<u>Basic Assumptions for the TESLA TDR</u>

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This note summarizes the basic layout and parameters of TESLA for the TDR. It is meant as a guideline for everybody involved in the preparation of the report. The assumptions made are according to the present status of discussions ongoing in the working groups.

last change: use of compressed 9-cell cavity module layout instead of superstructure for 500 GeV baseline design (used for cost estimate). The discussion of the ultimate energy reach of the machine (800 GeV) includes the superstructure concept (2×9-cell version) and an active Lorentz-force detuning compensation.

1. Overall layout

The exact longitudinal position of the e+e- IP and the corresponding lengths of the two halves of the machine have been determined, taking into account the asymmetries which are due to the FEL extraction lines, the pre-linac and the positron source. The southern half of the accelerator turns out to be 700m longer than the northern part (see Fig. 1). The assumptions on the different system lengths (as shown in the figure) are listed in Table 1.

	Length [m]
total site	32,800
main linac 5-->250 GeV	14,400
Beam Delivery System (includes separation for 2nd IP)	1,650
Positron source wiggler	100
FEL extraction 25 GeV	50
FEL extraction 50 GeV	100
5 GeV e^- pre-linac & bunch compressor	450
Position of IP (from starting point HERA-West)	16,750

Table 1: Summary of TESLA linac lengths

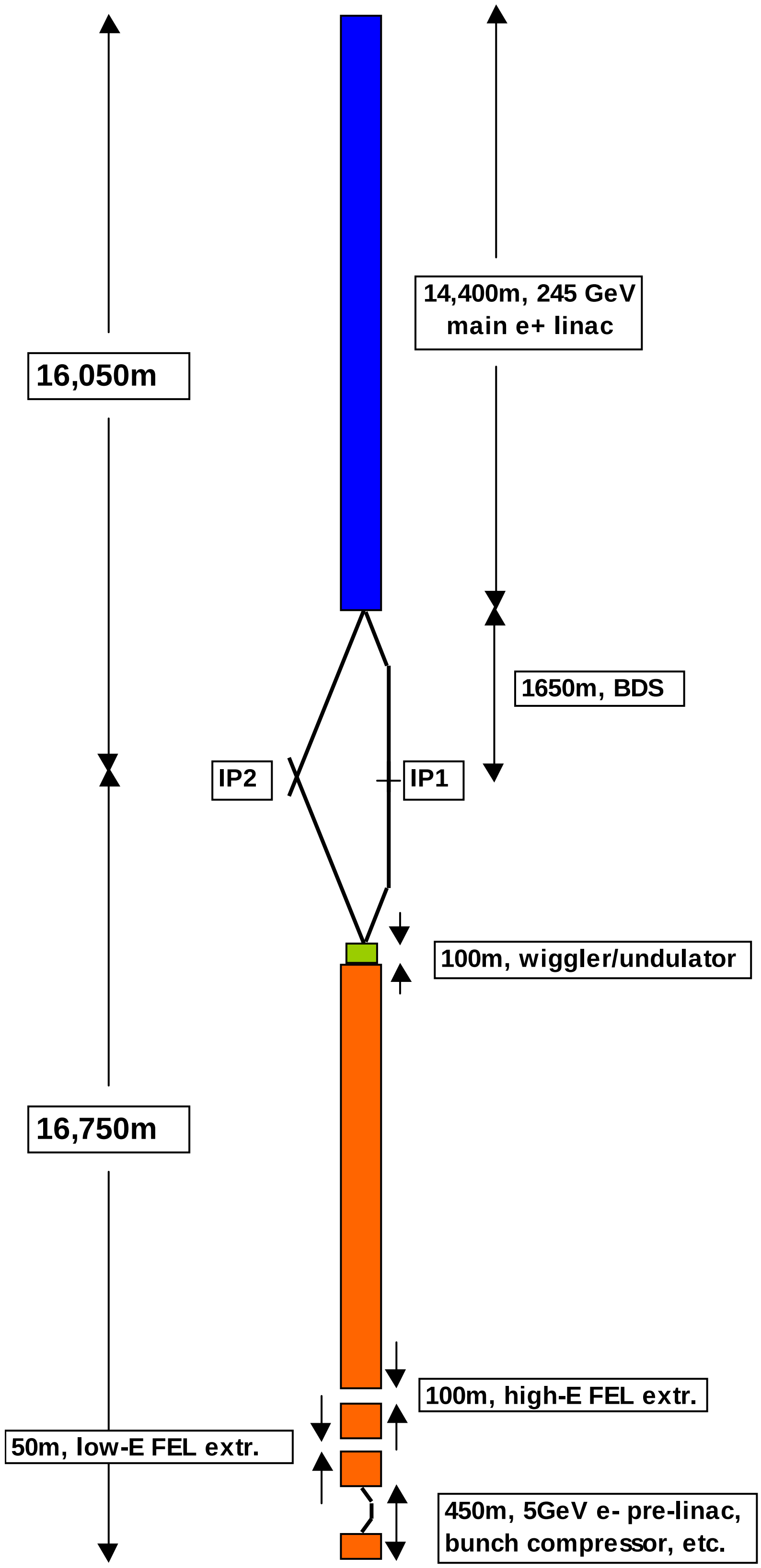

Fig. 1: Site, linac and subsystem lengths

2. Main Linac Components

Based on the most recent discussions in the Module-WG, an increased accelerator module length close to 16m is assumed. This reduces space for inter-connections and is a credible concept (concerning transport, installation,…) in view of the ~15m long LHC dipole magnets. A module accommodates 12 9-cell cavities with reduced (w.r.t. TTF) inter-cavity spacing. This is our reference concept for the TDR cost estimate, alternative versions based on superstructures will also be discussed in the TDR as way for further cost saving and increase of the energy reach.
The exact module length seems to converge towards the numbers quoted in the table below. Uncertainties of a few centimeters can be ignored at this stage. Modules with quadrupoles are assumed to be 0.82m longer than the ones without quad. The beam optics in the main linac are 60 deg. FODO cells with 4 modules per cell in the 1st and 6 modules per cell in the 2nd half of the linac. A summary of main linac components is given in Table 2. We include a 2% overhead for energy management (klystron failure) in the specified accelerating gradient.

