A Low Power Option and the ILC Parameter Plane

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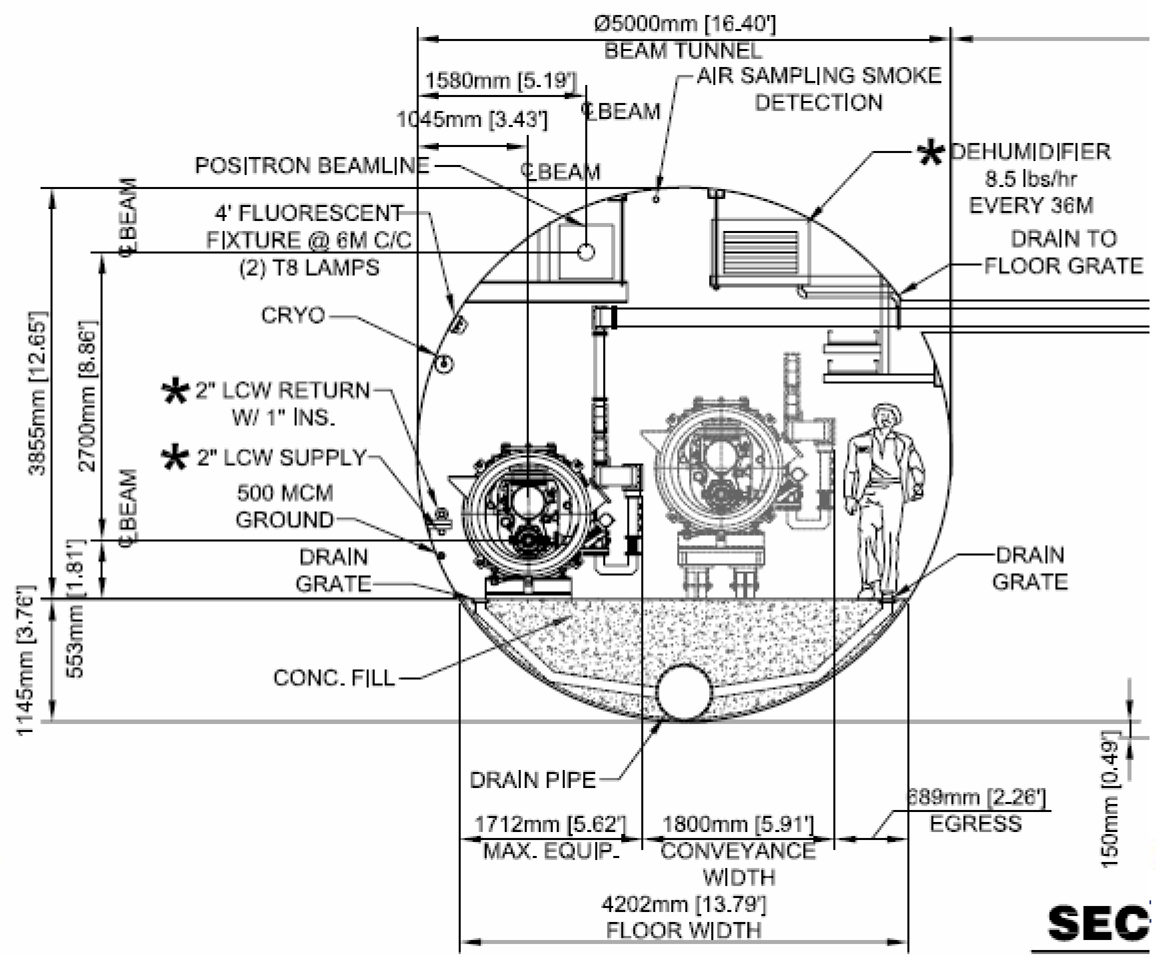
SLAC

