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TESLA CALCULATIONS PROGRAM*

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For the 2nd TESLA Workshop to be held in Hamburg in August 1991, there is a need for a parameters program as was made available by J. Rosenszweig for the 1st meeting at Cornell in July 1990[1]. At this stage, Rosenszeig's program is not generally available. Hence this program was written in the hope that it will be as useful to the parameters group as the original program was.

The program is divided into five main sections:

a) Beam Parameters
b) RF Power Calculations
c) AC wall plug power calculations
d) Wakefields, vibration and alignment tolerances
e) Capital and operating cost estimates

The approach is based on the output of the 1st TESLA Workshop. Beam parameter calculations come from the formulas given in Palmer's work[2]. Computation of the incoherent pair production from P. Chen's work was carried out with the help and advice from M. Leenen (DESY). In sections b and c several improvements and additions have been made over Rosenszweig's program. Data on peak power vs. RF pulse length for available klystrons have been put in. HOM power is recomputed using TBCI for multi-cells. Additional RF dissipation during strucuture filling and decay times have been included.

Sections d and e are new. Section d is based on D. Rubin's summary report from the accelerator physics group with further work by M. Tigner.

Section e on costs must be taken as very prelimnary. It is hoped that better numbers for costs can be derived in the coming workshops.

The program is written in MATHCAD so that the forumulas used are transparent.

All units are MKS and $.

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Contents of Report

- Description of the Program
- Baseline design exercise (0.5 TeV CM)
- Parameters for a 1 TeV Machine
- Parameter Explorations for W-Factory, Top Factory
- Variation of Input parameters
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- References

Description of the Program

Constants

The fundamental constants used throughout the program are defined below:

$ec := 1.6 \cdot 10^{-19}$	Electron Charge
$re := 2.82 \cdot 10^{-15}$	Classical electron radius
$c := 3 \cdot 10^{8}$	Velocity of light
$me := 0.511 \cdot 10^{6}$	Electron rest mass
$\alpha := \frac{1}{137}$	Fine structure constant
$\lambda c := 3.86 \cdot 10^{-13}$	Electron Compton Wavelength/2*pi
$Z0 := 377$	Impedance of free space

(a) The input quantities for calculating the Beam Parameters are defined below:

Input Parameters - Beam

$E := 2.5 \cdot 10^{11}$	Beam Energy
$G := 2.5 \cdot 10^{7}$	Gradient
$L := \frac{E}{G}$	Linac Length
$N := 5.14 \cdot 10^{10}$	No. of Particles/bunch
$f := 8 \cdot 10^{3}$	Beam Collision Rate
$\sigma z := 2 \cdot 10^{-3}$	Bunch Length
$\varepsilon x := 2.0 \cdot 10^{-5}$	Normalized hor. emittance
$\varepsilon y := 1 \cdot 10^{-6}$	Normalized ver. emittance
$\beta x := 0.01$	Horizontal beta*
$\beta y := 0.005$	Vertical beta*

Beam Calculations

$$\gamma := \frac{E}{me}$$

Beam Energy

Final Spot Size

$$\sigma x := \left[\varepsilon x \cdot \frac{\beta x}{\gamma}\right]^{0.5}$$

Horizontal Beam size at focus

$$\sigma y := \left[\varepsilon y \cdot \frac{\beta y}{\gamma}\right]^{0.5}$$

Vertical Beam size at focus

$$R := \frac{\sigma x}{\sigma y}$$

Aspect Ratio

Disruption:
When a particle of one beam is deflected by the collective electromagnetic field of the opposite beam, the process is called disruption. The luminosity is enhanced as a result of the pinching or focussing of the particles

N

$$Dx := 2 \cdot re \cdot \sigma z \cdot \frac{N}{\gamma \cdot \sigma x \cdot (\sigma x + \sigma y)}$$

Horizontal Disruption Parameter

$$Dy := 2 \cdot re \cdot \sigma z \cdot \frac{N}{\gamma \cdot \sigma y \cdot (\sigma x + \sigma y)}$$

Vertical Disruption Parameter

The collision process takes place within several bunch lengths around the interaction point. The natural variation of the beam size over this distance has an impact on the disruption process due to the finite beta function. The parameter A defines the divergence of the incoming beams. Luminosity enhancement increases with Dy if the two beams are in perfect alignment. The sensitivity to offsets starts to diverge rapidly for Dy > 15. Hence Dy < 15 is recommended

$$A := \frac{\sigma z}{\beta y}$$

Divergence of incoming beam

Disruption Enhancement Round beam:

$$HDr := 1 + Dy^{0.25} \cdot \left[\frac{Dy^{3}}{1 + Dy^{3}}\right] \cdot \left[\ln\left[Dy^{0.5} + 1\right] + 2 \cdot \ln\left[\frac{0.8}{A}\right]\right]$$

$$HD := HDr^{0.333}$$

Disruption Enhancement
flat beam

$$Lum := N^{2} \cdot f \cdot \frac{HD}{4 \cdot \pi \cdot \sigma x \cdot \sigma y}$$ Luminosity

Beamstrahlung

Beamstrahlung is the emission of acceleration radiation by individual particles as a result of bending by the e&m fields of opposing bunches. Particles with different trajectories experience different energy losses, resulting in an energy spread. This adds in quadrature to the energy spread from the linac. High energy spread means larger uncertainties in the interaction energy, which limits the performance of the machine for useful physics. Quantum effects have to be taken into account for the calculation of energy loss and energy spectrum when the beamstrahlung parameter approaches unity or exceeds it.

Enhancement factors due to Pinch Effect:

$$Hx := 1 + 1.37 \cdot \left[\frac{1}{\left(1 + Dx\right)^{-5.5}}\right]^{0.5}$$

$$Hy := 1 + 1.37 \cdot \left[\frac{1}{\left(1 + Dy\right)^{-5.5}}\right]^{0.5}$$

$$\sigma x' := \frac{\sigma x}{Hx} \qquad \sigma y' := \frac{\sigma y}{Hy}$$ Pinched spot size

$$\Upsilon := 0.43\cdot re\cdot\lambda c\cdot\gamma\cdot\frac{N}{\sigma z\cdot\sigma y'}\cdot\left[\frac{2}{1+\dfrac{\sigma x'}{\sigma y'}}\right]$$

Beamstrahlung Parameter

$$H\Upsilon := \left[\frac{1}{\left(1+1.33\cdot\Upsilon\right)^{0.667}}\right]^{2}$$

Quantum correction for beamstrahlung effects, also known as the reduction factor

$$\delta cl := 0.22\cdot re^{3}\cdot\gamma\cdot\frac{N^{2}}{\sigma z\cdot\sigma x\cdot\sigma y}\cdot\left[4\cdot\frac{R}{(1+R)^{2}}\right]$$

Fractional Energy Loss (Classical)

$$\delta := \delta cl\cdot H\Upsilon$$

Fractional Energy loss, including quantum corrections

Disruption Angles

The disruption process improves luminosity but increases the divergence of the beam which sets the aperture of the opposite beam focussing quads.

$$H\theta x := \frac{1}{\left[1+(0.5\cdot Dx)^{5}\right]^{0.1667}}$$

Pinch Enhancement of the disruption angle

$$H\theta y := \frac{1}{\left[1 + (0.5 \cdot Dy)^{5}\right]^{0.1667}}$$ Pinch Enhancement of the disruption angle

$kx := 0.75$ $ky := 1.25$ For R>>1

$$\theta Dx := 2 \cdot N \cdot re \cdot kx \cdot \frac{H\theta x}{\gamma \cdot \sigma x}$$ Horizontal disruption angle

$$\theta Dy := 2 \cdot N \cdot re \cdot ky \cdot \frac{H\theta y}{\gamma \cdot \sigma x}$$ Vertical disruption angle

$$\theta d := \frac{\sigma x}{\sigma z}$$ Diagonal Angle

$\theta m := \theta Dx$ Maximum Disruption Angle

$$\theta c := (\theta m \cdot \theta d)^{0.5}$$ Beam Crossing Angle

No. of Coherent Pairs from Beamstrahlung radiation [4]

$$\mathbf{Npairs} := 0.044 \cdot N \cdot \left[\alpha \cdot \sigma z \cdot \frac{\Upsilon}{\gamma \cdot \lambda c}\right]^{2} \cdot \exp\left[\frac{-16}{3 \cdot \Upsilon}\right]$$

Calculation of incoherent pair production. [3]

Constants:

$\Gamma 1 := 2.6789$ $\quad$ $\Gamma 2 := 1.3541$ $\quad$ $\psi 8 := 0.7818$ $\quad$ $\psi 1 := 0.5772$

Detector Properties:

