3.9 GHz Cryomodule Testing

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LCLS-II 3.9 GHz CM Delta Final Design Review

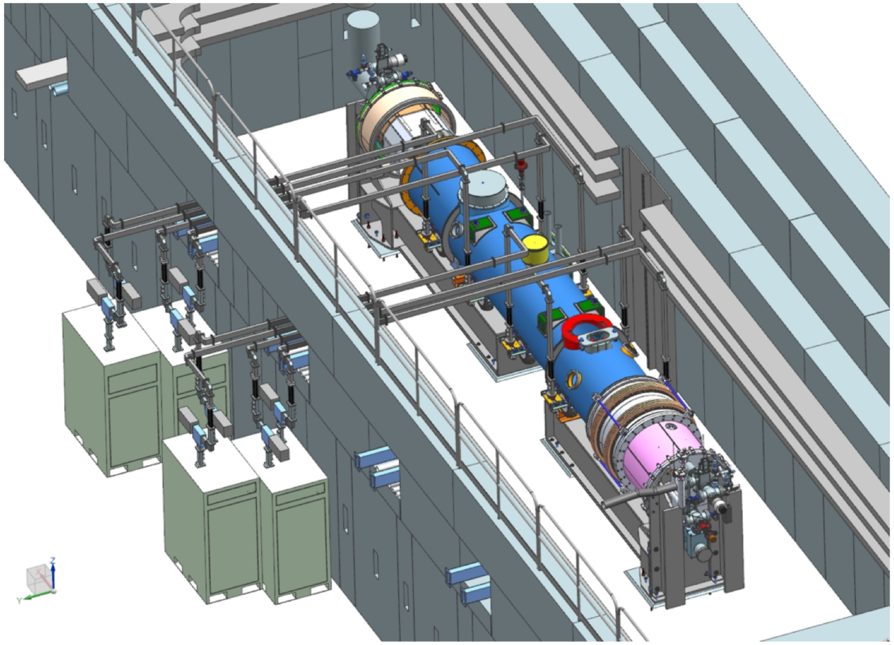
29-30 January 2019

Outline

- Status of and plans for infrastructure modifications
- Cryomodule handling at CMTS
- Status of test plan and traveler
- Lessons learned from 1.3 GHz
- Respond to charge questions:
  - Q5: Is the design likely to meet performance expectations?
  - Q8: Have lessons learned from the 1.3 GHz cryomodule quality assurance, assembly and test been applied?

Test stand infrastructure

- Move end cap girder
  - ~half the distance to the feed cap
- Replace cabling in cave as needed
- Cryo unchanged
- Reviewing/comparing instrumentation differences with 1.3 GHz
- 6-8 week changeover
- Testing at ~1/month rate

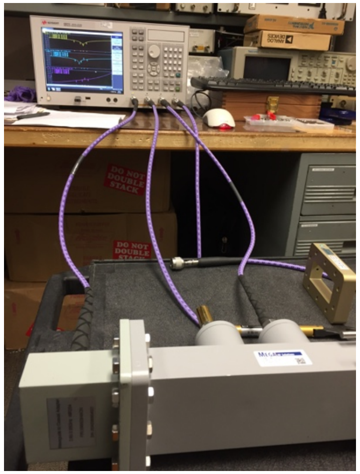


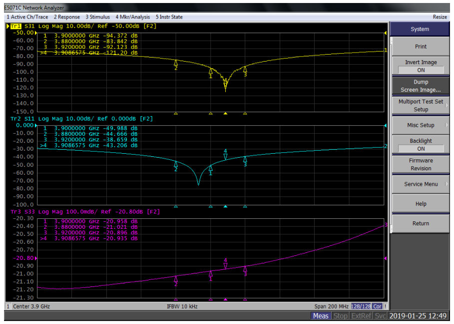
Test stand infrastructure – RF

- 3.9 GHz Amplifiers
  - All SSA’s in hand
  - One at CMTF and getting prepped for testing
  - Acceptance data received from SLAC
- LLRF will be different
  - Use the LCLS-II production system
  - Commissioning time will be needed
  - Schedule, staff availability of some concern

