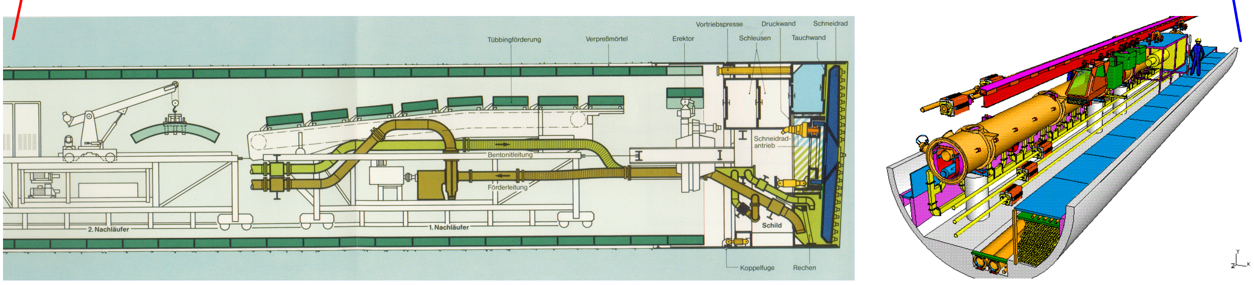
NLC Beam housing tunnel

Transport of a TESLA klystron

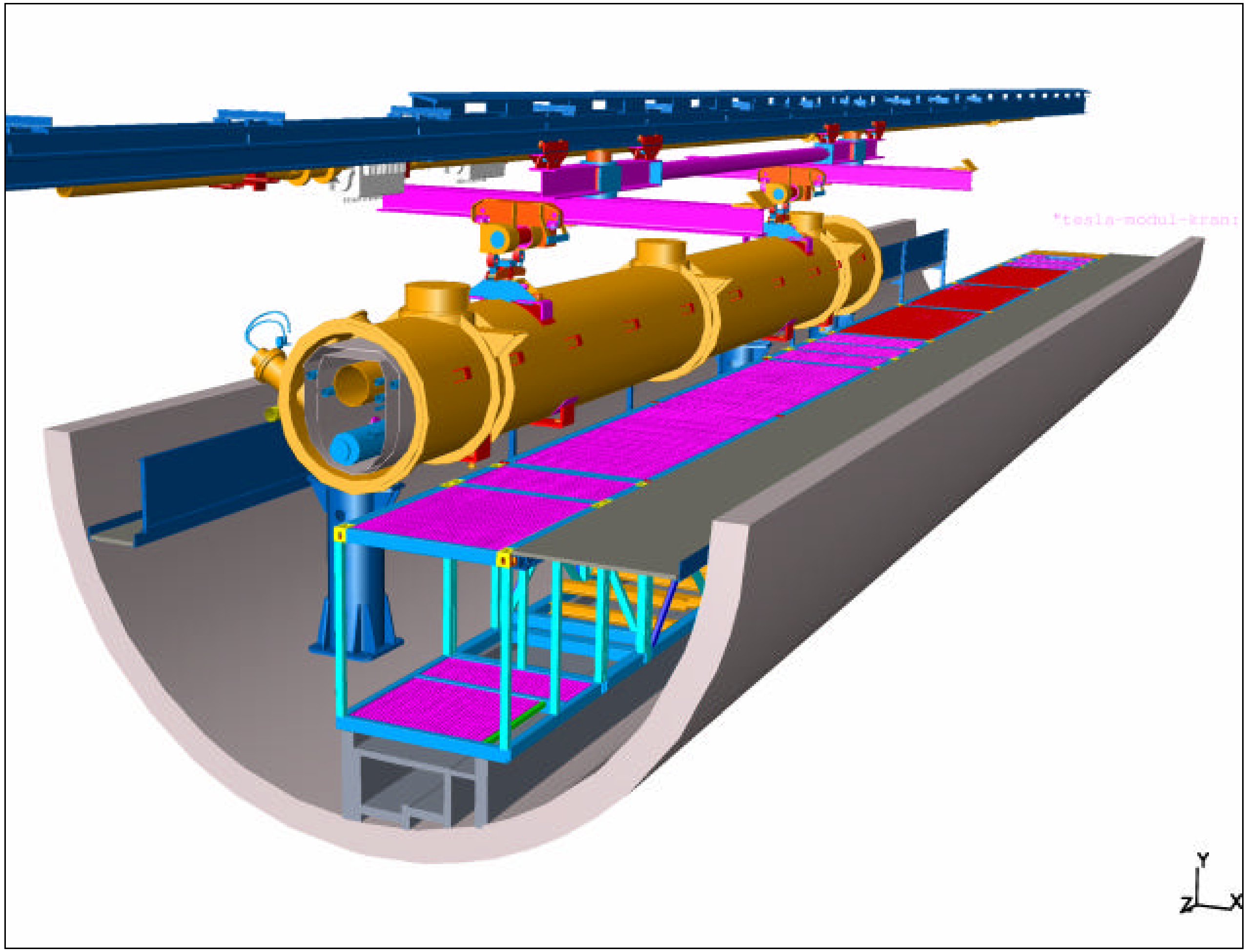
Snap shots of Linear Collider installation.