$pt0 := 4 \cdot 10^{-5}$ $\quad$ $c0 := \cos(0.1)$

Effective Beamstrahlung parameter to agree with Chen's definition:

$$\Upsilon' := \Upsilon \cdot \frac{5}{12}$$

Breit-Wigner Cross-Section:

$$\sigma bw := \frac{9}{16 \cdot \pi} \cdot \Gamma 1^{-1} \cdot \Gamma 2^{4} \cdot \frac{re^{2}}{\gamma^{2}} \cdot \left[\alpha \cdot \frac{\sigma z}{\gamma \cdot \lambda c}\right]^{2} \cdot \left[6 \cdot \frac{\Upsilon'}{pt0}\right]^{1.33}$$

$$\sigma bw := \sigma bw \cdot \ln\left[\frac{1 + c0}{1 - c0}\right]$$

Bethe-Heitler Cross-Section:

$$\sigma bh := \frac{54}{5 \cdot \pi} \cdot \Gamma 2 \cdot \alpha \cdot \frac{re^{2}}{\gamma^{2}} \cdot \left[\alpha \cdot \frac{\sigma z}{\lambda c \cdot \gamma}\right] \cdot \left[36 \cdot \frac{I'^{2}}{pt0^{5}}\right]^{0.33}$$

$$\sigma bh := \sigma bh \cdot \left[\left[\frac{1 + c0}{1 - c0}\right]^{0.167} - \left[\frac{1 - c0}{1 + c0}\right]^{0.167}\right]$$

$$mu := \ln\left[\frac{pt0}{2} \cdot \left[\frac{1 - c0}{1 + c0}\right]^{0.5}\right] + \psi 8 - \psi 1$$

$$\sigma bh := \sigma bh \cdot mu \cdot -1$$

Landau-Lifshitz Cross-Section:

$$\sigma ll := \frac{8}{\pi} \cdot \alpha^{2} \cdot \frac{re^{2}}{\gamma^{2}} \cdot \frac{1}{(pt0)^{2}} \cdot \ln\left[\frac{1 + c0}{1 - c0}\right]$$

$$qu := 3\cdot\ln\left[\frac{pt0}{2}\right] + \frac{73}{12} - \frac{\pi^{2}}{6}$$

$$\sigma ll := \sigma ll\cdot\left[\ln\left[\frac{pt0}{2}\cdot\left[\frac{1+c0}{1-c0}\right]^{0.5}\right]\cdot\ln\left[\frac{pt0}{2}\cdot\left[\frac{1-c0}{1+c0}\right]^{0.5}\right] + qu\right]$$

$$Lb := \frac{Lum}{f}$$ Luminosity/bunch

$Nbw := 2\cdot\sigma bw\cdot Lb$ $Nbh := 2\cdot\sigma bh\cdot Lb$ $Nll := 2\cdot\sigma ll\cdot Lb$

$Nbw = 101.0612$ $Nbh = 131.51429$ $Nll = 16.7777$

$\sigma sum := \sigma bw + \sigma bh + \sigma ll$ Total cross-section

$incprs := 2\cdot\sigma sum\cdot Lb$ Total number of incoherent pairs

According to Chen, a few hundred incoherent pairs are acceptable. For the large bunch spacing of microseconds for TESLA, it is not necessary to multiply by the number of bunches in the train. This is probably not the case for normal conducting machines where the bunches are spaced nanoseconds apart

Input Parameters - RF Power

$nb := 800$	No.of Bunches/Pulse
$bs := 1 \cdot 10^{-6}$	Bunch separation (s)
$rf := 1.3 \cdot 10^{9}$	RF frequency
$ROQ := 960 \cdot \frac{rf}{1.5 \cdot 10^{9}}$	Cavity shunt impedance R/Q

RF Power Calculations

$\lambda := \frac{c}{rf}$	RF Wavelength
$\omega := 2 \cdot \pi \cdot rf$	RF frequency angular
$tbeam := nb \cdot bs$	Beam on time
$d := f \cdot bs$	Duty Factor
$rep := \frac{f}{nb}$	RF Rep rate

$$Pb := N \cdot ec \cdot f \cdot E \cdot 2$$

Total Beam Power

$$u := \frac{G^{2}}{ROQ \cdot \omega}$$

Stored Energy/length

$$QL := \frac{G^{2}}{ROQ \cdot \left[\frac{Pb}{2 \cdot L \cdot d}\right]}$$

Loaded Q to match beam power

$$\tau e := \frac{QL}{\omega}$$

Filling time constant to equilibrium to match beam power

$$\tau d := \frac{QL}{\omega}$$

Power decay time

$$decay := \tau d$$

Area under decay

$$fill := 2 \cdot \ln(2) \cdot \tau e$$

To compensate for beam loading energy transient in a standing wave structure, fill time before bunch train starts should be as determined by R. Miller [5]

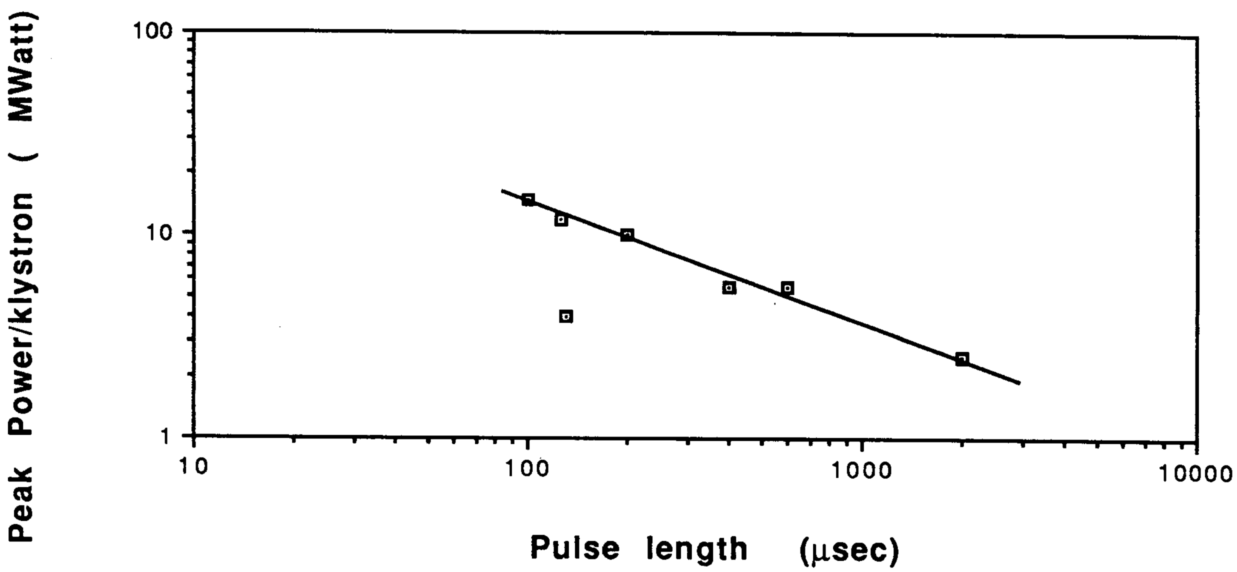
$$trf := tbeam + fill$$

Total RF on time

$$Ppk := \frac{u}{\tau e}$$ Peak RF Power/meter (using matched conditions). This is also the same as the peak beam power

$$RF := Ppk \cdot L \cdot 2$$ Total Peak RF Power

Peak Power of klystrons (MWatts) depends on RF pulse length as shown

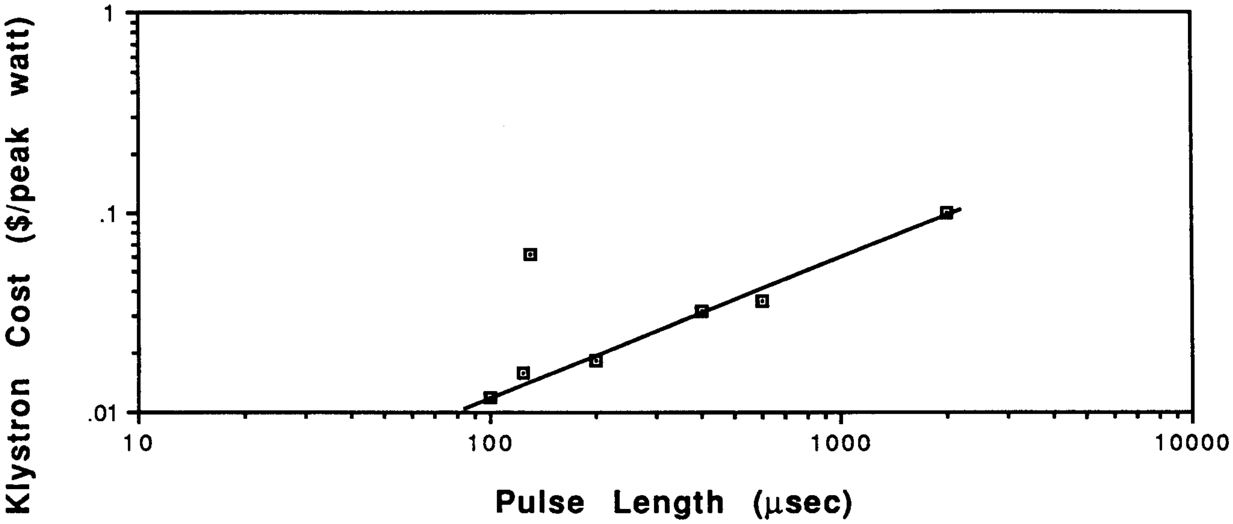


$$LPkly := -0.577 \cdot \log\left[\frac{trf}{10^{-6}}\right] + 2.304$$ Log of peak power

$$Pkly := 10^{LPkly} \cdot 10^{6}$$ Klystron peak power

$$Nkly := \frac{RF}{Pkly}$$ No. of Klystrons

$/peak RF Watt for klystrons is determined from the following graph derived from klystron catalog information:



$$LCrf := 0.708 \cdot \log\left[\frac{trf}{10^{-6}}\right] - 3.335$$

Log of cost

$$Crf := 10^{LCrf}$$

Cost of Peak power ($/watt)

$$BW := \frac{rf}{QL}$$

Bandwidth

$$AvRF := RF \cdot rep \cdot trf$$

Total Average RF Power: Includes beam power, dumped structure stored energy and RF power for filling

Input Parameters for Wall Plug Power Calculations

$a := 4.6 \cdot 10^{-2}$	RF cell aperture (radius)
$nc := 9$	No of Cells/cavity
$\eta k := 0.65$	Assumed klystron efficiency
$T := 2$	Cryogenic Temperature
$\eta r := 0.2$	Assumed refrigerator efficency
$h := 1$	Static heat leak (watts/m)
$frac := 0.5$	Fraction of HOM power at cryo. temp.
$Qr := 6 \cdot 10^{9}$	Residual Cavity Qo
$Lcell := \frac{\lambda}{2}$	Cell length
$LDR := nb \cdot 7$	Length of damping ring assuming 7 meter spacing between bunches for kicker operation
$ODR := 2000$	Operating power (watts/m) for DR (U. Amaldi/TESLA workshop addendum)

Power Calculations

$$Rr := \frac{290}{Qr}$$

Residual surface resistance

$$Rbcs := 2\cdot 10^{-4}\cdot e^{\frac{-17.67}{T}}\cdot\frac{\left[\frac{rf}{1.5\cdot 10^{9}}\right]^{2}}{T}$$

