ILC Cryogenic System Considerations

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TESLA Cryogenic System Overview

- Saturated He II cooled cavities @ 2 K
- Helium gas thermal shield @ 5 - 8 K
- Helium gas thermal shield @ 40 - 80 K
- Two-phase line (liquid helium supply and vapor return) connects to each helium vessel
- Two-phase line connects to gas return once per module
- A small diameter warm-up/cool-down line connects the bottoms of the He vessels (primarily for warm-up)
- Subcooled helium supply line connects to two-phase line via JT valve once per “string” (~10 modules)

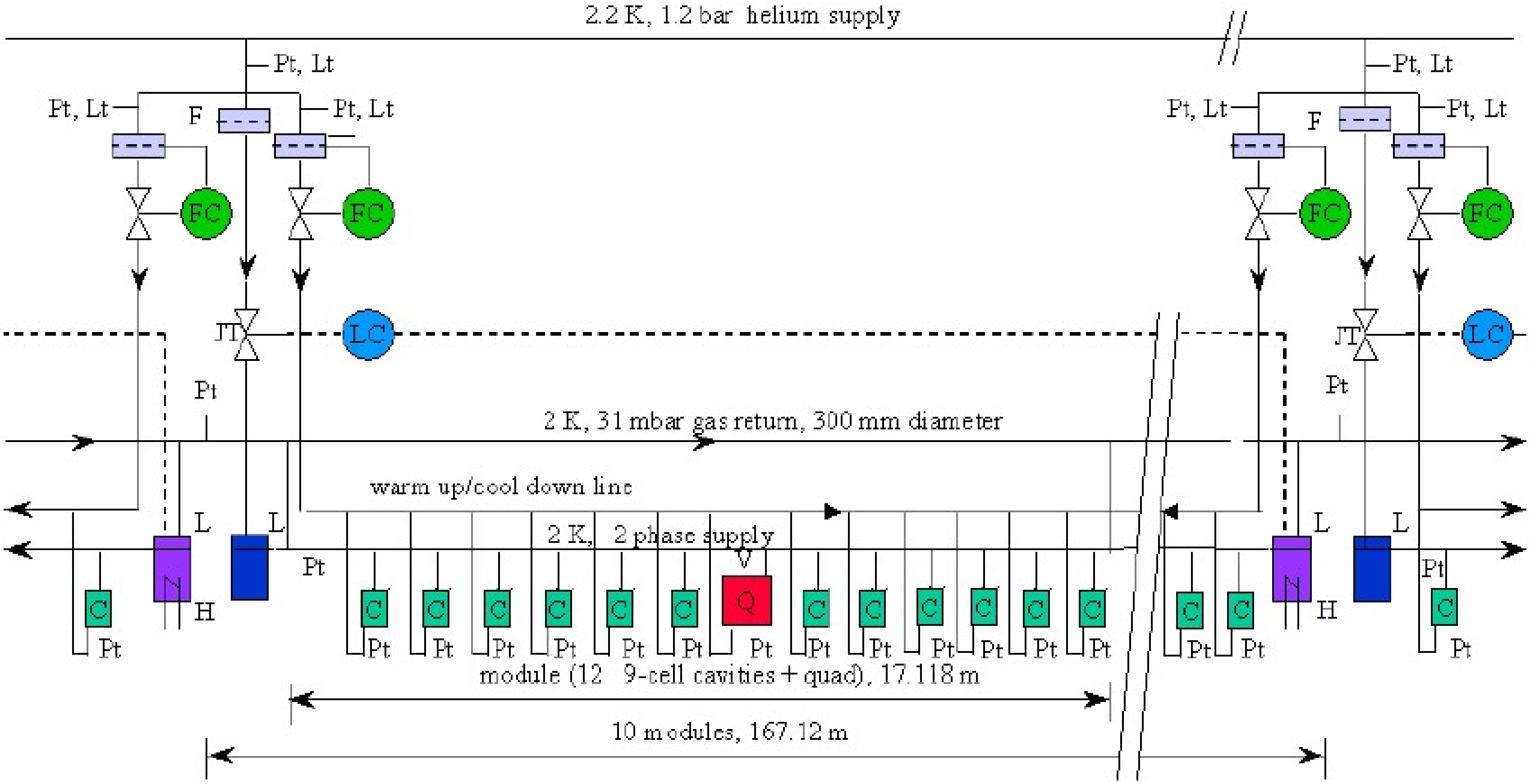

Figure 8.7.3: *Cryogenic string.*

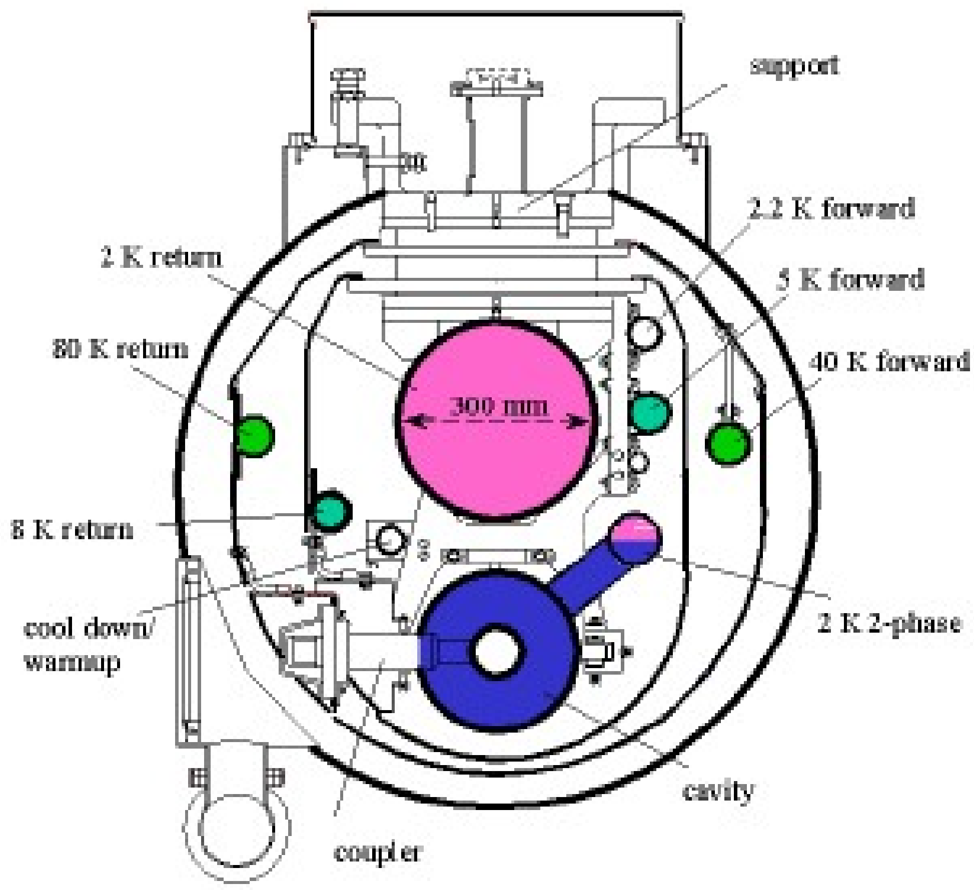

Figure 3.2.11: *Cross section of cryomodule.*

Surface cryogenic plant here with major tunnel access

2 - 2.5 km cryogenic unit implies 4 - 5 km between major surface cryo plants

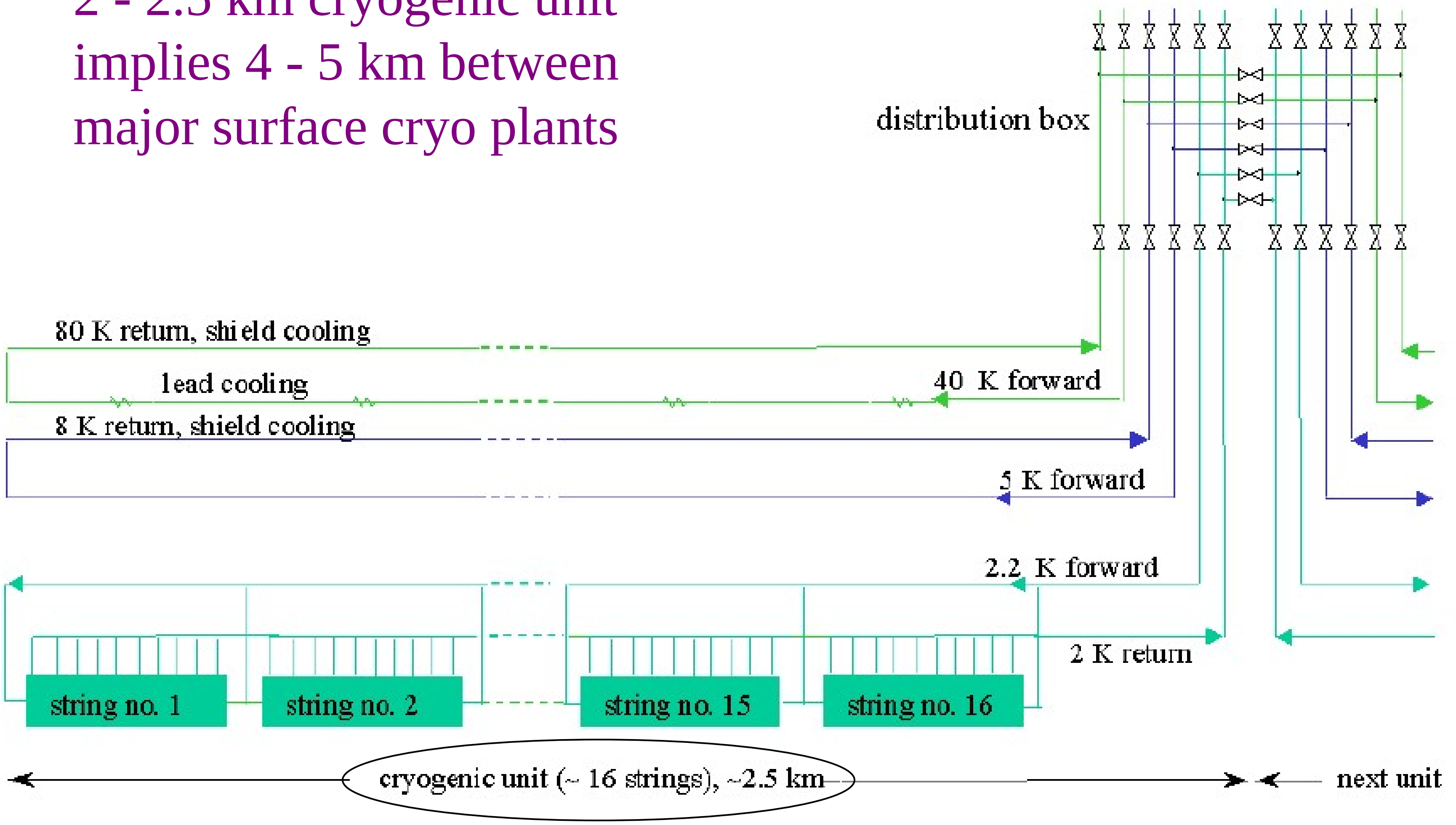

Figure 8.7.2: *Cryogenic unit.*

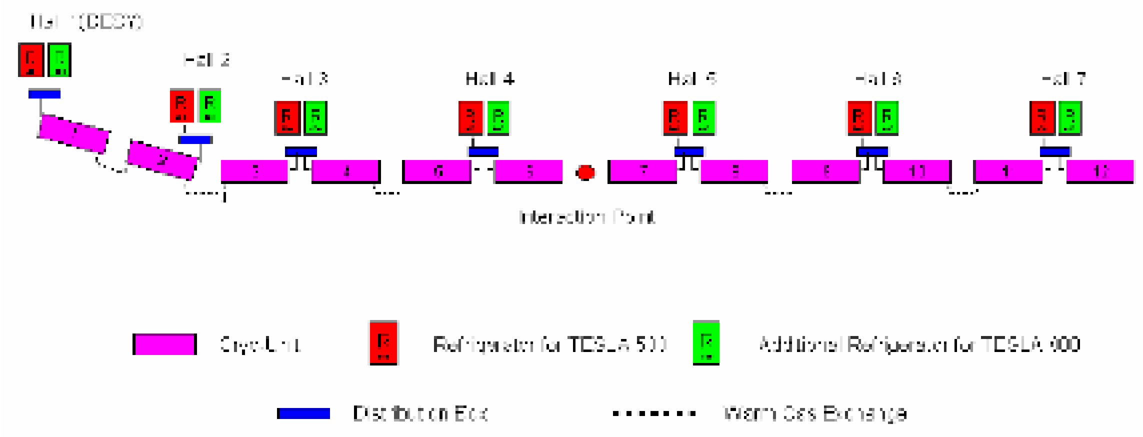

Figure 8.7.1: *Cryogenic system overview.*

Cryogenic System Design Issues

- ILC cryogenic system needs review in light of changing heat loads (about 2X since March, 2001)
  - TESLA TDR string and cryogenic unit lengths may no longer be suitable with ILC heat loads
  - Implications for pipe sizes
  - We should review uncertainty and overcapacity margins
- Cryogenic unit length, plant spacing (TESLA TDR provides the baseline -- about 5 km)
  - Cryo unit length depends largely on 2 K heat load
    - 2 K heat determines 300 mm header flow and pressure drop
    - Refrigerator size (24 kW at 4.5 K) limits cryogenic unit lengths
    - Cold compressor size (~250 gr/sec at 30 mbar) maximum?
    - ILC at 35 MV/m, Q0 = 8x10^9, 5 Hz is already somewhat exceeding the limit of plant size with TESLA spacing