module length	16.31m
add. length per quad	0.82m
# modules p. linac	858
# of quads p. linac	358
total length for modules p. linac	14,286m
remaining space p. linac	104m
# 9-cell cavities p. module	12
# 9-cell cavities p. linac	10,296
active length p. linac	10,666m
accelerating gradient	23.4 MV/m
energy gain p. linac	245 GeV + 2% reserve
# modules p. klystron	3
# cavities p. klystron	36
# klystrons p. linac	286

Table 2: Main linac components

3. Beam- and RF-power parameters

I discuss here first the 500 GeV case, the energy upgrade is added at the end of this note. All relevant parameters are listed in Table 3. A few comments: the RF-power overhead for compensation of Lorentz-Force detuning has been estimated at 10% (S. Simrock). The required peak klystron output power including regulation reserve must still be (slightly) below saturation, which means that the klystron efficiency will be around 65% rather than 70%. For the required modulator power, this aspect and the HV cable losses must be taken into account. For the determination of the total AC power for RF-generation, the 2% energy reserve has to be subtracted, i.e. we have 280 active RF-stations, not 286! I'm ignoring here the 1.6% e- energy loss for positron production, but this will have to be mentioned in the report.

beam current	9.5 mA
beam pulse length	0.95 ms
energy gain p. cavity	24.3 MeV
power-to-beam p. cavity	231 kW
power p. coupler including reg. reserve	254 kW
waveguide and circulator losses	4%
required klystron peak RF-power	9.5 MW
loaded Q_{ext}	$2.5 \cdot 10^6$
RF pulse length	1.37 ms
repetition rate	5 Hz

Table 3: Assumptions on beam- and RF-power at 500 GeV

To get an idea of total power consumption for RF-generation I assume an overall modulator AC-to-HV pulse efficiency of 80% (including the cables and pulse transformer) and a klystron efficiency of 65%. That adds up to ~36 MW AC power per main linac, to which the AC power of the cryo plants (12 MW) has to be added as well as power for auxiliary systems (klystron focusing etc.). The total AC-power for two main linacs (not including the FEL operation) amounts to 98MW, assuming 4kW per klystron solenoid. This number is traditionally quoted for the different LC designs and should therefore. also show up in our parameter table. I also recommend to quote the expected total operation power for the site, including all sub-systems. This still needs to be determined.