BCS Surface resistance

$$Qbcs := \frac{290}{Rbcs}$$

Geometry factor = 290 Ohms

$$Q := \frac{290}{Rbcs + Rr}$$

Q value

$$x := \left[\sigma z\cdot 10^{3}\right]^{-0.5}$$

$$bcis := -9.2926 + 40.493\cdot x$$

$$bcil := -5.8374 + 18.749\cdot x$$

BCI calculations of total loss factor on single cell shape V/C/m, bcis for 3GHz and bcil for 1.5 GHz

$$\mathrm{bcis} := \frac{\mathrm{bcis}}{1.55} \qquad \mathrm{bcil} := \frac{\mathrm{bcil}}{1.55}$$

Multicell BCI calculations at Cornell show that loss factor of multicells is 1.55 times less than N x single cell

$$\mathrm{kfun} := \omega \cdot \frac{\mathrm{ROQ}}{4}$$

Loss factor for the fundamental mode alone

$$\mathrm{ktot} := \mathrm{if}\left[\mathrm{rf} > 2 \cdot 10^{9}, \mathrm{bcis}, \mathrm{bcil}\right]$$

$$\mathrm{kll} := \mathrm{ktot} \cdot 10^{12} - \mathrm{kfun}$$

HOM Loss factor in V/C/meter

$$\mathrm{Pdump} := u \cdot L \cdot 2 \cdot \mathrm{rep}$$

Total Dumped RF Power

$$\mathrm{Pdumpac} := \frac{\mathrm{Pdump}}{\eta k}$$

AC power for dumped RF stored energy

$$\eta c := \frac{T}{293 - T}$$

Carnot Efficiency

$$\eta t := \eta c \cdot \eta r$$

Overall refrigerator efficiency

$\mathrm{filla} := \int_0^{\mathrm{fill}} \left[1 - e^{\frac{-t}{\tau e}}\right] dt$	Area under fill
$d' := \mathrm{rep}\cdot(\mathrm{nb}\cdot\mathrm{bs} + \mathrm{filla} + \mathrm{decay})$	Effective duty factor
$\mathrm{Pdiss} := G^2\cdot L\cdot 2\cdot\frac{d'}{\mathrm{ROQ}\cdot Q}$	Total Fund. Power at Cryo. Temp.
$\mathrm{Pdbeam} := G^2\cdot\mathrm{rep}\cdot\frac{\mathrm{tbeam}}{\mathrm{ROQ}\cdot Q}$	Dissipated power/meter during beam on time
$\mathrm{Pdfill} := G^2\cdot\mathrm{rep}\cdot\frac{\mathrm{filla}}{\mathrm{ROQ}\cdot Q}$	Dissipated power/meter during fill
$\mathrm{Pddecay} := G^2\cdot\mathrm{rep}\cdot\frac{\mathrm{decay}}{\mathrm{ROQ}\cdot Q}$	Dissipated power/meter during decay
$\mathrm{Pstat} := 2\cdot L\cdot h$	Total Static Heat Leak
$\mathrm{Phom} := (\mathrm{kll})\cdot 2\cdot L\cdot(N\cdot\mathrm{ec})^2\cdot f$	HOM power
$\mathrm{Phomcryo} := \mathrm{frac}\cdot\mathrm{Phom}$	HOM Power at Cryo Temp

$\mathrm{Pdhom} := \dfrac{\mathrm{Phomcryo}}{2 \cdot L}$	Dissipated HOM power/meter
$\mathrm{Pcryo} := \mathrm{Phomcryo} + \mathrm{Pstat} + \mathrm{Pdiss}$	Total Refrigerator Load
$\mathrm{Pacref} := \dfrac{\mathrm{Pcryo}}{\eta c \cdot \eta r}$	Total Refrigerator AC Power
$\mathrm{Pacrf} := \dfrac{\mathrm{AvRF}}{\eta k}$	Wall Plug Power for RF
$\mathrm{PDR} := \mathrm{ODR} \cdot \mathrm{LDR} \cdot 2$	AC Power for damping ring
$\mathrm{AC} := \mathrm{Pacrf} + \mathrm{Pacref}$	Total Linac Wall Plug Power
$\mathrm{Eff} := \dfrac{\mathrm{Pb}}{\mathrm{AC}}$	Beam/Linac Wall Plug efficiency
$\mathrm{Pbac} := \dfrac{\mathrm{Pb}}{\eta k}$	AC power for Beam Power
$\mathrm{Prfac} := \mathrm{Pacrf}$	AC Power for RF

$\mathrm{Phomac} := \dfrac{\mathrm{Phom}}{\mathrm{nk}}$	AC Power for for HOM
$\mathrm{Phomcryoac} := \dfrac{\mathrm{Phomcryo}}{\mathrm{nt}}$	AC Power for HOM Power lost in He
$\mathrm{Pstatac} := \dfrac{\mathrm{Pstat}}{\mathrm{nt}}$	AC Power for static heat leak losses in He
$\mathrm{Pdissac} := \dfrac{\mathrm{Pdiss}}{\mathrm{nt}}$	AC Power for RF dissipation in He
$\mathrm{I} := \mathrm{N} \cdot \mathrm{ec} \cdot \mathrm{f}$	Average Beam current
$\mathrm{Ipk} := \dfrac{\mathrm{I}}{\mathrm{d}}$	Peak beam current

Wakefield and Alignment Tolerances for Quadrupoles

$$\mathbf{E0} := 3\cdot 10^{9}$$

Injection energy

Energy spread is important for
1) Quadrupole alignment tolerances
2) Energy bandwidth of the final focus

Variation in accelerating voltage over the length of a bunch leads to an energy spread. Change in voltage over (+- 2) x bunch length is considered:

$$\sigma\mathbf{Erf} := 2\cdot\left[2\cdot\pi\cdot\frac{\sigma\mathbf{z}}{\lambda}\right]^{2}$$

Energy spread from RF wavelength (Rubin-Tesla) [6]

Wake voltage induced by the head of the bunch and witnessed by the tail:

$$\sigma\mathbf{Ewake} := 2\cdot\mathbf{N}\cdot\mathbf{ec}\cdot\mathbf{ktot}\cdot\frac{10^{12}}{\mathbf{G}}$$

Energy spreads from wake (Rubin-Tesla)

$$\sigma\mathbf{Ewake'} := \frac{\sigma\mathbf{Ewake}}{10}$$

The wake induced energy spread can be reduced by a factor of 10 by accelerating the bunch ahead of the peak RF voltage [6]

$$\mathbf{valwake} := \begin{bmatrix}\sigma\mathbf{Ewake'}\\ \sigma\mathbf{Erf}\end{bmatrix}$$

Choose the larger of the two energy spreads

$$\sigma\mathbf{E} := \mathbf{max}(\mathbf{valwake})$$

Transverse wakes dilute the emittance of a bunch. In a 2 particle model, the tail witnesses a transverse field from the displacement of the head (x). We want to limit the displacement of the tail (dx) w.r.t the head, ie dx/x. This quantity is given in terms of the beta function, the transverse wakes and the energy along the length of the machine. (See D. Rubin's summary in TESLA proceedings.) Putting the integral of dx/x along the linac to be = 1, allows us to determine the beta function if we also take the energy scaling of the beta function, i.e. beta increases as the square root of the energy. The strength of the quads allows us to determine the number of quads. The alignment tolerance for the quads then can be determined as it depends on the size of the beam at the end of the linac, the energy spread and the the number of quads.

To calculate the transverse wake of a cavity/unit length we use the formula from Gluckstern given in the TESLA proceedings

$$\mathrm{crit} := \frac{a^2}{5\cdot\sigma z\cdot \mathrm{Lcell}}$$

Range for validity of kt formula below

$$\mathrm{test} := \begin{bmatrix}\mathrm{crit}\\ \mathrm{nc}\end{bmatrix}$$

Here nc is the number of cells

$$\mathrm{val} := \min(\mathrm{test})$$

$$\mathrm{kt} := Z0\cdot c\cdot\frac{\sqrt{\pi\cdot\dfrac{\sigma z}{\mathrm{Lcell}\cdot\mathrm{val}}}}{4\cdot\pi\cdot a^3}$$

Transverse loss factor (Rubin-Tesla) [6]

$$\gamma 0 := \frac{E0}{me}$$

Injection energy

$$\beta av := 2 \cdot \frac{G}{3 \cdot ec \cdot N \cdot kt}$$

Average beta from ∂x/x =1 (Rubin-Tigner)

$$\beta 0 := \beta av \cdot 1.5 \cdot \sqrt{\frac{E0}{E}}$$

Initial beta from energy scaling of the betal function

$$\beta f := \beta 0 \cdot \sqrt{\frac{E}{E0}}$$

Final beta from energy scaling of the beta function

$$\psi := \frac{\pi}{4}$$

Phase advance per cell

$$Nq := 4 \cdot \frac{L}{\psi \cdot \sqrt{\beta 0 \cdot \beta f}}$$

Number of quads(Palmer-87) [7]

$$\sigma fx := \sqrt{\epsilon x \cdot \frac{\beta f}{\gamma}}$$

Final horizontal beam size in linac

$$\sigma fy := \sqrt{\epsilon y \cdot \frac{\beta f}{\gamma}}$$

Final vertical beam size in linac

$$xrms := \frac{\sigma fx}{2 \cdot \sigma E} \cdot \sqrt{\frac{3}{Nq}}$$

Horizontal alignment tolerance

$$yrms := \frac{\sigma fy}{2 \cdot \sigma E} \cdot \sqrt{\frac{3}{Nq}}$$

Vertical alignment tolerance.