Cryogenic System Design Issues (2)

- String length depends partly on 2-phase liquid supply flow velocity -- some issues remain
  - String 2-phase flow control is difficult.
    - 10 cm/sec liquid flow velocity (LHC experience) means 1/2 hour time constant for control based on end level
    - Difficult transient when RF turns on
    - Perhaps lowering the position of the cool-down/warm-up line allows it to help equalize liquid levels
  - Vapor and liquid flow may be in the same or opposite directions
- Quadrupole cool-down and warm-up in parallel with cavities needs some thought (different masses and flow impedance)

Details Regarding Elevation

- Depth of access shaft
  - Hydrostatic heads, at some height some active refrigerator elements have to go to the tunnel level, like LEP and LHC
  - Result is civil engineering cost
- 1mbar/10 meters elevation difference for 2 K saturated vapor
- So 30 meters depth implies about 3 mbar loss, about 10% of pumping pressure, a "soft" limit (the entire 2.5 km, 300 mm pipe will have a comparable loss)
- For a depth greater than 30 m, one should consider placing some portion of the cryogenic refrigeration system in a cavern at tunnel level

Illustration of "split" refrigerator

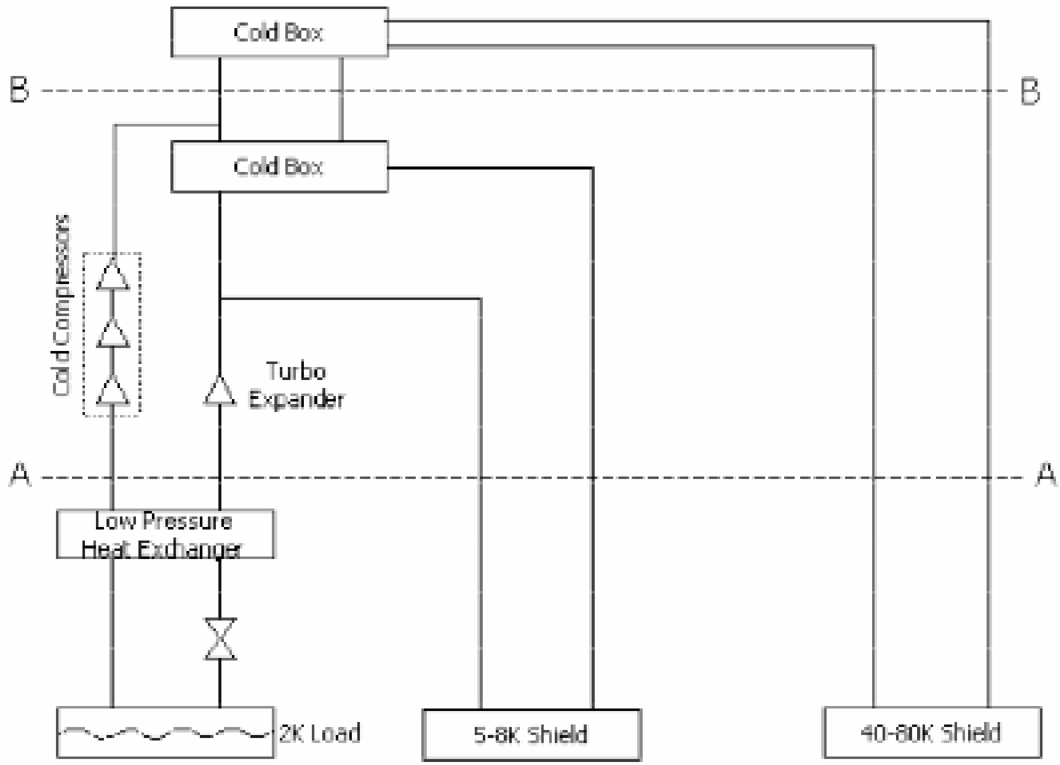

Figure 3.5.7.3: Simplified cryogenic plant schematic

Cryogenic System Design Issues (3)