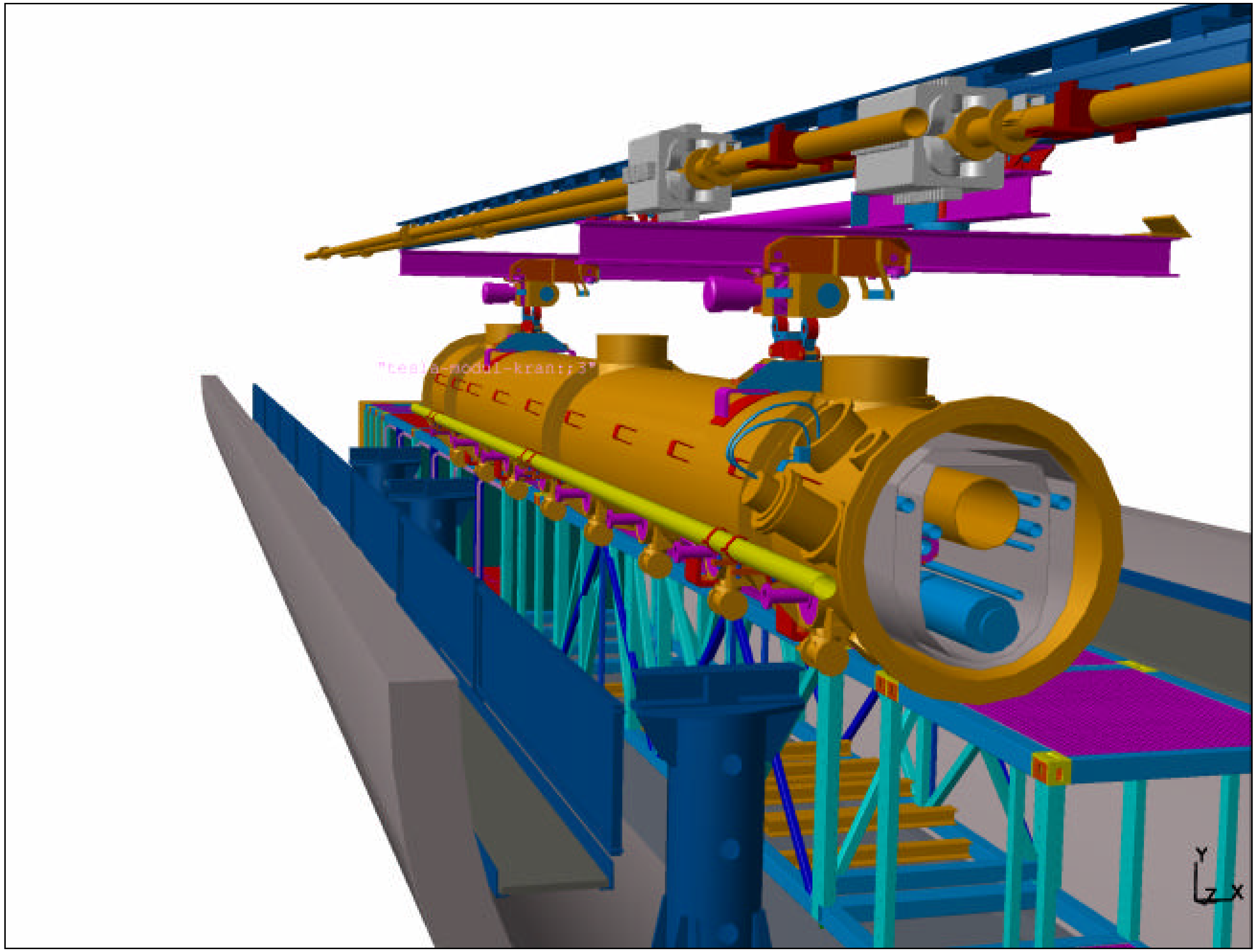
Zero order installation schema for TESLA.