Horizontal vibration tolerance
(Rosenzweig-Tesla from Ruth)

$$\Delta x := \sigma fx \cdot \sqrt{\frac{0.375}{Nq}}$$

$$\Delta y := \sigma fy \cdot \sqrt{\frac{0.375}{Nq}}$$

Vertical vibration tolerance

Input Parameters - Cost ($)

$\mathrm{Cmod} := 1.35 \cdot 10^{5}$	Cost of modulators & High Voltage
$\mathrm{CDR} := 20 \cdot 10^{3}$	Cost/meter damping ring
$\mathrm{Clin} := 50 \cdot 10^{3}$	Cost/Active meter -LInac
$\mathrm{bp} := 0.394 \cdot T^{5.798}$	He bath presssure vs T
$\mathrm{Cref} := 1250 + 3 \cdot 10^{4} \cdot \left[\frac{1}{\mathrm{bp}} - \frac{1}{760}\right]$	Cost/watt in He
$\mathrm{Cref} = 2.57905 \cdot 10^{3}$	
$\mathrm{El} := 0.08$	Cost/Kwatt-hour
$\mathrm{Life} := 4$	Integrated running time (years)

Cost Calculations

$\mathrm{Linac} := \mathrm{Clin} \cdot L \cdot 2$	Linac Cost
$\mathrm{DR} := \mathrm{LDR} \cdot \mathrm{CDR} \cdot 2$	Damping rings cost
$\mathrm{Ref} := \mathrm{Cref} \cdot \mathrm{Pcryo}$	Refrigerator Cost
$\mathrm{RFc} := \mathrm{Crf} \cdot \mathrm{RF} + \mathrm{Nkly} \cdot \mathrm{Cmod}$	RF cost
$\mathrm{Cap} := \mathrm{Linac} + \mathrm{Ref} + \mathrm{RFc} + \mathrm{DR}$	Total Capital Cost
$\mathrm{Op} := \left[\dfrac{\mathrm{AC} + \mathrm{PDR}}{1000}\right] \cdot \mathrm{Life} \cdot 365 \cdot 24 \cdot \mathrm{El}$	Operating Cost including damping ring power

Baseline Design Exercise (0.5 TeV CM)

(All in MKS Units)

Input Parameters - Beam

$E = 2.5\cdot 10^{11}$	Beam Energy
$G = 2.5\cdot 10^{7}$	Gradient
$L = 1\cdot 10^{4}$	Length
$N = 5.14\cdot 10^{10}$	No. of e/bunch
$f = 8\cdot 10^{3}$	Beam Collision Frequency
$\sigma z = 0.002$	Bunch Length
$R = 6.32456$	Aspect Ratio
$\varepsilon x = 2\cdot 10^{-5}$	Normalized Horizontal Emittance
$\varepsilon y = 1\cdot 10^{-6}$	Normalized Vertical Emittance
$\beta x = 0.01$	Horizontal beta*
$\beta y = 0.005$	Vertical beta*
$bs = 1\cdot 10^{-6}$	Bunch separation (s)

Derived Beam and Final Focus Parameters

$I = 6.5792 \cdot 10^{-5}$	Average Beam Current
$Ipk = 0.00822$	Peak beam current
$\sigma x = 6.39375 \cdot 10^{-7}$	Horizontal Beam Size
$\sigma y = 1.01094 \cdot 10^{-7}$	Vertical Beam Size
$Dx = 2.50317$	Horizontal Disruption Parameter
$Dy = 15.83146$	Vertical Disruption Parameter
$HD = 1.90856$	Disruption enhancement
$\theta Dx = 5.50033 \cdot 10^{-4}$	Maximum Horizontal Disruption angle
$\theta d = 3.19687 \cdot 10^{-4}$	Horizontal Diagonal Angle
$\Upsilon = 0.03761$	Beamstrahlung Parameter
$\delta = 0.01762$	Fractional Energy Loss
$Npairs = 0$	No. of Coherent Pairs
$incprs = 249.3532$	No. of incoherent pairs
$\theta c = 4.19331 \cdot 10^{-4}$	Beam Crossing Angle
$Lum = 4.96629 \cdot 10^{37}$	Luminosity MKS Units

Input Parameters -Power

$a = 0.046$	RF cell aperture (radius)
$nc = 9$	No of Cells/cavity
$\eta k = 0.65$	Assumed klystron efficiency
$T = 2$	Cryogenic Temperature
$\eta r = 0.2$	Assumed refrigerator efficency
$rf = 1.3 \cdot 10^{9}$	RF frequency
$h = 1$	Static heat leak (watts/m)
$frac = 0.5$	Fraction of HOM power at cryo. temp
$Qr = 6 \cdot 10^{9}$	Residual Q
$Qbcs = 2.65268 \cdot 10^{10}$	BCS Q
$Q = 4.89322 \cdot 10^{9}$	Cavity Qo
$ROQ = 832$	Cavity shunt impedance R/Q
$\lambda = 0.23077$	Wavelength
$Lcell = 0.11538$	Cell length
$nb = 800$	No.of Bunches/Pulse

Derived Power Parameters

$kll = 3.08822 \cdot 10^{12}$	Loss Factor in V/C/meter-BCl22
$tbeam = 8 \cdot 10^{-4}$	Beam on time
$trf = 0.00142$	RF Pulse Length
$rep = 10$	RF Rep rate
$d = 0.008$	Duty Factor
$d' = 0.01532$	Effective duty factor
$fill = 6.20106 \cdot 10^{-4}$	fill time
$filla = 2.84622 \cdot 10^{-4}$	Area under fill
$decay = 4.47312 \cdot 10^{-4}$	Area under RF decay
$u = 91.96731$	Stored Energy/length
$Pb = 3.2896 \cdot 10^{7}$	Total Beam Power
$Pdump = 1.83935 \cdot 10^{7}$	Total Dumped RF Power
$AvRF = 5.83948 \cdot 10^{7}$	Average RF power, includes beam power and dumped stored energy
$nt = 0.00137$	Overall ref. efficiency

$\eta c = 0.00687$	Carnot Efficiency
$Pdiss = 4.70362 \cdot 10^{4}$	Total Fund. Power at Cryo. Temp.
$Pdbeam = 1.22815$	Watts/m into He during beam on
$Pdfill = 0.43695$	Watts/m into He during fill
$Pddecay = 0.68671$	Watts/m into He during decay
$Pdhom = 0.83548$	Watts/m HOM power into He
$h = 1$	Watts/meter into He static
$Pstat = 2 \cdot 10^{4}$	Total Static Heat Leak
$Phom = 3.3419 \cdot 10^{4}$	HOM Power
$Phomcryo = 1.67095 \cdot 10^{4}$	HOM Power at cryogenic temp
$Pcryo = 8.37457 \cdot 10^{4}$	Total Refrigerator Load
$Pacref = 6.0925 \cdot 10^{7}$	Total Refrigerator AC Power
$Pacrf = 8.98381 \cdot 10^{7}$	Total AC power for RF
$QL = 3.65371 \cdot 10^{6}$	Loaded Q to match beam
$BW = 355.80314$	Bandwidth (Hz)
$\tau e = 4.47312 \cdot 10^{-4}$	Filling time constant to equilibrium

$\mathbf{Ppk} = 2.056 \cdot 10^{5}$	Peak RF Power/meter
$\mathbf{Nkly} = 1.34568 \cdot 10^{3}$	No. of Klystrons
$\mathbf{Pkly} = 3.0557 \cdot 10^{6}$	Peak power of klystron
$\mathbf{RF} = 4.112 \cdot 10^{9}$	Total RF Power
$\mathbf{AvRF} = 5.83948 \cdot 10^{7}$	Average RF Power

Breakdown of AC Power

$\mathbf{Pbac} = 5.06092 \cdot 10^{7}$	Ac power for beam power
$\mathbf{Pdumpac} = 2.82976 \cdot 10^{7}$	AC power for dumped stored energy
$\mathbf{Phomac} = 5.14139 \cdot 10^{4}$	AC power for HOM RF
$\mathbf{Phomcryoac} = 1.21562 \cdot 10^{7}$	AC Power for ref- hom
$\mathbf{Pstatac} = 1.455 \cdot 10^{7}$	AC power for ref -static heat leak-
$\mathbf{Pdissac} = 3.42188 \cdot 10^{7}$	AC Power for ref. - rf losses in cavity
$\mathbf{LDR} = 5.6 \cdot 10^{3}$	Length of damping ring
$\mathbf{PDR} = 2.24 \cdot 10^{7}$	AC Power for damping ring

$AC = 1.50763 \cdot 10^{8}$ Total Linac Wall Plug Power

$Eff = 0.2182$ Beam power /Linac Wall Plug Power

Input Parameters - Cost ($)

$\mathrm{Clin} = 5\cdot 10^{4}$	Cost/Active meter -Linac
$\mathrm{Cref} = 2.57905\cdot 10^{3}$	Cost/watt in He
$\mathrm{Crf} = 0.07886$	Cost/watt RF
$\mathrm{Cmod} = 1.35\cdot 10^{5}$	Cost/modulator
$\mathrm{El} = 0.08$	Cost/Kwatt-hour
$\mathrm{Life} = 4$	Integrated running time (years)
$\mathrm{ODR} = 2\cdot 10^{3}$	Operating cost for Damping ring (watts/m)
$\mathrm{CDR} = 2\cdot 10^{4}$	Linear cost for damping ring ($/m)

VI. Derived Cost Parameters

$\mathrm{Linac} = 1\cdot 10^{9}$	Linac Cost
$\mathrm{DR} = 2.24\cdot 10^{8}$	Damping ring cost
$\mathrm{Pcryo} = 8.37457\cdot 10^{4}$	Total cryogenic heat load
$\mathrm{Ref} = 2.15984\cdot 10^{8}$	Refrigerator Cost
$\mathrm{Ppk} = 2.056\cdot 10^{5}$	Peak RF power/m
$\mathrm{RFc} = 5.05929\cdot 10^{8}$	RF cost
$\mathrm{Cap} = 1.94591\cdot 10^{9}$	Total Capital Cost
$\mathrm{Op} = 4.85411\cdot 10^{8}$	Operating Cost (includes damping ring AC power)
$\mathrm{AC} = 1.50763\cdot 10^{8}$	Linac AC Power
$\mathrm{TOTAL} := \mathrm{Cap} + \mathrm{Op}$	
$\mathrm{TOTAL} = 2.43132\cdot 10^{9}$	Total cost