4. Beam parameters and luminosity

The high-luminosity parameters, which have been the reference for our design work since autumn 1997, exploit the full potential of the TESLA concept with its very small emittance dilution in the linac. In the competitive environment in which we are it is important that this high performance potential is clearly visible in the TDR. At the same time, the conservative alignment tolerances in the linac (0.5mm rms for cavities) should not be compromised. The present status of the studies regarding the small beam emittance/high luminosity can be summarized as follows.

The space charge limitation on the beam emittance in the damping ring can be removed or at least significantly relaxed by increasing the energy 3.2-->5 GeV and introducing a betatron coupling bump in the straight sections. Simulation studies with space charge have been completed and show that we are now well below the tune shift limit.

The large beam-beam disruption parameter (D_y = 33 instead of 17 in the CDR) makes the luminosity very sensitive to relative offsets of the colliding beams in vertical orbit or angle due to the so-called kink instability. Beam stabilisation at a level of one tenth of a sigma in orbit and angle is provided by the fast intra-bunchtrain feedback system. This limits the luminosity reduction to less than 10%, which is fine. The emittance growth in the linac, according to simulations, is also acceptable at about 20%. However, there is a potential problem in context with the kink instability which tends to amplify any internal bunch deformation during collision. Thus an emittance growth which is correlated ("banana" shape of the bunch due to transverse wakefields) has a stronger impact on luminosity reduction than an incoherent emittance dilution. Furthermore, the banana effect can spoil the convergence of the fast feedback towards optimum luminosity. These effects are presently under study. Also, the fraction of correlated emittance growth in the linac (part of the 20% dilution is filamented or uncorrelated in the first place, like the chromatic dilution from incoherent energy spread) is being determined. From what we know now, a drastic parameter change towards smaller lumi and D_y does not seem to be justified. The only suggested change is to reduce the bunch length from 0.4 to 0.3 mm. This has three beneficial effects:

- nominal luminosity is higher by about 8% (reduction of hourglass effect)
- disruption goes down to D_y = 25
- transverse wakefield in the linac is smaller

On the negative side we have an increase in beamstrahlung energy loss from 2.8% to 3.3%, which must be discussed with colleagues in the ECFA-DESY study, but at first sight does not seem to be a problem. A solution for the bunch compressor to reduce σ_z is available. The incoherent energy spread at injection into the main linac goes up from about 1.6% to around 2.2…2.5%. The increase in chromatic dilution should be acceptable since it concerns the "harmless" incoherent emittance growth.

The resulting parameter list, which we should use in the TDR unless further beam dynamic studies force us to make a change, is shown in Table 4.

	TESLA CDR	**TESLA TDR**
t_{pulse} [μs]	800	**950**
# bunches n_b/pulse	1130	**2820**
bunch spacing Δt_b [ns]	708	**337**
rep. rate f_{rep} [Hz]	5	**5**
N_e/bunch [10^{10}]	3.6	**2**
ε_x / ε_y (@ IP) [10^{-6}m]	14 / 0.25	**10 / 0.03**
beta at IP $\beta_{x/y}^*$ [mm]	25 / 0.7	**15 / 0.4**
spot size σ_x^*/σ_y^* [nm]	845 / 19	**553 / 5**
bunch length σ_z [mm]	0.7	**0.3**
beamstrahlung δ_B [%]	2.5	**3.3**
Disruption D_y	17	**25**
lumin. L [10^{34} $cm^{-2}s^{-1}$]	0.68	**3.4**

Table 4: Updated parameters at E_{cm}=500GeV for the TDR. The original parameters used in the CDR are shown for comparison.