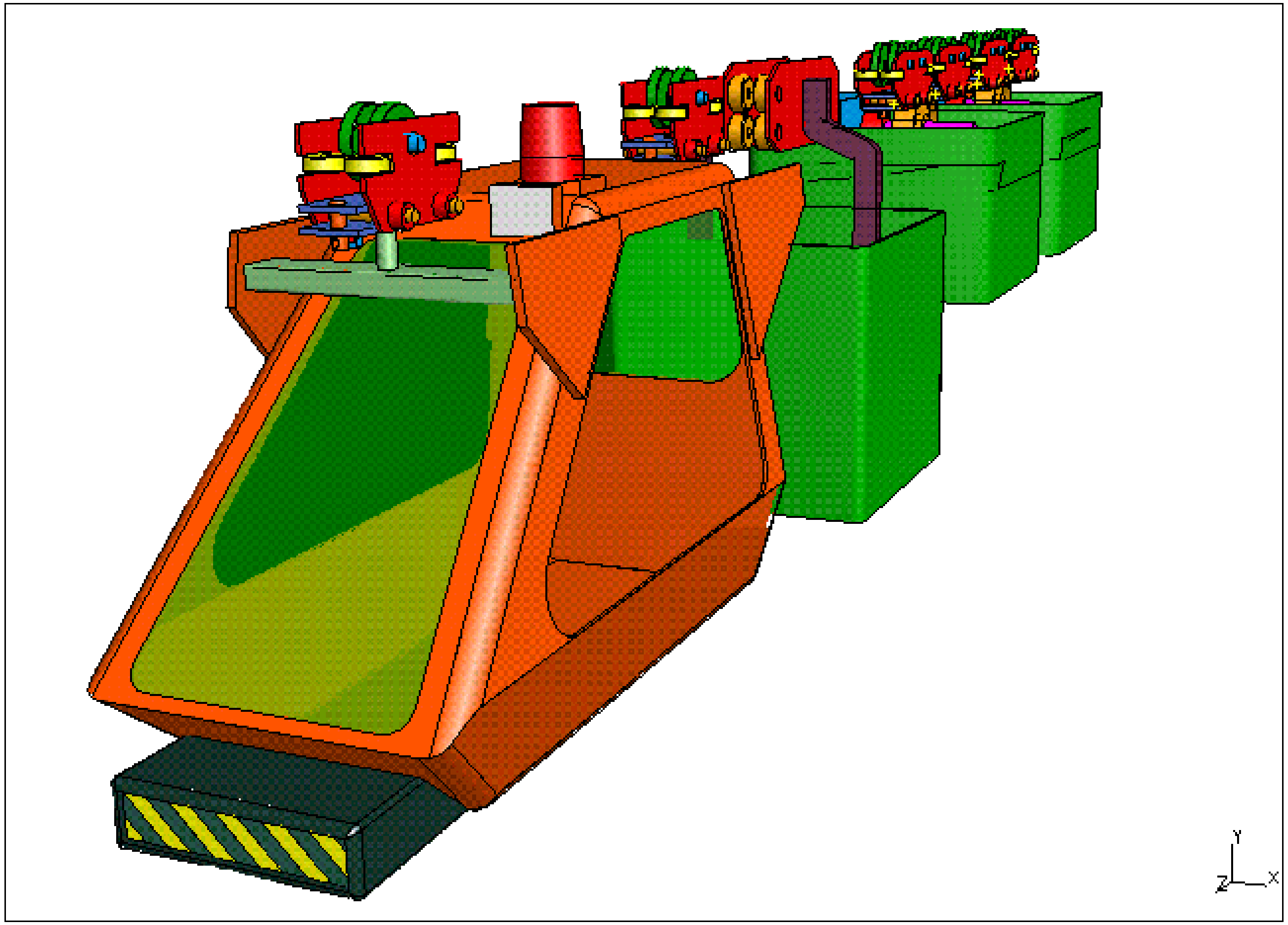
The TESLA is drilled with a tunnel boring machine similar to the HERA machine is constructed by concrete segments called tubbings. The thickness of the concrete tubbings is 30 cm and the shield diameter of the boring machine is 6 m. At HERA the boring speed was 10 m per day in average and 14 m per day in maximum. A tunnel boring machine is running around the clock, five days a week and 250 days a year. At a shaft 283 m^3 soil has to be transported per day in average. A truck can transport 15 m^3 of soil. About 20 transports per day are necessary. After two years 5 km of tunnel will be finished and the construction site moves to the next shaft. The length of the tubbings is 1.20 m. A ring consists of seven tubbings. And has a weight of 15 t. Eight trucks deliver the concrete segment from a concrete company.



