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HIGH LEVEL RF TECHNICAL SYSTEMS GROUP

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I. HLRF WORKING DECISIONS

1. Main Linac

1. *Tunnels*: The Baseline model is a two-tunnel system with a Service Tunnel containing all equipment other than the beam structure and immediate supports, and a parallel Beam tunnel. The Service Tunnel will be a nominal 5m in diameter and has been sized to accommodate the RF equipment and supports. Sizes have been taken from DESY klystron and modulator models with some proposed modification of the modulator packaging into a thinner cabinet.
2. *RF Station Footprint:* All components will be along one side of the tunnel to leave adequate space for (a) transport vehicles, (b) personnel, and (c) safety and working clearances around equipment. The maximum width of the large RF station components will be nominally 1.3 meters. The maximum length of all components together including linear clearances will be 34 meters (2 meters minimum at each end between stations).
3. *Penetrations:* Three penetrations will be provided between tunnels. The maximum diameter is based on radiation considerations. Three waveguides will occupy a single penetration and fan out in the Beam tunnel to three cryomodules. Two other penetrations will carry separately power cables and low level signal and control cables. The waveguide penetrations will be sized according to needs for insertion space and proper separation of power, high voltage and low level signal cables.
4. *Modulator Power Source:* The main power source in the support tunnel will be a 34.5 kV AC line. This will be tapped at every RF station to provide a step-down to 12 kV AC for the charging supply which delivers 10kV DC to the modulator. The transformer will be a commercial unit rated for the 150kW average pulsed load with at least a 20% overhead. The unit will include the switchgear necessary to isolate the single modulator while adjacent units continue running.
5. *Charging Supply:* The current Baseline charger has a 480V to 10kV step-up transformer. In the ILC installation with primary power at 34.5 kV, this unit will be redesigned to accommodate 12kV input power to eliminate the transformer and reduce the footprint.
6. *Rack Equipment Power Source*: Rack equipment will be powered from a 120/208V nominal 3 phase AC source transformer that will power racks for a maximum of 4 RF stations. The distribution will fed the racks so that a failure at a single rack can be isolated from other racks so the other racks remain operational. Lower level tunnel area lighting will be powered from an independent source. Internal rack lighting may be desirable for tasks that are done when the rack door is open
7. *DC Emergency Power*: The control and safety systems will require some level of emergency DC power to ensure safe shutdown and egress in case of a general AC power failure. The primary DC load will be the interlock and protection systems including the personnel protection (PPS).
8. *Equipment Racks Subsystem:* Each station has approximately 6 racks plus at least one spare for unforeseen needs. Racks containing support equipment such as controls, instrumentation, LLRF electronics, motor drivers, vacuum and magnet power supplies will be closed and cooled by circulating air through an internal rack air-water

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heat exchanger. All racks will be procured according to standard features and performance specifications, taking into account operational needs and costs.

9. *Rack Height*: The rack height shown on current drawings appears shorter than necessary and should be reviewed to see if a taller standard rack can be accommodated. Racks need overhead clear space for AC distribution getaways, circuit breakers, and rack cooling system getaways. The tallest possible racks should be used to minimize the number since instrumentation and cooling costs are almost constant up to 10kW dissipation..

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10. *Rack Footprint:* The footprint we will use from one of the commercial water-cooled racks is hxwxd = 2000x800x1100 mm. These racks have side air and cable plenums and heat exchangers and are fully instrumented with feedback temperature control[1], which makes about 200mm wider and 340mm deeper than a typical un-cooled rack (2000x600x760mm).
11. *Rack Cooling Water*: The water inlet temperature for racks should not exceed 25C and water and air flow sized to keep the maximum temperature excursion in the rack to approximately 5C[2].

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12. *Klystron Oil Tank:* The klystron will have an independent oil tank covering the high voltage cathode end, with a cable connection from the modulator pulse transformer.
13. *Klystron Windows:* Windows should be mounted in the transition sections vertically with respect to the normally installed position of the tube.
14. *Waveguide Distribution:* The waveguide system that attaches to each cryomodule should be designed to be mounted on the module and the matching adjusted prior to loading into the tunnel. This minimizes assembly operation once installed to a single RF connection. The cryomodule waveguide needs to be on the aisle side of the tunnel for service access.
15. *Klystron Power Dissipation:* At full power the klystron power rating will be exceeded if the beam is interrupted. In this case the pulse repetition frequency (PRF) will be reduced from 5 Hz to 3 Hz[?] to keep dissipation within ratings.