Wakefields, Alignment and Vibration Tolerances

$E0 = 3 \cdot 10^{9}$	Injection energy
$\beta 0 = 20.89951$	Initial beta
$\beta f = 190.78559$	Final beta
$\beta av = 127.19039$	Average beta
$Nq = 806.54618$	Number of quads
$kt = 1.59335 \cdot 10^{13}$	Transverse wake V/C-m^2
$\sigma Erf = 0.00593$	Energy spread from RF
$\sigma Ewake = 0.00315$	Energy spread from wakes
$\sigma E = 0.00593$	
$xrms = 4.54099 \cdot 10^{-4}$	Horizontal alignment tolerance
$yrms = 1.0154 \cdot 10^{-4}$	Vertical alignment tolerance
$\Delta x = 1.90427 \cdot 10^{-6}$	Horizontal vibration tolerance
$\Delta y = 4.25808 \cdot 10^{-7}$	Vertical vibration tolerance

The end

Parameters for a 1 TeV Machine

As in the first TESLA workshop, we have allowed the final spot size to shrink to 50 nm for the 1 TeV case by using smaller final focus beta values. The source emittances are the same as in the baseline case, however. It is expected that techniques for achieving and colliding smaller beams will have advanced when the time is ripe to proceed from 0.5 to 1 TeV. A luminosity of 10^{34} is possible in this design exercise, while keeping the AC power below 200 MWatts. To permit such a high luminosity the collision energy spread has been allowed to grow to 12%, and the beamstrahlung parameter to 0.25, still near the classical regime. It was necessary to shorten the bunch length to near 1 mm to keep the vertical disruption parameter near 15. Any shorter bunch lenth will increase the number of coherent pairs very fast. Wakefields, quadrupole alignment and vibration tolerances all remain attractive as in other superconducting machines.

TeV Parameters		**Units**
Length	16.6 x2	km
Gradient	30	MV/m
No. of Bunches	800	
Injection Energy	3	GeV
CM Energy	1000	GeV
Luminosity	10	10^{33} cgs

Beam Parameters		
emittance x,y	2×10^{-5}, 1×10^{-6}	m-rad
final beta x,y	8, 2.5	mm
No. of e/bunch	5.8	10^{10}
Collsion Freq	4.1	kHz
Bunch Length	1.1	mm
Bunch Separation	1	µsec
Beam size vert	50.5	nm
Disruption Dy	16	
Beamstr. Param.	0.25	
Coll. Energy Spread	12.2	%
No.of Coherent. Pairs	40	
No. of Incoh. Pairs	235	

Beam Power	38	MWatts
Linac Efficiency	19	%

RF Parameters

Q_0	4.9	10^9
RF Frequency	1.3	GHz
Aperture	4.6	cm
R/Q	832	Ohms
RF pulse length	1.46	msec
Rep rate	5.1	Hz
Eff. duty factor	0.8	%
RF Dissipation	1.78	watts/m
Total HOM power/m	2.14	watts/m
Total Cryogenic Load	129	kwatts
Loaded Q	3.9	10^6
Bandwidth	335	Hz
Peak RF Power/m	278	kwatt/m

Wakes, Alignment and Vibration Tolerances

RF ind. energy spread	0.18	%
Wake ind. en. spread	0.48	%
beta initial	29	m
beta final	369	m
beta average	246	m
No. of Quads	827	
Vert. Align. Tol	326	µm
Vert. Vibration Tol.	0.41	µm

Cost

Capital	3.39	10^9 $
AC Wall Plug Power	200	Mwatts

Parameter Exploration

Baseline Parameter Set

At the June Workshop on TESLA in DESY, this program was used to create parameter sets according to a strategy outlined by B. Wiik.[8] Consider a 10 km active length machine to provide the maximum possible luminosity at 0.5 TeV cm energy, with an AC power limit of 150 Mwatts. A gradient of 25 MV/m can be adopted. Further consider operating such a machine at lower gradients in Top Factory and W Factory modes. For the Top Factory an additional requirement of $\partial E/E < 0.001$ is imposed from physics. For the W factory, a Luminosity > 2×10^{33} is desirable to be an order of magnitude above LEP II. In all operating modes the source and final focus are taken with the same characteristics. This is an attractive strategy as it calls for a gradient of only 10 MV/m for the Top Factory mode and 12.5 MV/m for the W-Factory mode, both within reach with existing cavity preparation techniques. Higher Q_0's were used for the lower gradients.

Table 1 compares some of the parameters for the three operating modes. It was possible to design a Luminosity of 5×10^{33} for the 0.5 TeV mode with a collision energy spread below 2%.

Using the 0.5 TeV machine as the baseline, further exploration of the parameter space has been carried out. Of course the relative trends shown by these exercises depend on our choices of the relative cost coefficients, so that some of these conclusions may be revised after the collective judgement of the second workshop is incorporated.

Fixed Parameters for All Three Modes of Operation :

Length	10	km
emittance x,y	2×10^{-5}, 1×10^{-6}	m-rad
final beta x,y	10, 5	mm
No. of Bunches	800	
Injection Energy	3	GeV
RF Frequency	1.3	GHz
Aperture	4.6	cm
R/Q	832	Ohms
AC Wall Plug Power	150	Mwatts

Beam Parameters

	W-Factory	Top-Factory	1/2 TESLA	Units
CM Energy	200	250	500	GeV
No. of e/bunch	2	2	5.14	10^{10}
Collsion Freq	45	40	8	kHz
Bunch Length	2	1	2	mm
Bunch Separation	0.8	0.4	1	µsec
Beam size vert	0.16	0.14	0.1	µm
Disruption Dy	9.2	3	16	
Beamstr. Param.	0.0054	0.0056	0.038	
Coll. Energy Spread	0.12	0.16	1.8	%
No. of Coh. Pairs	0	0	0	
No. of Incoh. Pairs	125	18	249	
Beam Power	43	32	33	MWatts
Linac Efficiency	28	22	22	%
Luminosity	3.6	1.8	5	10^{33} cgs

RF Parameters

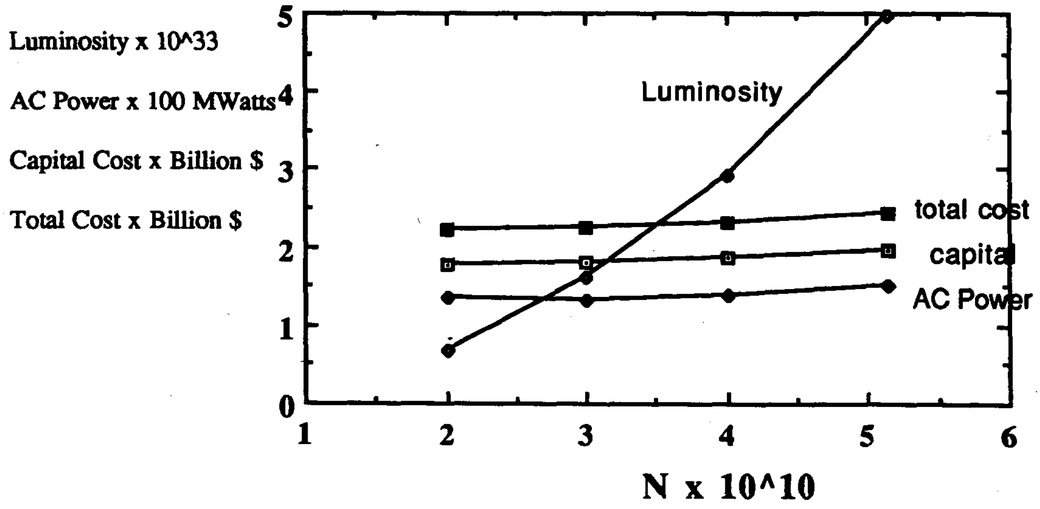
	W-Factory	Top-Factory	1/2 TESLA	Units
Gradient	10	12.5	25	MV/m
Q_0	7.3	6.1	4.9	10^9
RF pulse length	0.98	0.64	1.42	msec
Rep rate	56	50	10	Hz
Eff. duty factor	5.8	3.5	1.5	%
RF Dissipation	0.97	1.06	2.35	watts/m
Total HOM power/m	3.2	2.8	1.7	watts/m
Total Cryogenic Load	71	68	84	kwatts
Loaded Q	2	1.9	3.7	10^6
Bandwidth	649	692	355	Hz
Peak RF Power/m	60	100	200	kwatt/m

Wakes, Tolerances and beta function

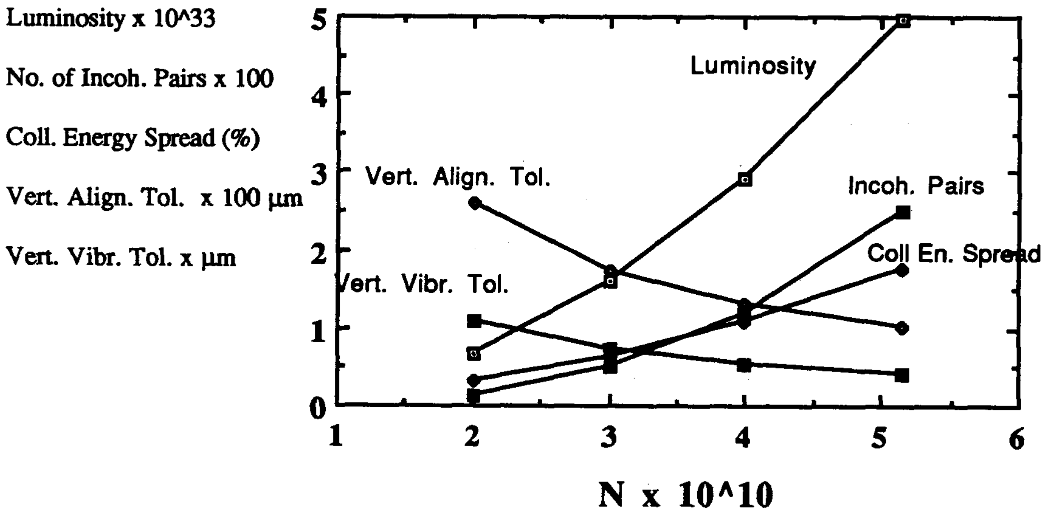
	W-Factory	Top-Factory	1/2 TESLA	Units
RF induced energy spread	0.59	0.15	0.59	%
Wake ind. en. spread	0.46	0.43	0.31	
beta initial	22.6	75.9	20.9	m
beta final	131	490	191	m
beta average	87	327	127	m
No. of Quads	936	264	807	
Vert. Align. Tol	0.12	1.6	0.1	mm
Vert. Vibration Tol.	0.52	1.7	0.42	µm

Variation of Input Parameters

In the first study, we vary the number of particles per bunch down from the baseline value of $5x10^{10}$ to $2x10^{10}$.

