1) Vertical Test

1. Motivation/Purpose – Cavity Acceptance Criteria

    a. what range of Q0 for qualification? should we look at Rs_res, Rs_BCS for acceptance? (example, if cavity has good BCS but very large residual that can be from mag field, triggers re-test under improved field conditions)
    b. What minimum gradient for qualification? Do we set an admin limit? at what field?
    c. what FE level and what field triggers reprocessing?
    d. for reprocessing, how many times? when to re-EP?

2. Test Procedure – (including infrastructure and instrumentation)
    a. Active pumping or not
    b. Standardizing the instrumentation - decide what, how many, locations
        i. Field emission instrumentation: two locations (top, bottom, discuss)
        ii. Fluxgates
        iii. Temperature sensors
    c. Cooldown procedure, acceptable mag field levels? should we use PID controller to zero the mag field during the cooldown via coils?
    d. Conditioning procedures, administrative limits?
    e. Q disease test – not needed?
    f. Test at different T? only 2K? 2, 1.8, 1.5K?

3. Test Reports format and content

2) Horizontal Test

Motivation/Purpose

Unlike vertical testing, HTS testing is not intended to determine if a cavity meets the project-specified performance requirements. Likewise, HTS does not provide a final assurance that a cryomodule or its components are ready for installation into the linac, as cryomodule testing does. Rather, it is used in the context of cryomodule production to provide the following information as a kind of secondary check and risk-mitigation:

1. Are the processes, procedures, tooling, and staffing yielding the required performance of the combined SYSTEM when assembled from qualified individual components and
2. Are the vendor-supplied components conforming (or still conforming) to required performance specifications when used/operated under conditions similar to those encountered during cryomodule operation (and which cannot be duplicated “on the bench”).
3. If unforeseen performance issues arise in early cryomodule tests that require either iterative

investigations in a cryomodule environment or evaluation of a modified or re-designed component or procedure, this can be done with a scheduled HTS test.

4. Facilities at other partner labs (e.g, Cornell) could be dedicated to long-term stability or lifetime tests of systems/components (tuner, LLRF) long before they could be pursued in cryomodules, and allowing for timely feedback into production.

Measured Parameters

1. Determine cavity gradient limit (16MV/m + margin (TBD), administratively limited), with little or no FE. (verifies that the cavity assembly (FPC) or transport/handling has not introduced any contaminants to the RF surface)
2. Determine cavity Q_0 at E_{op} . (Verifies that the RF surface treatment has not been compromised, that there is no undue influence from magnetized parts, no unacceptable heating of end group from HOMs/FPC)
3. Verify Tuner operation (range, center freq, deadband, pre-load, PZT & stepper operation). verifies that the complicated tuner assembly has been performed correctly and that parts' tolerances are acceptable, that PZTs and tuner motor operate reliably in a cryogenic/vacuum environment, and that warm pre-load/pre-tuning achieves desired 2K cavity frequency.
4. Verify acceptable HOM and FPC heating, HOM power extraction (perfomed concurrently with 1.) above). Verifies that notch frequency and HOM antenna lengths are correct and more importantly that HOM and FPC thermal strapping provides adequate thermal management, and that the FPC can reliably operate at full power level and Q_{ext} target and adjustment range is being achieved

Since this is a restricted number of tests which would have well-defined acceptance criteria, the cold test duration is compressed to about 7 working days (potentially less). Reserving about 2 ½ working weeks for installation, cooldown, warmup, and removal, an entire HTS cycle can be accomplished in just under 4 weeks.

3a) Prototype Cryomodule (pCM) Test

Motivation/Purpose

pCM testing will verify engineering design that was not fully tested during the horizontal cavity test, namely the fast cool down and warmup for an entire cavity string. pCM testing should provide optimized cryogenic operational procedures for maximized cavity performances.

pCM testing should also validate production test plan, identify changes that need to be made and ensure that we are getting the same information from both test facilities. This is separate from topics to be addressed in production CM testing session.