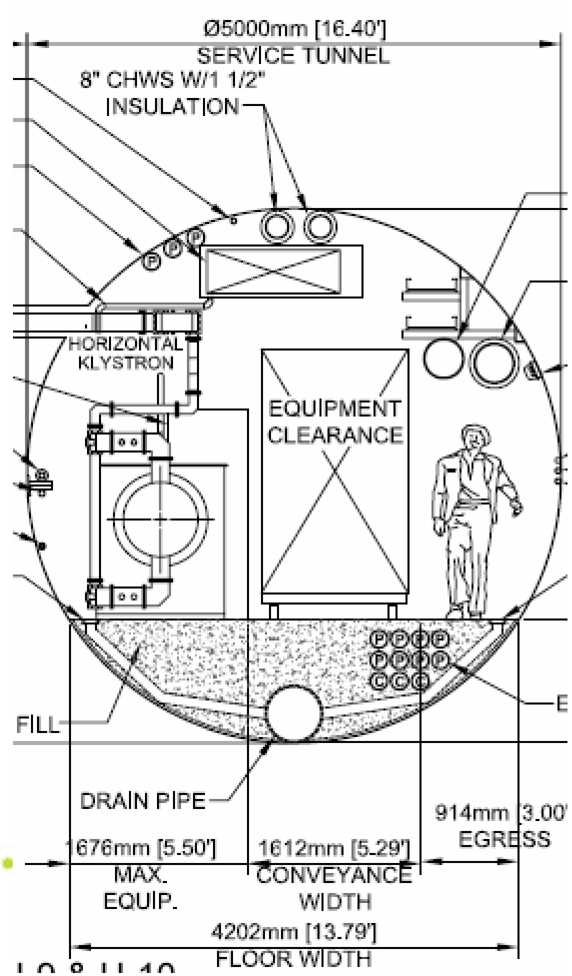
Introduction – ½ Power Option

- A proposal to operate with half the number of bunches (approximately 1330 bunches) over the same train length (one ms) is being considered.
- Because of a factor of two reduction in the size of the RF system, this modification will result in a net savings of 2-3% of the total project cost.
- Although the peak luminosity of the machine will be reduced by a factor of two, a relatively straightforward upgrade of the RF system can fully restore the machine's luminosity performance to that of the current baseline.