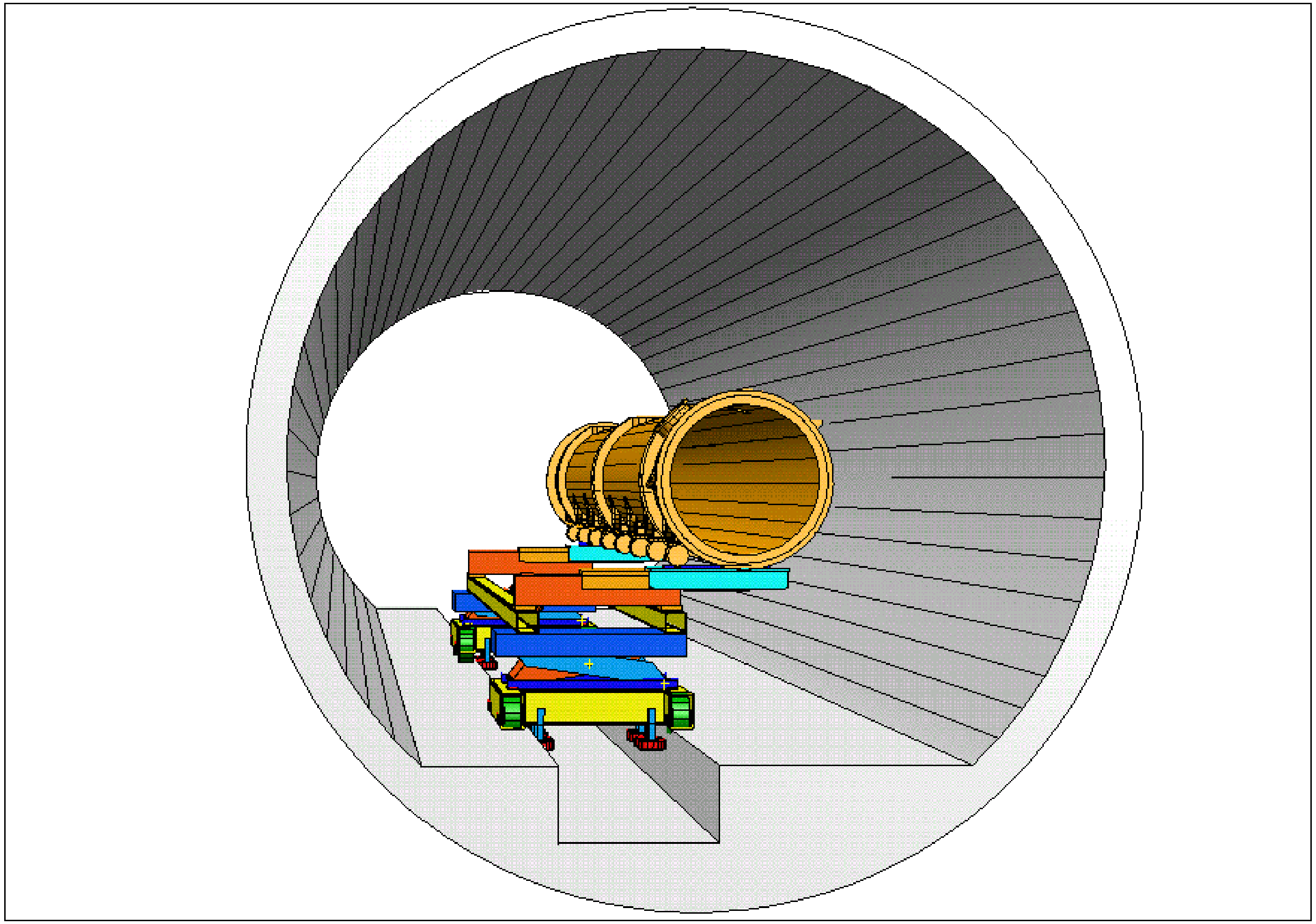
Installation of a TESLA module with a monorail crane.