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[1] We assume racks are independently water cooled for optimum protection and performance of electronics, and to avoid sending any heat from rack electronics into tunnel air. Current estimates are that the amount of heat dissipated in all support racks for a linac RF station is approximately 13 kW spread among approximately 6 racks. Commercial racks are available from several vendors and a learning-curve derived estimate has been used in the recent cost buildups. We are currently in process of gathering rack details to make more precise estimates of the actual number required and drawings of placement in the tunnel. These racks have both front and rear doors that require working clearances.

[2] In recent discussions on the subject of maximum allowable instrument temperatures in racks, Brian Chase estimated a maximum internal outlet air temperature of 40C, which means components are running hotter than 40C, and a 10C maximum water-to-air delta T, or 30C inlet water. But to have some compliance for regulation he suggested specifying 25C inlet water, the same number quoted above. The purpose of going to 40C would be to reduce flow to save water capacity. The lowest water inlet temperature that will avoid condensation is preferable because in general electronics lifetime degrades exponentially with higher temperature. This is probably 20C, depending on tunnel humidity. Commercial instrumentation is typically specified to operate at 50C ambient so in some racks it may be possible to set a higher water inlet temperature, but for LLRF and precision instrumentation we recommend not exceeding 25C.

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2. ELECTRON SOURCES WORKING DECISIONS

3. POSITRON SOURCES WORKING DECISIONS

4. DAMPING RINGS WORKING DECISIONS

5. RINGS TO MAIN LINAC WORKING DECISIONS

6. BEAM DELIVERY WORKING DECISIONS

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II. HLRF SYSTEM DESCRIPTIONS

1. Main Linac HLRF Functional Description

1.1 Baseline Conceptual Design (BCD) System Definition

1.1.1 The High Level RF (HLRF) system consists of approximately 670 10 MW RF Stations, comprising the complete power train from wall plug to RF outputs of the delivery system at the superconducting cavities of the Main Linac (ML), e+ and e- Source booster linacs and Ring-To Main-Linac (RTML) compressors. Each ML station distributes RF power to twenty-four accelerating cavities housed in three Cryomodules of eight cavities each, about 36 meters of accelerator structure.

1.1.2 The major components of each station starting with the 34.5 kV HV power distribution are: 34.5-12 kV step-down transformer and switchgear, modulator charging supply, modulator pulse-forming system, HV cables, 10–120 kV output step-up transformer, klystron, and HLRF distribution system from klystron to RF accelerating structure.

1.1.3 Each station includes auxiliary support systems such as: Klystron filament and focusing magnet power supplies; klystron, waveguide and cryomodule blanket vacuum power supplies; water flow, temperature, safety interlock controls and monitoring; and Main Control System interface. These systems all reside in local racks near the HLRF components.

1.1.4 Also in the local racks is a Low Level RF (LLRF) subsystem for each station that dynamically monitors and adjusts power and phase of every cavity with respect to an RF reference line and the beam itself to optimize the power contribution of every klystron to the beam energy. This subsystem includes the RF drive amplifier to the 10 MW klystron; tuner motor drives for waveguide distribution; cavity motor and piezoelectric tuner drives; and RF diagnostic monitors for forward and reverse energy to each cavity.

1.1.5 Additional local rack subsystems are: Cryomodule vacuum pump drivers and temperature monitoring; XY Beam Position Monitor electronics; and power supplies for cryogenic Quad focusing and XY Corrector dipole steering magnets.

1.2 System Component Details

1.2.1 <u>Modulator</u>

1.2.1.1 The modulator has two main sections, one that switches current from the charged capacitor bank to the output to the pulse transformer, and a bouncer that discharges another capacitor bank to compensate the capacitor droop to produce a pulse that is flat to less than 1% for the ~1.5 millisecond duration. The flat top is 1 millisecond and the leading edge beam loading section is ~0.45 milliseconds. The switch is a dual redundant series on-off IGBT array that partially discharges the capacitor bank.

1.2.1.2 The modulator IGBT switches are water-cooled.

1.2.2 <u>DC Charger Supply</u>

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1.2.2.1 The charger replenishes the storage capacitor after each pulse back to 10 kV in a time of less than 200 milliseconds for 5 kHz operation. The current design operates from 480V AC and contains an oil-filled step-up transformer.