- Linac upgrade scenario (would like input)
  - Missing cavity scheme
  - Missing cryogenic unit scheme (extend tunnel?)
  - Increase cavity accelerating gradient?
- Slope of system (gravitationally level is desired baseline)
  - Liquid level in 2-phase helium supply pipe
  - Hydrostatic heads
  - Flow direction (co-current vapor and liquid is better)

Cryogenic System Design Issues (4)

- Divisions (or sectorization) for warm-up and repairs
  - Not in TESLA TDR (?). Still need to review concepts.
  - Consider repair intervention into insulating vacuum
  - Consider replacement of entire module
  - Parallel lines for bypass? Separate cryo line? Periodic valve boxes which can serve as alternate end boxes?
  - Keep cold sections "floating" while adjacent section warm is easier than continued cooling--consider helium inventory and how one forces the warm-up of the isolated section
- Required temperature stability (would like advice)
  - Power turn-on results in pressure/temperature excursion
  - Temperature uniformity, temperature profile, along cryogenic unit
- System reliability, impact of thermal cycles -- much reliability information will come from LHC!

Cryogenic System Design Issues (5)

- Other operation modes (remember to size valves and pipes for these various modes). Some work still required regarding these other operational modes
  - 80 K standby
  - 80 K redundancy for cryo plant turned off
  - 4.5 K cold standby (cold compressors off, helium vessels full of helium)
  - Cool-down and warm-up
- Consider alternative cryoplant configurations such as “satellite” 2 K plant (this goes beyond the baseline but provides some possible cost savings)
  - Grouping of cryo plants, but . . .
  - Parallel operation of cryo plants presents difficulty

Cryogenic System Design Issues (6)

- Safety and upset conditions
  - Loss of beam vacuum or insulation vacuum and venting of helium vessels with pressure limit of 4 bar (?)
  - Location and frequency of venting devices
  - Recovery of helium and transport to surface
  - Oxygen Deficiency Hazard considerations
- Model refrigerator refinements
  - Phase separators at 4 K supply and 2 K return levels
  - Mixing for control in cold compressor inlet T
  - Possible replacement of first stage compressors with centrifugal machine (gain efficiency, fewer machines, perhaps capital and operational cost savings)
- Second tunnel may provide radiation protection for instrumentation electronics, reducing some costs

A few more details to review

- Temperature sensor locations as listed in TESLA TDR should be reviewed
- Cool-down/warm-up supply header size
  - Increase size to reduce number of valves (why two CD valves per cryo string?)
- Need 5 K thermal shield, or would 5 K intercepts on couplers, etc., be sufficient? This issue has been studied before, but we should have another look in light of heat load changes and other design changes

TELSA 500 and ILC compared

- TESLA 500 (March 2001 TDR) with 23.4 MV/m, Q0 = 1×10^{10}, 5 Hz
- 17 m long module, 12 cavities per module
- 2 K heat load of 9.05 W/module
- Maximum cryogenic plant size is about 24 kW (the largest produced by industry) *for cooling two cryo units*
- Total cryo power is equivalent to 146 kW at 4.5 K, which is about equivalent to LHC

- ILC with 35 MV/m, $Q_0 = 8 \times 10^9$, 5 Hz
- 11 m long module, 8 cavities per module
- 2 K heat load of 16.7 W/module
- Maximum cryogenic plant size is about 26 kW *for cooling one cryo unit* (of TESLA 500 length, 2.5 km)
- Total cryo power is equivalent to 316 kW at 4.5 K, which is about equivalent to 2.2 LHC's

Some Cost Considerations

- About 50% of the ILC refrigeration power goes to 2 K cooling, and of that, about 90% is the dynamic portion of the 2 K load.
- At about 3.6 kW at 2 K plus the predicted 5 K and 40 K loads, we are at the 24 kW, 4.5 K equivalent load limit for large helium cryoplants. At 35 MV/m, Q0 = 8x10^9, 5 Hz, we are there.
- As we increase cooling power, we are adding more cryoplants and adjusting plant spacing, so scaling is not with the 0.6 power of the load, but may be more nearly linear with total cooling required.
- Clustering of plants may be possible to some extent, but 2 K cold compressor spacing will still be limited by 300 mm header pressure drop and cold compressor sizes

Cryogenic plant spacing as set by the practical limit of total capacity for a single plant equivalent to 24 kW at 4.5 K.