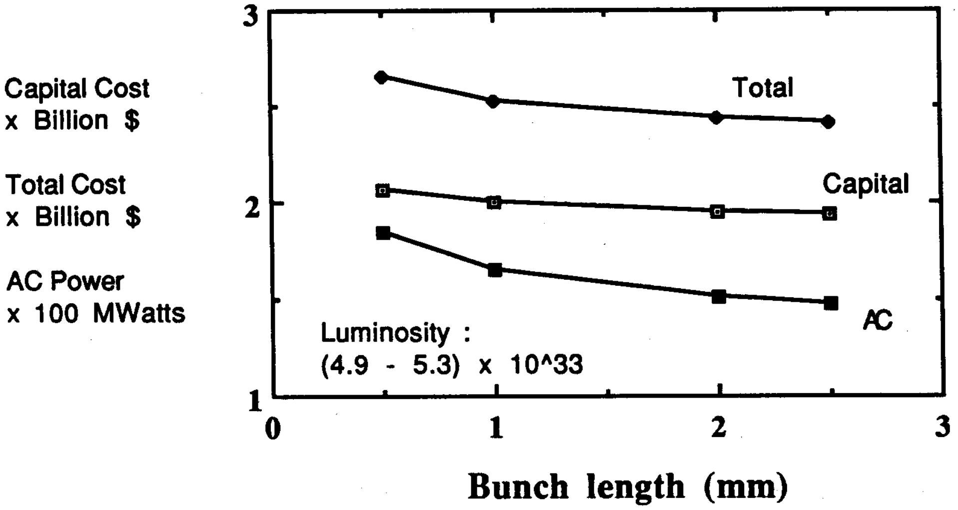


Not much impact is seen on the capital and operating cost, but there is a substantial loss of luminosity shown in Figure above. The companion figure below shows the down side of a high bunch charge.

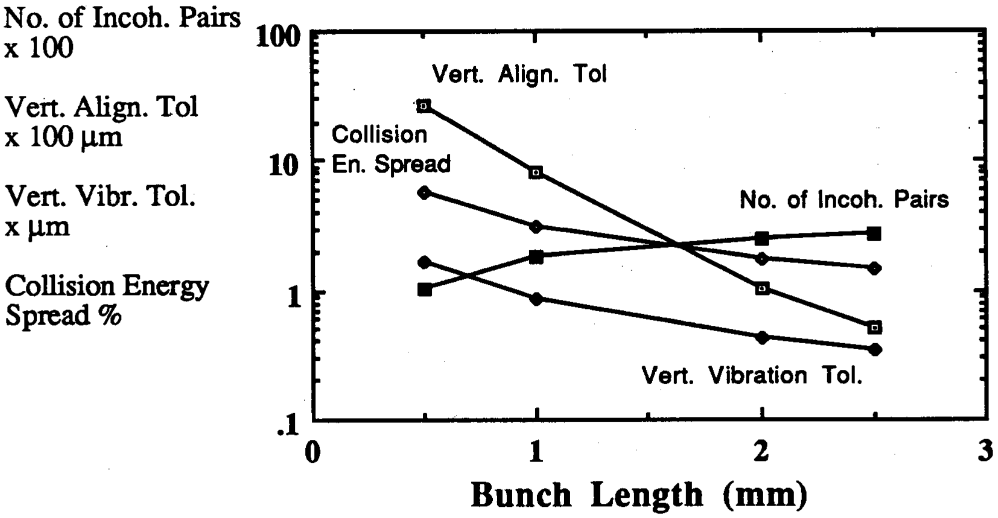


Vertical quadrupole alignment and vibration tolerances get more stringent, but still far relaxed (> 100 µm) over normal conducting versions (< 30 µm). The collision energy spread and the number of incoherent pairs likewise increase significantly with bunch charge but still superior to normal conducting colliders. Of course the multi-bunch effects (not covered by the program) also get worse, but existing simulations reported in the 1st TESLA proceedings suggest that the baseline values are acceptable if Qext of the HOM's can be kept below 10^6 .

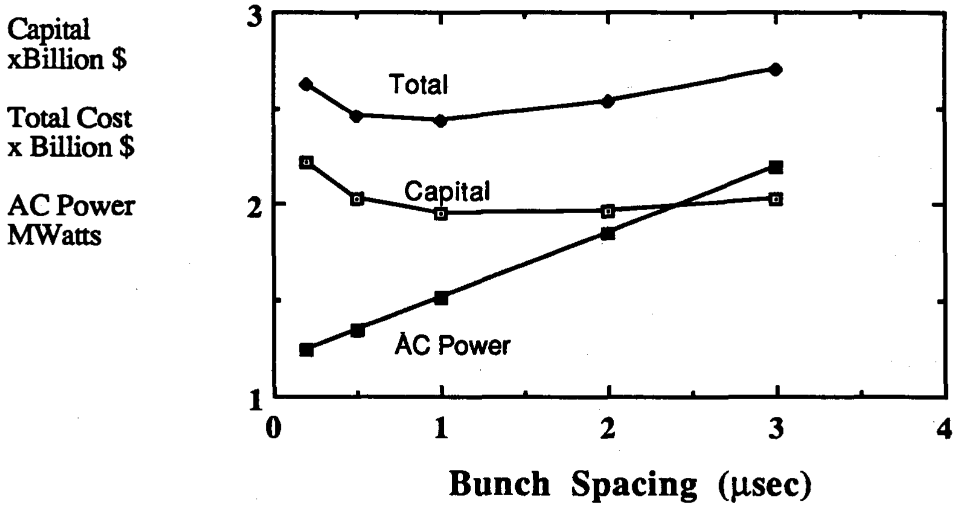
Longer bunch lengths are preferred from the standpoint of AC power, and collision energy spread, but do not have a strong impact on the capital or total cost.



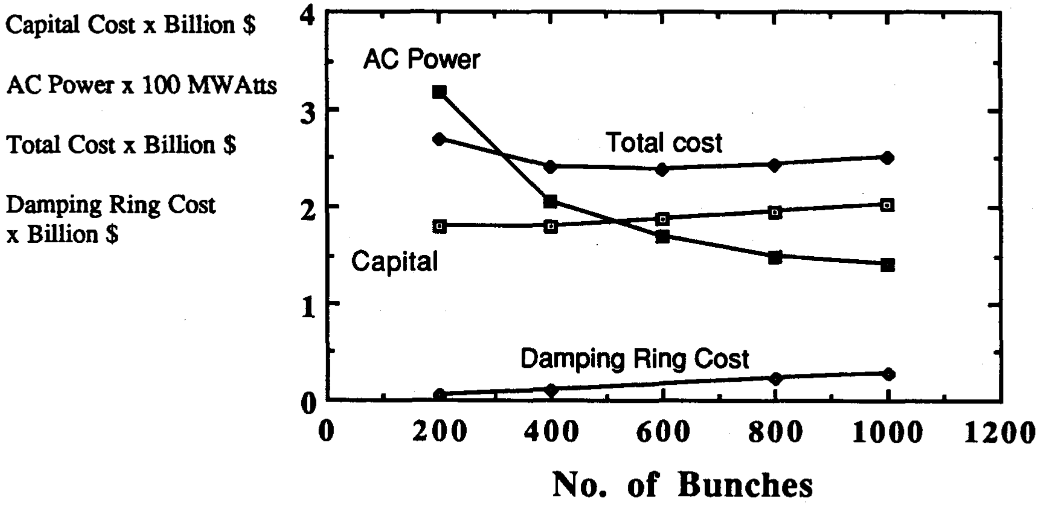
On the other hand short bunch lengths are strongly preferred for relaxed alignment and vibration tolerance as well as for limiting the number of incoherent pairs generated. A bunch length between 1 - 2 mm appears to be good compromise.



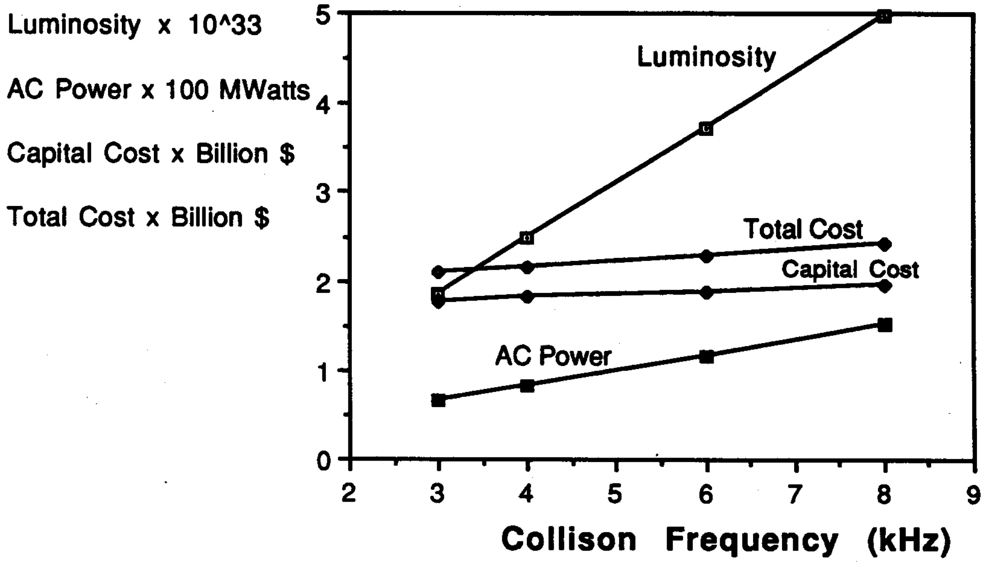
Next we explore the effect of varying the bunch spacing from the baseline value of 1 μsec. The AC wall plug power increases nearly proportional to bunch spacing, whereas the capital cost has an optimum near the baseline value of 1 μsec. Again, multibunch effects prefer long bunch spacing.