1.2.2.2 The oil-filled transformer may be water-cooled or air cooled.

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1.2.3 Modulator Output Cables

1.2.3.1 The current design has four (4) cables in parallel to match the impedance of the pulse transformer-klystron load combination. This design can accommodate cables up to 2.5 km length. In the current model, klystron and modulator are co-located so the cables are very short.

1.2.4 Pulse Transformer and HV Output Cable

1.2.4.1 The pulse transformer steps up the 10 kV at 1680A to 120 kV at 140A delivered to the klystron. The housing is oil-filled and water-cooled.

1.2.4.2 The HV output will be a single short cable to a separate oil tank at the cathode of the klystron.

1.2.5 Klystron and Supports

1.2.5.1 The klystron will be similar to current commercial Multi-Beam designs but will be horizontally mounted to more easily fit into the tunnel. It will have a separate oil-filled tank around the cathode end to receive the HV input cable.

1.2.5.2 Local power supplies will provide power to focusing electromagnets and cathode heater.

1.2.6 Protection Interlocks & Controls Interface

1.2.6.1 All monitors, interlocks and controls for the station will be supervised by a local Programmable Logic Controller (PLC) system and reported to the main control system by Ethernet link. This will include interlocks from the Personnel Protection System.

1.2.6.2 The klystron will have special protection from damage from klystron arcs or external equipment arcs, consisting of local transient protection as well as fast-turnoff of the modulator switch when an arc is detected.

1.2.7 Waveguide Distribution

1.2.7.1 The waveguide distribution consists of splitters, combiners, protection circulators, tuners and couplers. All components are available as standard units but the final system will be optimized for functionality and cost. Power from two klystron windows at 5 MW each is split and recombined at the klystron to provide three waveguides at 3.33 MW maximum each. Waveguide system losses plus the need to provide an operating overhead for the klystron for feedback delivers approximately 8 MW to the 24 cavities or about 330kW per cavity.

1.3 Main Linac Support Tunnel Configuration

1.3.1 Support Tunnel

1.3.1.1 Maximum width widest RF component

1.3.1.2 Maximum height RF components

1.3.1.3 Maximum Length All Components

1.3.1.4 Aisle Keep-Clears

1.3.1.5 Rack Footprint Requirements

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1.3.2 Penetrations
1.3.2.1 Three separate penetrations are needed, one each for Waveguides, Power Cables and Signal Cables.
1.3.2.2 Welded waveguides with cooling attached require penetration diameter of 48 cm (~19 inches) diameter.
1.3.2.3 Power cables consist of DC power for cold magnets and HV (~5 kV) DC low current cables for Vacuum Pumps mounted on structure. HV cables must be separated in tray or conduit from low voltage magnet DC cables.
1.3.2.4 Signal cables consist of all low loss coaxial cables carrying Low Level RF, timing and RF reference signals. Separate conduits may be desirable through the penetrations to provide separation and shielding of sensitive analog from digital cables.

1.4 Other Main Linac Subsystems

1.4.1 Low Level RF
1.4.2 Beam Position Monitors
1.4.3 RF Monitoring
1.4.3.1 Cavity Power
1.4.3.2 Cavity Forward & Reverse Power
1.4.3.3 RF Load Temperature
1.4.4 Power Supplies
1.4.4.1 Cryogenic Quads
1.4.4.2 Cryogenic XY Correctors
1.4.5 Cryomodule vacuum pump drivers
1.4.6 Cryomodule temperature sensors
1.4.7 Cryomodule Tuner Drivers & Motors
1.4.7.1 3-stub tuner drivers
1.4.7.2 Cavity tuner drivers
1.4.7.3 Piezo tuner drivers
1.4.8

1.5 Tunnel Infrastructure

1.5.1 *AC Power*
1.5.2 *High Voltage AC Power for the DC Charger Power Supply to the Modulator:*
1.5.2.1 DC Charger Power Supply power will be tapped from the main 34.5 kV line and stepped down to approximately 12 kV AC in a separate 225 kva transformer at every station. The transformer will provide power only to the DC Charger Power Supply and will be an enclosed unit with integral switching under oil.
1.5.2.2 *Rack Power:* 3-Phase 208/120V AC power will be supplied by a separate AC transformer supplying the racks for no more than four (4) RF stations rack sets.

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1.6 Cooling Water

1.6.1 Table of Flow, Temperature Requirements

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1.7 Cable Plant

1.8 Radiation

1.9 Temperature

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