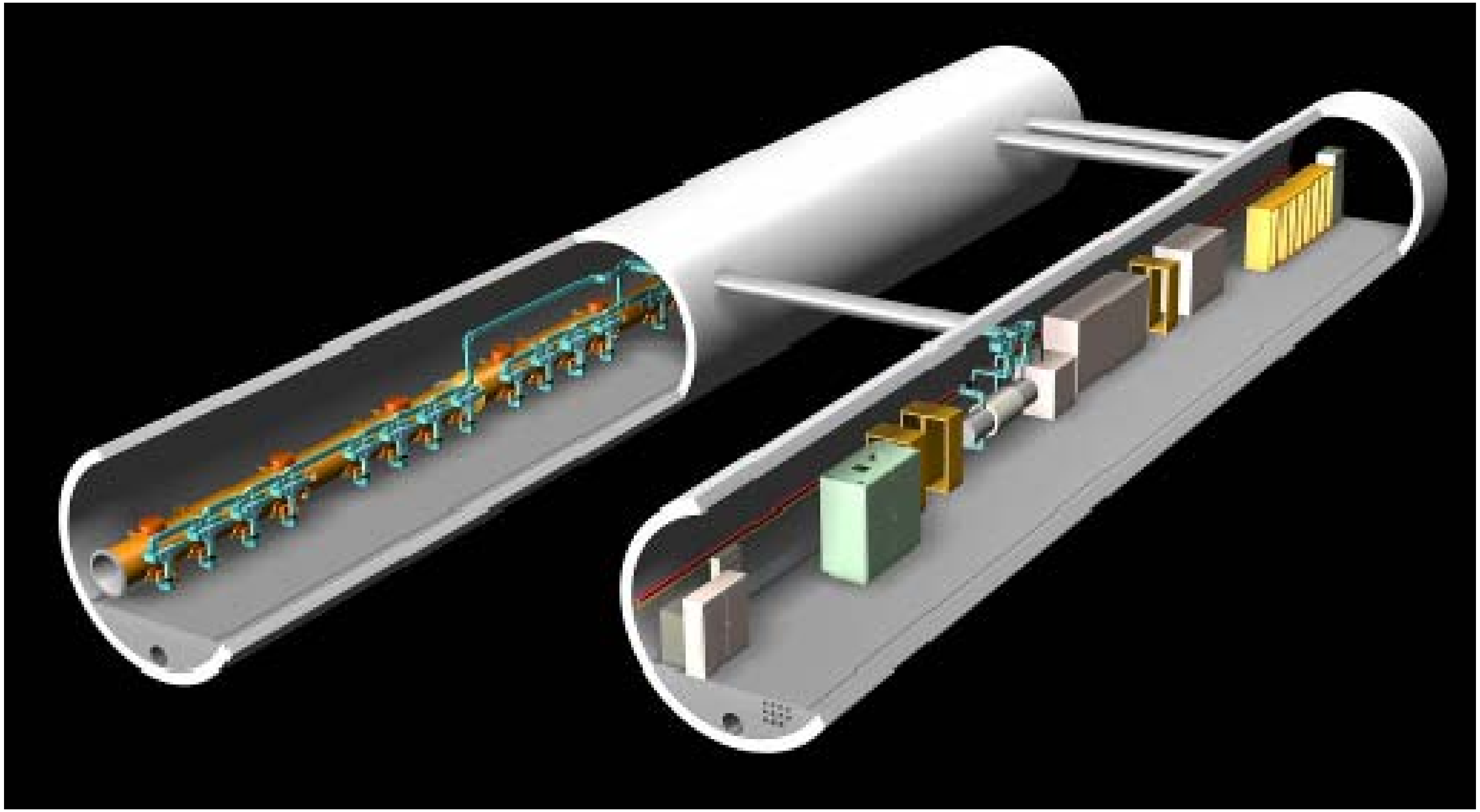
Baseline Main Linac Tunnel

- Looking at smaller diameter tunnels to reduce costs



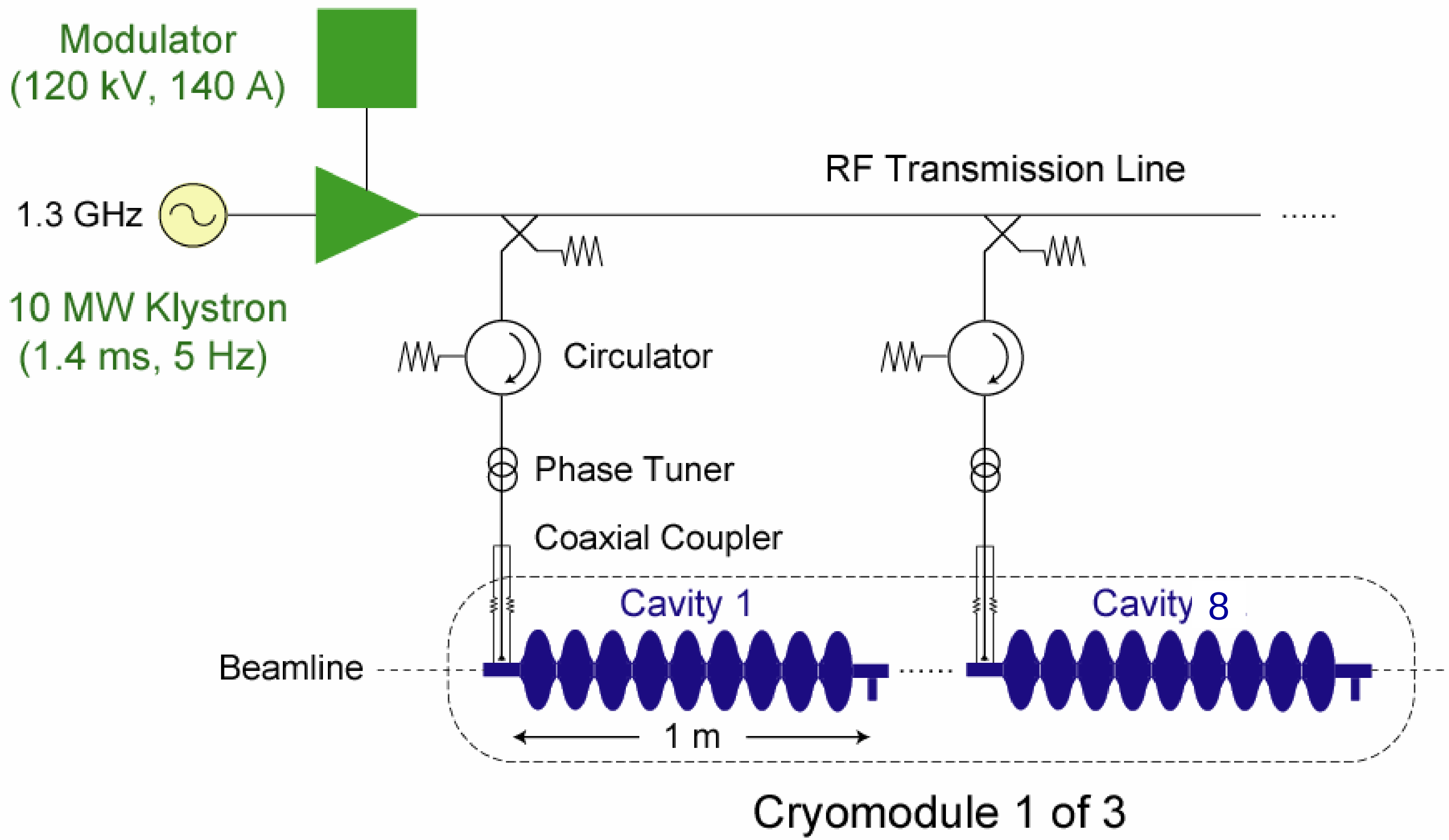


Conceptual View of Dual Tunnel

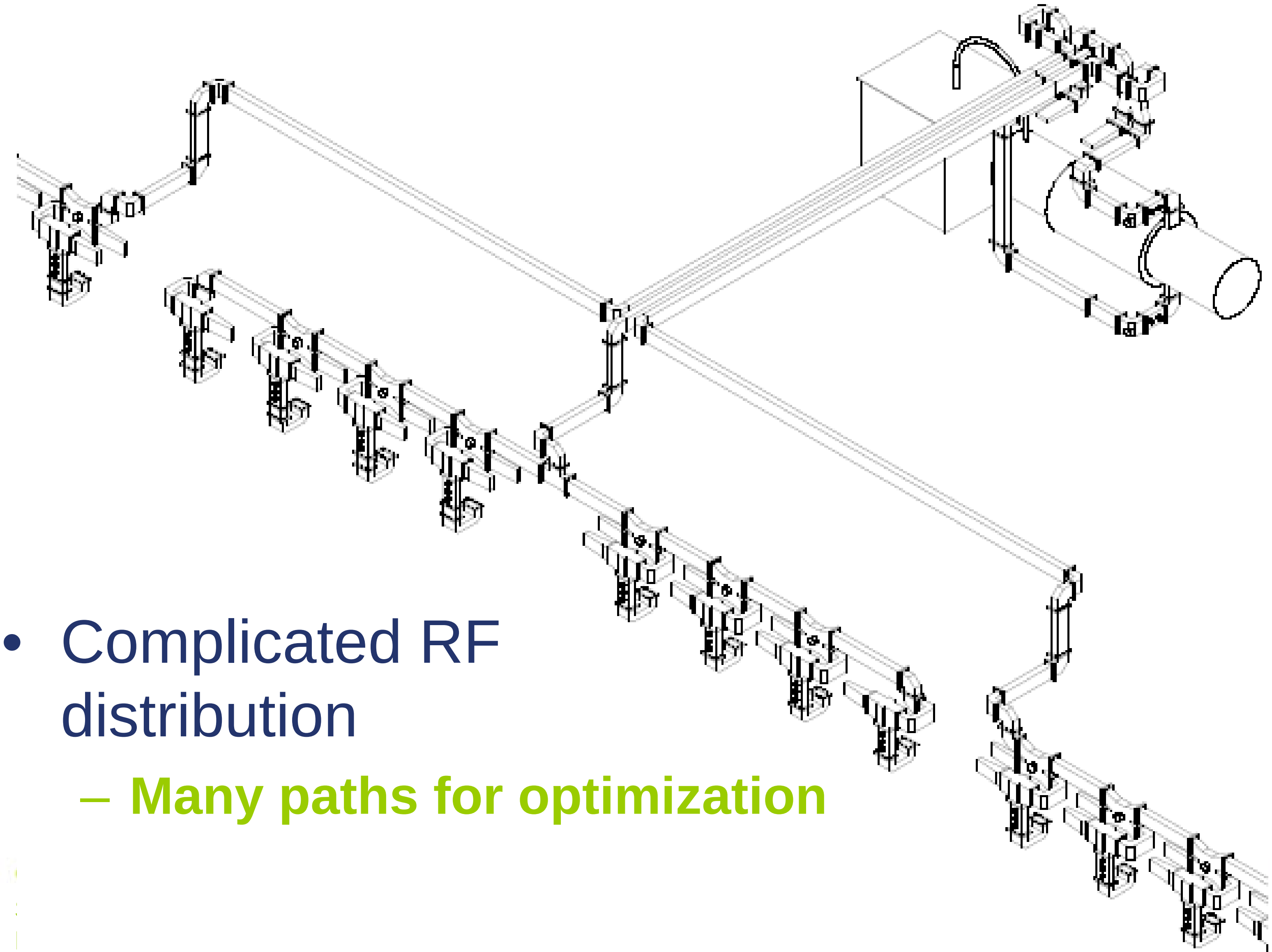


- Three RF/cable penetrations every rf unit
- Safety crossovers every 500 m
- 34 kV power distribution

Main Linac RF Unit



RF Distribution System



- Complicated RF distribution
  - **Many paths for optimization**

Assumptions – ½ Power Option

- In the service tunnel, only every other rf unit would be fully built and installed.
  - **There would be an essentially empty 36 m long space between rf units that could be filled later as an upgrade. For this 'empty' unit, the penetrations would be built and would include the three waveguides that feed the three cryomodules in this area. These waveguides would connect via a three-way splitter in the service tunnel to a waveguide that runs 36 m to the neighboring rf unit, where it would connect to one of the two 5 MW ports on the 10 MW klystron.**