Reducing the number of bunches below the baseline 800 increases the AC power but lowers the capital cost, so that a broad optimum number is 600 - 800 bunches.



Finally, the choice of collision frequency is dictated essentially by the desired luminosity and the allowable AC power. Attractiveness for physics would suggest shooting for the highest possible collision frequency.



ON THE CHOICE OF THE RF FREQUENCY FOR TESLA

To make progress on TESLA, it will be important to narrow down the RF frequency as early as possible, so that machine parameters can be optimized, and prototypical hardware made at the appropriate size. At the1st TESLA worskhop, there appeared to be no overwhelming criteria in favor of 1.5 or 3 GHz. We present arguments here to show that 1.3 -1.5 GHz is definitely preferred.

As pointed out at the TESLA workshop and in other references, the advantages of the lower frequency are:

a) The BCS losses in the walls of the cavity decrease as f^2. Losses can be lowered for the higher frequency by choosing a lower operating temperature, but this would drive up the capital cost of the refrigerator, as well as the operating cost for removing heat from other sources such as static heat leak and higher mode losses.

b) The number of RF input feeds and cryostat penetrations per unit length decreases with f, reducing the capital cost. The same is true for HOM couplers.

c) The longitudinal wakefields decrease as f^2, and the transverse wakefields decrease as f^3. Wakefield induced energy spread is less, and alignment and vibration tolerances are relaxed. The advantages offered by the lower wakefields can be alternately realized by reducing the bunch spacing, which lowers the RF pulse length and consequently the RF dissipation for establishing the gradient. Alternatively, the lower wakefields permit use of higher bunch charge for gains in luminosity. These advantages can be used to optimize the parameters in design exercises.

d) The higher mode loss factor decreases with frequency, so the higher mode power deposited at liquid helium temperature is less.

e) In principle, with longer wavelengths, longer bunch lengths (σz) are permissible for the same RF curvature related energy spread, which opens up a favorable parameter for adjusting other performance aspects. For example, HOM losses decrease with increased bunch length. For the same collision spot size (σx, σy) the beamstrahlung induced energy spread decreases with σz and so does the beamstrahlung parameter. This reduces the number of coherent pairs. On the other hand, the number of incoherent pairs and the disruption parameters increase with σ_z, so longer bunch lengths must be used judiciously.

The advantages of the higher frequency are:

a) The shunt impedance/unit length is proportional to f, therefore the RF power dissipated in the cells is lower for the same Q_0. This lowers both the capital and operating cost, depending on the scenario for Q_0.

b) The dumped power when the RF is turned off decreases as (f^{-2}).

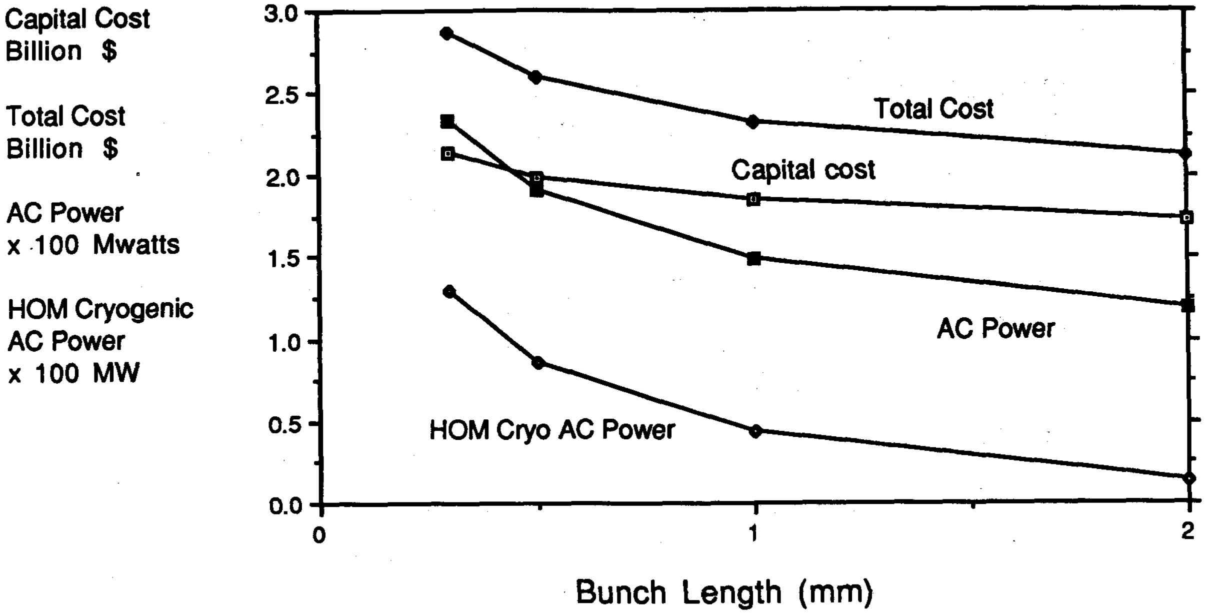
c) The RF fill time and decay time decrease as f^{-2}, reducing RF losses.

All arguments in favor of the higher frequency translate to the possibility for savings in operating cost.

Here we show that at the lower frequency, two of the above discussed factors more than offset the savings in operating power at the higher frequency. At the higher frequency, a shorter bunch length is demanded by the need to keep down the wakefield induced energy spread, and to keep the alignment and vibration tolerances from becoming too severe. Also a larger bunch spacing is demanded by multibunch stability considerations. At the shorter bunch length, the increased HOM power at 3 GHz offsets the savings in dumped RF power, and the larger bunch spacing offsets the reduced RF dissipation.

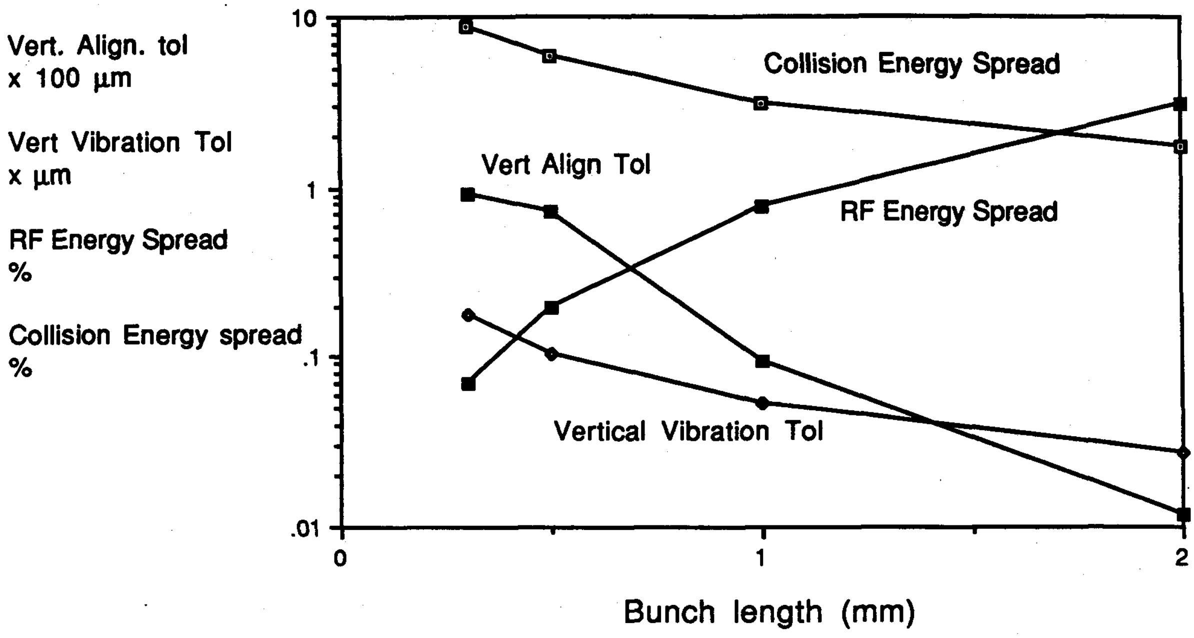
Using the parameters program and the baseline parameters for the 0.5 TeV machine, we changed the RF frequency from 1.3 to 3 GHz. In anticipation of the requirements from multibunch stability, we also increased the bunch spacing from 1 µsec to 2 µsec. Only more detailed simulations can show if this increase is enough.

The figure below then shows how the AC power, capital and total costs change as the bunch length is reduced from 2 mm.



Note that at 2 mm bunch length, the 3 GHz case appears to have significant advantages over the baseline : lower capital cost (1.74 vs. 1.95 B$) , lower AC power (110 vs. 151 Mwatts).

However as shown in the next figure below, there are some very serious problems arising from the choice of 2 mm bunch length.