Installation of a TESLA module with a monorail crane.



Monorail for TESLA.



Installation vehicle for TESLA.

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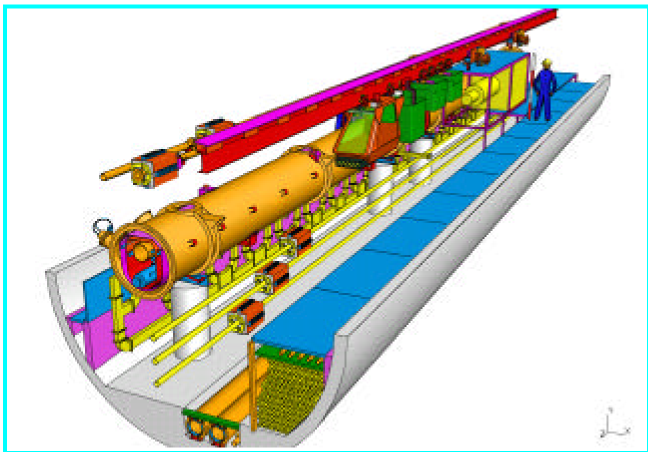

Vincent van Gogh: Das Schlafzimmer in Arles, Rijksmuseum Vincent van Gogh, Amsterdam

Mein lieber Theo,

ich schicke Dir hier eine kleine Zeichnung, um Dir einen Begriff von meiner derzeitigen Arbeit zu geben. Heute habe ich sie wieder aufgenommen. Diesmal ist es ganz einfach mein Schlafzimmer. Nur die Farbe muss hier die Wirkung erzielen und durch ihre Vereinfachung den Dingen einen größeren Stil und die allgemeine Suggestion der Ruhe und des Schlafes geben. Kurz, der Anblick des Bildes soll den Kopf oder vielmehr die Phantasie beruhigen. Die Wände sind von einem hellen violett. Der Fußboden hat rote Fliesen. Das Holzbett und die Stühle sind gelb wie frische Butter. Das Laken und die Kopfkissen hellgrün wie eine Zitrone. Die Bettdecke scharlachrot. Das Fenster grün. Der Waschtisch orange. Die Waschkanne blau. Die Türen lila. Und das ist alles. Sonst nichts in diesem Zimmer mit geschlossenen Läden. Die eckigen Möbel müssen eine unerschütterliche Ruhe ausstrahlen. Portraits an der Wand und ein Spiegel und ein Handtuch und ein paar Kleidungsstücke. Der Rahmen soll weiß ein, weil es sonst nichts Weißes in diesem Bild gibt. Ich werde morgen noch den ganzen Tag daran arbeiten. Aber Du siehst, wie einfach die Konzeption ist. Schatten und Schlagschatten sind unterdrückt. Die Farben flach und kühn aufgetragen wie bei japanischen Krepons. Ich schreibe Dir nur kurz, weil ich gleich morgen im Frühlicht mit der Fertigstellung meines Bildes beginnen will. Ich drücke Dir fest die Hand.
Ganz der Deine
Vincent

The high art of yellow (Die hohe Kunst des Gelben).

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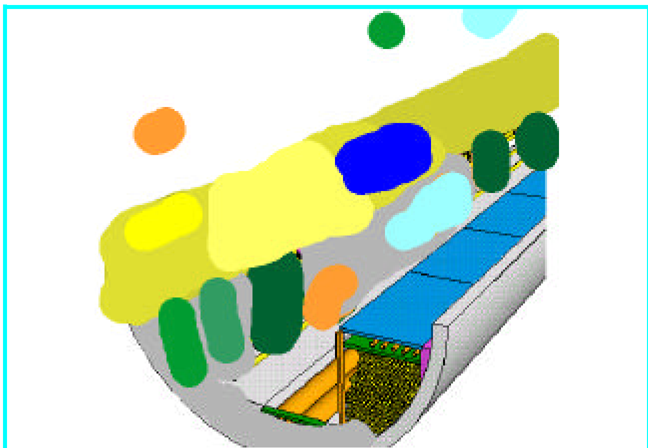

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