  - **Because of the lower beam current, the cavity fill time would increase from 0.565 ms to 1.130 ms, but the 1.0 ms long stored energy 'flat top' would remain the same. The rf pulse length would thus increase from 1.565 ms to 2.130 ms, and all power and water cooling requirements would scale accordingly.**

Cost Impacts (1)

- Klystrons
  - **The number of klystrons would decrease from 628 to 314, but the per unit cost would increase by 13% due to the smaller number, and by 8% due the modifications required for the longer rf pulse. The net savings would be a 39% reduction**
- Modulators
  - **The number of modulators would decrease from 628 to 314, but the per unit cost would increase by 9% due to the smaller number, and by 17% due the modifications required for the longer rf pulse. The net savings would be a 36% reduction.**
- LLRF
  - **The LLRF system would basically remain unchanged. The associated electronic racks would be located in both the 'filled' and 'empty' sections of the service tunnel, just as in the baseline design. However, the LLRF stabilization of the cavity gradient during the pulse would be more challenging due to the two-times larger cavity Qext.**

From Chris Adolphsen with #'s removed

Cost Impacts (2)

- RF Distribution
  - **Except for the short waveguides runs between the tap-offs and couplers, WR770 waveguide would be used instead of the baseline WR650 waveguide. This larger waveguide has a lower power loss per unit length (0.14%/m versus 0.21%/m), and with the added 36 m length of waveguide, the average power loss is compensated to 0.1%. That is, in the baseline, the average length of the three waveguide runs in each rf unit is 37 m, so the average loss is 0.21*37 = 7.8%. With the half current option, the average loss is 0.14*(37 + 36/2) = 7.7%. Thus, the number of rf units would not need to be changed to maintain the same final beam energy.**
  - **The total length of WR650 in the baseline design is about 628*3*37 = 69.7 km while that of WR770 in the half current option would be 314*6*55 = 103.6 km. The additional cost of waveguide for the half current option is a few M$.**

From Chris Adolphsen with #'s removed

Cost Impacts (3)