5. Operation at lower and higher energies

The variability of the center-of-mass energy is an important aspect for the Physics potential of TESLA. We assume for the TDR that an upper limit is set at a usable accelerating gradient of 35 MV/m. In contrast to the TDR, the path to higher gradients is now more clearly defined with the recent results on electropolished cavities. Still, the energy upgrade is on less solid grounds than the 500 GeV baseline design. I assume that in context with the energy upgrade discussion we include the concepts of superstructures and the Lorentz force compensation with the piezo-tuner. This allows to define the energy reach of the machine at 800 GeV and to realistically limit the RF-regulation overhead at 10% also at higher gradients (according to the piezo-tuner test results, 10% seems to be rather on the conservative side!). Operation at 800 GeV with reasonable luminosity requires hardware upgrades (discussed below), but a certain range of energies above 500 GeV is already accessible with the initial installation.

On the lower energy side a limitation occurs due to the strong energy dependence of the positron production rate. We have included an e+ yield overhead of about a factor of two at the reference beam energy of 250 GeV, which should be sufficient to allow for operation with full design bunch charge down to about the top quark threshold (E_{beam} = 175 GeV). For such a moderate reduction in accelerating gradient, significantly larger emittance dilution in the linac does not have to be taken into account (we have a 50% dilution budget between the DR and the IP!) and the beam cross section at the IP follows a simple $\sigma_x\sigma_y \sim 1/E_{cm}$ rule. For lower energies, the reduction in e+ intensity causes a steeper drop in luminosity. In order to recover a high luminosity ($\approx 5\cdot 10^{33}$) on the Z-pole ($E_{beam} \approx 50$ GeV), a scheme can be used where the first part of the e- linac accelerates the colliding beam and the 2nd part (~200 GeV) the drive beam for the e+ source. An additional drive beam injector and a 50 GeV transfer line are required. For the TDR we consider this as an option, without working out the technical details of the layout.

In the electron linac, at reduced gradient the RF-system allows in principle to increase the beam current, but to avoid complications regarding the injection system and damping ring layout, a constant beam current and pulse length are assumed. Altogether, the luminosity in the region up to 500 GeV behaves as shown in Fig. 2.

The cryogenic plants are laid out such as to give us a safety factor of 1.5 w.r.t. the required capacity at 500 GeV. Since only about 70% of the 2K load is due to fundamental mode losses in the cavities and the rest doesn't depend on the gradient, there is potential to increase the energy without any hardware upgrades. If we use the plant capacity to ~90%, operation up to 600 GeV at 5Hz rep. rate and 650 GeV at 4Hz rep. rate is possible, assuming that the cavity quality factor scales linearly from 10^{10} to $5{\cdot}10^{9}$ between g=23MV/m and 35MV/m. The accelerated beam current and pulse length follow from the condition of constant RF-power and an adjustment of the external $Q \sim g^2$. This provides an at least approximate picture of the luminosity in this energy range, as shown in Fig. 2 (beam current is adjusted by bunch charge and normalized horizontal emittance is scaled as $\varepsilon_x \sim N_e$).

For the ultimate energy upgrade the number of klystrons is doubled and the cryo plant upgraded by close to a factor of two in the 2k. This allows operation at 800 GeV with 4 Hz rep. rate. Assuming the same klystron peak power and RF-pulse length as before, the resulting beam and RF parameters are shown in Table 5 As pointed out above, here the assumption of superstructures is made (specifically, a 6% improvement in the fill factor, which results from J. Sekutowicz's recent proposal of pairs of 9-cell cavities).

beam current	12.7 mA
beam pulse length	0.86 ms
energy gain p. 2×9-cell structure	72.5 MeV
power-to-beam p. superstructure	921 kW
power p. coupler including10% reg. reserve	1013 kW
waveguide and circulator losses	4%
required klystron peak RF-power	9.5 MW
# of klystrons p. linac	606
loaded Q_{ext}	$2.8{\cdot}10^{6}$
RF pulse length	1.37 ms
repetition rate	4 Hz

Table 5: Assumptions on beam- and RF-power at 800 GeV, assuming a linac based on 2×9-cell superstructures.