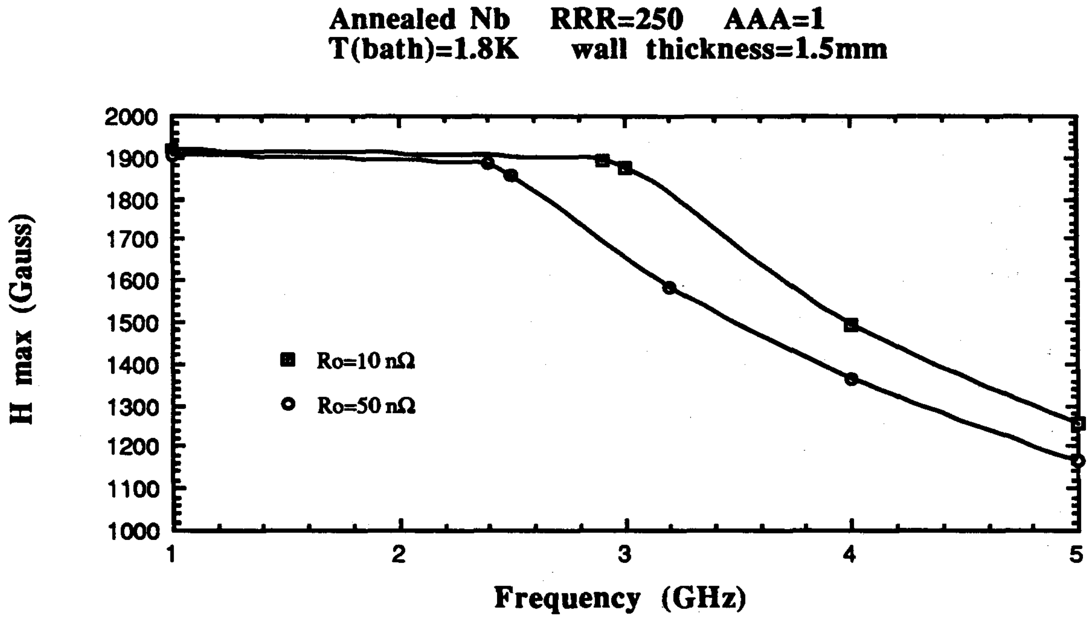


The RF induced energy spread is 3.1 % vs. 0.6%. which leads to severe alignment tolerances (1.2 µm vs. 102 µm) and vibration tolerances (27 nm vs. 426 nm). These numbers are poorer than for normal conducting colliders sacrificing key attractive features of superconducting colliders. As the bunch length is reduced to correct these serious difficulties, the advantages of capital and operating cost at 3 GHz evaporate. A bunch length of less than 0.5 mm is needed to come close to the tolerances of the baseline case. In this case the costs and AC power exceed the baseline. Most of the increased cost and AC power arise from the increased HOM losses with shorter bunch length. Of course the problem can be attacked by trying to remove larger fractions of the HOM power than the 0.5 assumed. (Recall that in all cases we have taken 0.5 of the HOM power to be deposited in liquid helium) But the same technique can then be applied to the 1.3 GHz case.

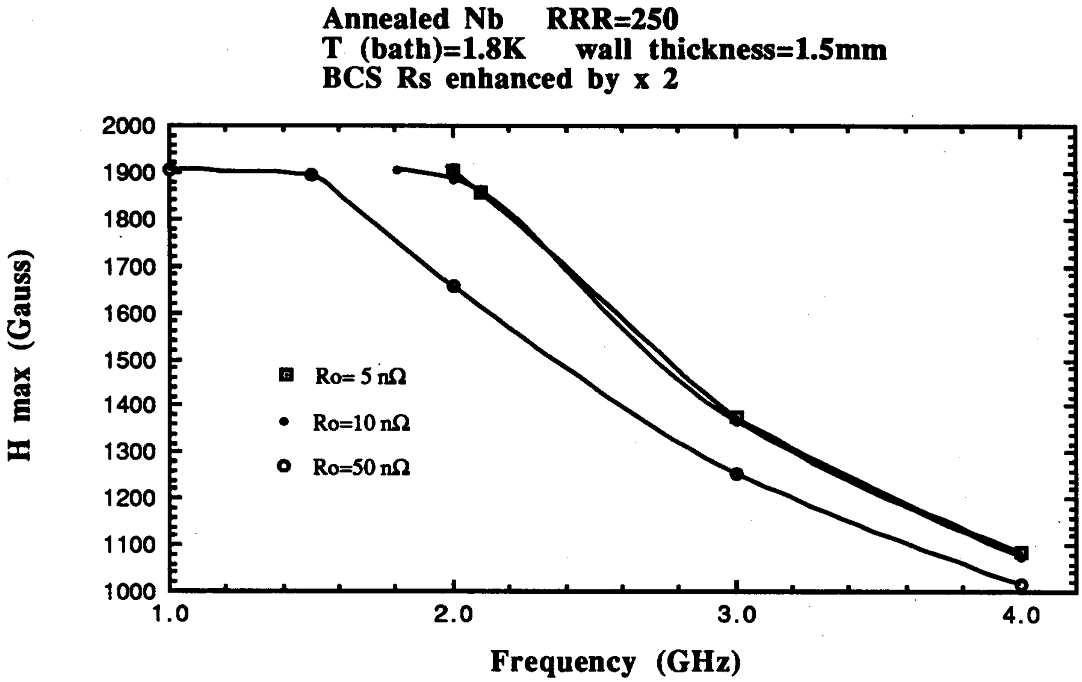
One idea that may be proposed for 3 GHz is to lower the operating temperature so that the Q_0 is higher. Note that by going to the low temperature, the gains in RF dissipation are lost by the impact of the decreased refrigerator efficiency on the static heat leak and higher mode loss.

In totally separate arguments, we show that for the higher frequency case, the ultimate magnetic field limit is lower than at 1.3 or 1.5 GHz. This fundamental field limit arises mainly from the strong temperature dependence of the BCS surface resistance, which leads to a thermal instability in the defect free case, the best we may hope to achieve.

The Figure below shows the defect free magnetic breakdown limit calculated (from a numerical thermal model program) as a function of RF frequency for two levels of residual losses corresponding to $Q_r = 3x10^{10}$ and $Q_r = 6x10^9$. While there is no significant penalty for the lower frequency, the maximum field drops from 1920 Oe to 1650 Oe at 3 GHz. Here we have assumed a favorable case for the BCS surface resistance, corresponding to a low surface RRR. The bulk Nb RRR was taken as 250.



Under certain circumstances, the theoretically allowed accelerating field at 3 GHz can become as low as 32 MV/m, compared to 48 MV/m at 1.5 GHz. In the Figure below is considered the double jeopardy of a high surface RRR along with increased residual loss. Again the low frequency is insensitive, but at 3 GHz defect free breakdown can be encountered at 1250 Oe. For a good structure geometry, with 40 Oe/MV/m, this translates to an accelerating field limit of 31 MV/m. Recently, just this type of thermal instability was encountered in an S-band single cell cavity [9]], and clearly demonstrated by thermometry data. This type of limitation has also been suggested to explain past maximum fields reached at 3 Ghz and higher frequencies. [10]



Annealed Nb RRR=250
T (bath)=1.8K wall thickness=1.5mm
BCS Rs enhanced by x 2

Thus the maximum achievable field becomes significantly more sensitive to expected variations in the residual surface resistance, and to the possible rise in the BCS surface resistance through increased surface RRR.

In principle these limits would rule out a very high energy (1.5 TeV CM) TESLA machine at 3 GHz, for which a gradient of 40 MV/m was used at the 1st TESLA workshop. At present, however, with field emission as the predominant limiting mechanism, this argument by itself is not overwhelming.

Given the other advantages of the low frequency, as well as the new factors pointed out here, we recommend the selection of 1.3 -1.5 GHz. Given the present availability of klystrons at 1.3 GHz makes the choice clear.

Recent Changes Made to the Parameters Program

The following changes were made to the Parameters program as a result of discussions and recommendations that emerged from the 2nd TESLA workshop. Although the text here does not show these changes, the changes were used in computing parameter lists presented in the paper "Status Report on TESLA Activities.

1) Klystron effciency is decreased from 0.65 to 0.55
The efficiency is still higher than 0.45 used by NC 3 GHz machine, because TESLA RF frequency is lower (1.3 GHz) and also because TESLA pulse length is longer (1 msec).

2) The fraction of power deposited in the liquid helium from higher order modes is reduced from 0.5 to 0.1, based on the recommendation of the structures group final summary. It is expected that most of the HOM power can be removed by 60 K loads.

3) The power dumped into the liquid He during decay of the RF pulse is reduced by a factor of 2, based on the idea that the RF phase can be reversed after the bunch train is gone, and so the decay can be made faster than exponential. An exact analysis of the net benefits of this scheme needs to be worked out, but a factor of 2 gain is expected.

4) Although there was a recommendation to increase R/Q by decreasing the aperture, this was not followed. Using the aperture of 3.3 cm instead of 4.6 cm has a substantial negative effect on the alignment and vibration tolerances. The alignment tolerance for the baseline half TESLA machine becomes 25 µm instead of 100 µm and the vibration tolerance also becomes much harder.
To give up these key advantages of TESLA is too much. This is basically because the transverse wakefields increase as the cube of the iris diameter. Probably the multi-bunch stability considerations will be similarly affected, but this will take a lot more work to evaluate. I'm afraid the structures group will have more work to do in coming up with a better design!

5) The gradients for the W and Z Factory modes of operation were kept relatively high (14-15 MV/m) so that multibunch stability would not be badly affected. In principle, given the 10 km long linacs available even gradients as low as 5 and 10 MV/m would suffice, but the beam would not

be as stiff in the low energy parts of the linac and this may spell trouble. Instead only a fraction of the existing linac would be powered for the W, Z and Top factory modes of operation. In making this choice an attempt was made to keep the peak power < 200 Kwatts/meter and the cryogenic power < 4 watts/meter, to allow use of existing RF and refrigeration distribution systems already sized for Half TESLA operation.

6) New parameter lists are generated for Z factory mode of operation and for a 2 TEV machine.

7) In upgrading from HALF TESLA to TESLA and to TWO TESLA , it was necessary to change the final spot size, first from 100 nm to 50 nm then to 5 nm. This was accomplished by changing the final focus for TESLA, and for TWO TESLA, by going to much lower emittance damping rings as well as further adjusments in fianl focus. All this was necessary to keep the AC power reasonable. It was also necessary in the case of TWO TESLA to have more bunches (3200 instead of 800) which will mean construction of additional damping rings.

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