- Cryogenics
  - **The longer fill and discharge times increase the rf heat load while the lower beam current reduces the HOM related heat loads. To account for the rf heat load during the fill and discharge times, an effective rf pulse length is used that equals the bunch train length plus 1.11 times the fill time.**
  - **For the half current option, the main linac plant sizes for each of the five plants per linac would have 5.02 MW installed power (equivalent to 22.9 kW of 4.5 K refrigeration, which is below the ~ 25 kW plant size limit). This is to be compared to 4.41 MW installed power (equivalent to 20.1 kW of 4.5 K refrigeration) for the baseline design. The cost of the main linac cryo plants scale as the installed power to the 0.6 power, so for the half current option, the plants would cost about 8% more.**

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Cost Impacts (4)

- Civil
  - **The AC power load in the service tunnel would scale by a factor of ((168 - 15)*(2.13/1.57)/2 + 15)/168 = 71% where 168 kW is the baseline power load per rf unit, 15 kW is the rack related power load per rf unit (assumed to be all LLRF related) and 2.13/1.57 is the rf pulse length ratio. The water and air cooling load would scale by a factor of 0.5*[(168 - 15)*(2.13/1.57) - 37]/(168 - 15 - 37) = 74% where 37 kW is the power transferred to the beam per rf unit.**
  - **The 2-3% savings includes ½ of the civil savings to facilitate the upgrade.**
- Installation
  - **Assuming the cryomodule and rf system installation costs are roughly equal, halving the rf system would save ~½%.**
- Net Savings
  - **Summing the above cost savings yields a total of 2~3% for the half current option.**

From Chris Adolphsen with #'s removed

Other Linac Cost Savings

- Decrease TESLA Cavity Aperture to 60 mm
  - **Harder to tune cavities and 2-times higher wakes**
  - **Lower cryo-load and faster fill (1/2% savings)**
- Half Diameter Quad and BPM
  - **Wakes 10% higher, use superferric quads everywhere**
  - **Saves ½%**
- Second Generation RF System
  - **Marx modulator (1~2%), sheet beam klystron (~3/4%) and circulator-less rf distribution (~1/4%), larger waveguide (~3/4%).**
- Soft energy limit (let uptime decrease as approach within a few percent of 500 GeV).
  - **Save ~1/2% per percent linac overhead**
- Assume lower overhead for cryogenic system.
  - **Save ~1/2%**

From Chris Adolphsen with #'s removed

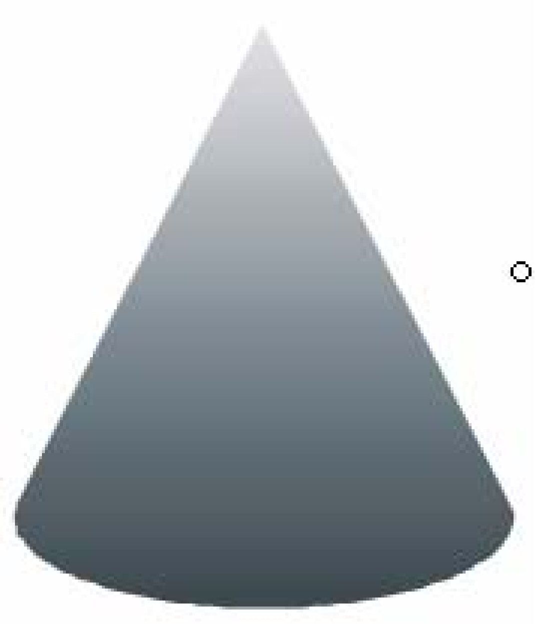
ILC Parameters

- Parameter plane established at KEK ILC mtg
- TESLA TDR pushed parameters:
  - **Emittance dilution**
  - **Disruption and kink instability**
  - **Luminosity enhancement**
- Parameter plane established for flexibility in achieving goal of 500 fb-1 in 4 years
  - **Accelerators rarely optimize at design parm.**
    - SLC, HERA, PEP-II, KEKB, DAPHNE, …
  - **Linear collider has fewer options for optimization**
    - Already used most tricks to maximize specific luminosity