For the beam parameters (Table 6) a further reduction of beam emittance is assumed. This is supported by a reduction in bunch charge so that (also due to the higher gradient) the relative emittance dilution should be comparable to the 500 GeV case. The vertical emittance in the damping ring is reduced by a factor of two (from $2{\cdot}10^{-8}$ to 10^{-8}), which is supported by the lower rep. rate (=more damping times) and the bunch charge reduction (approx. unchanged space charge effect).

	TESLA 800 TDR
t_{pulse} [μs]	**860**
# bunches n_b/pulse	**4886**
bunch spacing Δt_b [ns]	**176**
rep. rate f_{rep} [Hz]	**4**
N_e/bunch [10^{10}]	**1.4**
$\varepsilon_x / \varepsilon_y$ (@ IP) [10^{-6}m]	**8 / 0.015**
beta at IP $\beta_{x/y}^*$ [mm]	**15 / 0.4**
spot size σ_x^* / σ_y^* [nm]	**391 / 2.8**
bunch length σ_z [mm]	**0.3**
beamstrahlung δ_B [%]	**4.7**
Disruption D_y	**28**
lumin. L [10^{34} cm^{-2}s^{-1}]	**4.7**

Table 6: Updated parameters at E_{cm}=800GeV for the TDR.

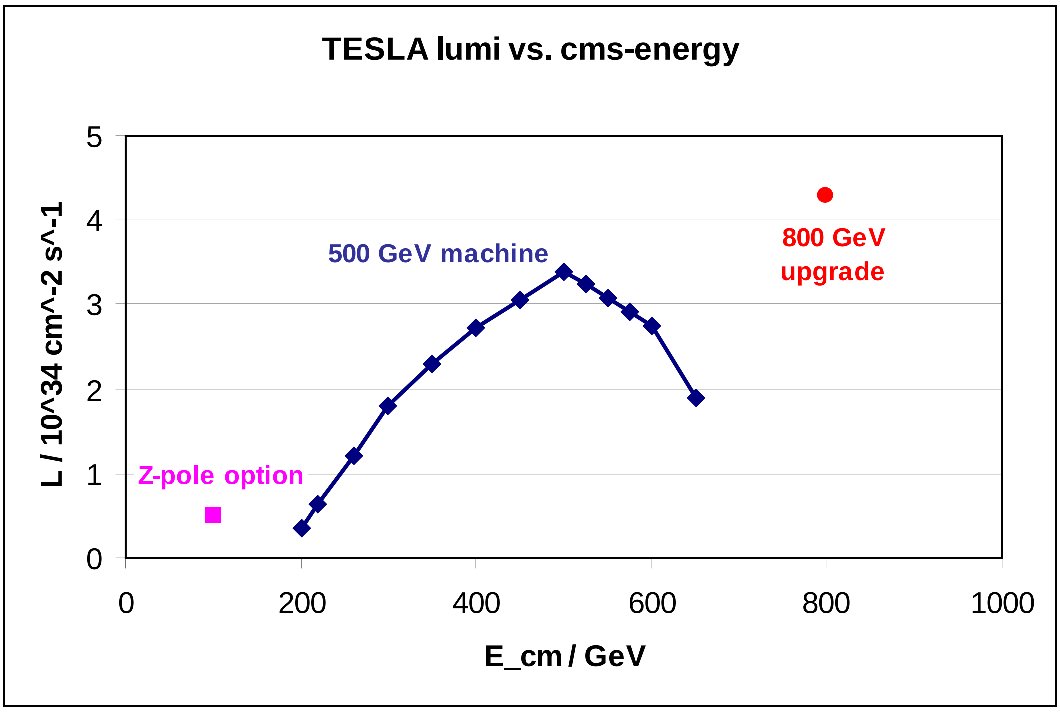

Fig. 2: TESLA luminosity at different center-of-mass energies