Goals:

1. A complete written test plan for the production CM testing.
2. The first 2 CMs for LCLS-II.

3. An optimized cryogenic operational procedures for linac operation

1. Measured Parameters - pCM Module Testing acceptance criteria (25 min)

   a. Usable Gradient
   b. Maximum testing gradient (VT max – 2 MV/m?) (nominal Eacc + 2 MV/m, whichever is smaller)
   c. Q_0 of each cavity or only average Q_0 of module
   d. Q_0 as a function of temperature
   e. Q_0 as a function of coupler Qext
   f. Resistance calculations R_{BCS}, Rs_res
   g. HOM Qext
   h. Static heatload and total heatload of 2K, 5K, 50K circuits
   i. FE onset
   j. FE@nominal
   k. FE maximum – admin limit
   l. Dark current measurement
   m. Ancillary component measurements
      i. Quadrupole magnet operation and temperature measurement
      ii. Magnetic operational effect to cavity Q
      iii. FPC adjustment range verification
      iv. FPC load to 5K intercept and 50K shield
      v. Off- resonance coupler conditioning
      vi. Tuner & piezo range test and resolution
      vii. Microphonics measurements
      viii. Cavity pressure sensitivity
      ix. Cavity Lorentz force coefficient
      x. BPM function test
      xi. Operation of new LLRF and SSA systems – needs to be integrated with SLAC – beyond scope of this workshop (RF bandwidth, amplitude and phase control, interlocks, machine protection for cryomodule)
   n. Cavity magnetic hygiene
      i. Magnetic shield temperature monitoring
      ii. Mag shielding performance
      iii. Active compensation implementation

2. Test Procedure / Measurements need to be standardized – (including infrastructure and instrumentation)

   a. What is the cryogenic configuration at each lab?
   b. How do we ensure the module cooldown plan is the same at both labs?
   c. How will this be transferred to cooldown process at SLAC?
   d. How is the fast cooldown performed & documented?
   e. Fluxgate magnetometers mounted inside the HV on cavities 1,4,5 & 8.
   f. Active magnetic field compensation coils on the module (time to study operation will be during pCM testing)

g. Instrumentation and layout for field emission measurements
h. Temperature measurements
i. Connection between Cryo and RF measurements (including fast and slow cool down)
j. Connection between fast cool down and active magnetic coil condition
k. RF components and calibration methods, including phasing process if possible
l. Cavity gradient measurement methods
m. Cavity Q0 measurement methods
n. Q0 vs. time of 2K soaking
o. Cavity RF conditioning limit

3. Test Reports format and content
    a. Development of Standardized test report
    b. Development and use of CM testing Travelers

3b) Production Cryomodule Test

1. Motivation/Purpose – Production CM Acceptance Criteria
    a. When to reject; how long does one troubleshoot before warming up and removing?
    b. What is the Rework plan?
    c. Magnetic Shielding
    d. Acceptance criteria – How are tests ranked?
    e. Usable Eacc (operating vs. breakdown or administrative limit)
    f. Q0
    g. Rs_res,Rs_BCS (are R measurements possible on a CM?)
    h. Onset of FE, magnitude at nominal gradient
    i. Dark current
    j. Coupler condition
    k. QE range
    l. Tuner/piezo range & resolution
    m. Microphonics/LFDC

2. Test Procedure
    a. What are the critical Cryogenic operating parameters and acceptable limits? How long a cold soak after cool down is needed?
    b. What are the acceptable vacuum limits in all three circuits – beam tube, coupler, insulating. Are RGA scans needed?
    c. What instrumentation needs to be standardized especially with respect to position relative to the cryomodule and readout (especially for Field Emission)?
    d. Cooldown/Test procedure – how to verify flux expulsion/minimization given different test set ups
    e. What to test – overall performance with all cavities on, and with single cavities For many couplers this will be the first operation at cold. How extensive are single cavity tests?
    f. Ancillary systems – what and how does one measure/verify thermometry, BPM, magnet, etc?
3. Test Reports format and content
    a. Standardized test report definition

b. Development and guidance for the use of CM testing Travelers