Parameters

TESLA peak luminosity

3×10^{34}

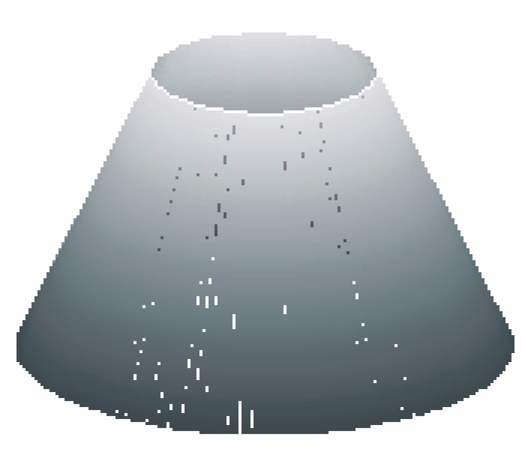


parameter space

- Possible due to very high beam-beam disruption (D_y~25)
- Well into kink-instability regime (unstable)
- Little head room to play with

ILC peak luminosity

2×10^{34}



parameter space

Schematic from Nick Walker, LCWS 2005

Parameter Plane

- Nominal – reduced Dy and more reasonable ε budget → $2x10^{34}$ with similar *L* spectrum
- Provide paths to deal with:
  - **IP: kink instability → Lower Dy (LowN)**
  - **IP: beamstrahlung → Lower dB (LowN)**
  - **Dumps or losses → lower power (LowP)**
  - **RF pulse length → shorter pulse (LowP)**
  - **RF peak power → lower current (LowP)**
  - **LET: emittance preservation → (LargeY)**
  - **DR: SBI → Lower N (lowN)**
  - **DR: CBI or kicker → fewer bunches (LowP)**
  - **DR: bunch length → dual stage BC**

Example Parameter Sets

Parameter range established to allow operating optimization

		nom	**low N**	**lrg Y**	**low P**	**High L**
N	$\times 10^{10}$	2	1	2	2	2
n_b		2820	5640	2820	1330	2820
$\varepsilon_{x,y}$	μm, nm	9.6, 40	10, 30	12, 80	10, 35	10,30
$\beta_{x,y}$	cm, mm	2, 0.4	1.2, 0.2	1, 0.4	1, 0.2	1, 0.2
$\sigma_{x,y}$	nm	543, 5.7	495, 3.5	495, 8	452, 3.8	452, 3.5
D_y		18.5	10	28.6	27	22
δ_{BS}	%	2.2	1.8	2.4	5.7	7
σ_z	μm	300	150	500	200	150
P_{beam}	MW	11	11	11	5.3	11
Lumi	10^{34}	2	2	2	2	

Luminosity Overhead

- The design does not have 2.5x *L* overhead
  - **Linear colliders have limited operating space**
  - **Many parameters are already at the limit**
    - Beam power, gradient, DR emittances, …
  - **Additional parameter space is primarily gained by focusing harder**
    - Requires shorter IP bunch lengths or causes a large increase in IP disruption → some cost impact in BC
  - **High luminosity parameters push everything to the design limit – unlikely to achieve *L***
    - Beamstrahlung increases and degrades luminosity cleanliness while complicating BDS operation
  - **Significant cost savings in low Power design**

Parameter Plane Costs

- Four main cost impacts:
  - **Single stage BC (-1%)**
    - Eliminates options of LowP and LowN
    - Increases risk for DR, LET, abd BDS
  - **Reduced RF system (-2~3% and another -1% civil)**
    - Only allows LowP parameters at full energy
    - Increases risk in LET and BDS but reduces risk in DR
    - Possible to upgrade in quasi-adiabatic manner
  - **Smaller damping ring circumference (-2~4%)**
    - Only allows LowP parameters
    - Increases DR risk – hard to upgrade
  - **Simpler extraction line design → (-0.3%)**
    - Increases risk in BDS; Eliminates option of LowP and limits peak luminosity

Summary

- Clear trade for maintaining parameter plane versus adopting lowP parameters
  - **How important is luminosity goal of 500 fb-1 in 4 years?**
    - Personally believe that operating space will be needed to meet design goals but can lower the goals
  - **How important is luminosity spectrum (Hitoshi's talk)?**
    - Which is preferable 7% reduced energy or LowP only?
    - Reduced RF with full DR → L ~ const vs Energy
  - **Still have parameter plane at reduced luminosity of ~1x10^{34} with reduced rf system**