Test stand infrastructure – RF

- All RF distribution hardware received
  - Characterization in progress
  - Waveguide through wall pre-installed





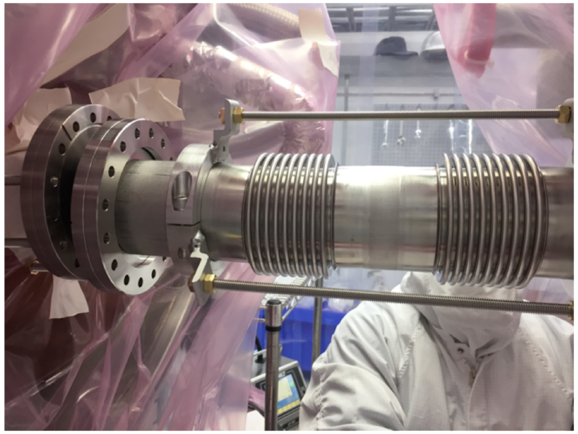
Mega WR284 Dual Directional Coupler
Jan, 2019 --- Feb, 2019
Data @ 3.9 GHz

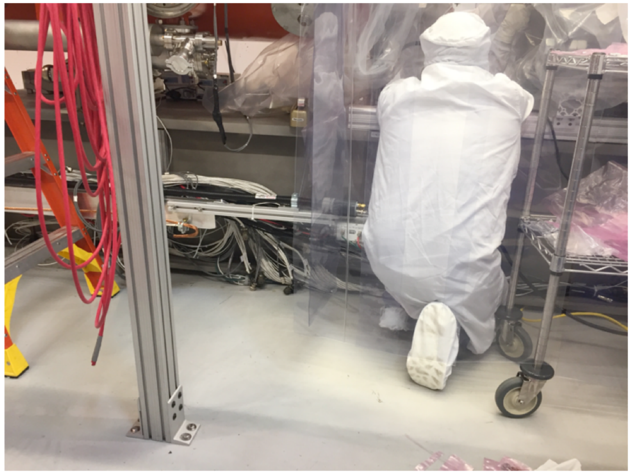
Part No	Insertion Loss (from Input to Output Port) db	Return Loss (Input Port) db	Forward Coupling db	Reflected Coupling db	Return Loss (Output Port) db	Return Loss (Forward Coupling Port) db	Return Loss (Reflected Coupling Port) db	Directivity at Forward Coupling Port db	Directivity at Reflected Coupling Port db
1845196	0.007	41.720	40.196	40.498	41.065	22.789	22.003	34.117	38.064
1845194	0.007	38.461	40.439	39.944	39.671	22.788	20.827	43.875	48.447

Courtesy Ding Sun

Cryomodule handling at CMTF

- Vacuum and cryogenics connections are identical to 1.3 GHz cryomodules
  - Use clean room practices where appropriate
- 1.3 GHz experience valuable
  - Proven quality techniques and staff
  - All aspects
    - Arrival
    - Installation
    - Prep for test
    - Cooldown
    - Cold testing
    - Warmup & removal





Test stand operation – ESH&Q

- ESH&Q engaged
  - ORC for 3.9 GHz is being planned for
  - Existing shielding and detectors appear adequate
    - Do due diligence and confirm
  - TLM detector already modified
    - Runs the length of the cryomodule
    - Split into 2 parts to ensure easy switchover for shorter length.

Status of test plan & traveler

- Acceptance criteria drafted
  - Under initial review
- Test plan under development
  - Based on 1.3 GHz plan with appropriate changes
- Traveler draft prepared and under review
  - Based on 1.3 GHz Test Traveler, # 464421

Acceptance criteria (draft)

Table 1 Production Cryomodule Minimum Acceptance Criteria

Parameter	Value	Minimum acceptable performance during test
Minimum acceptable operating gradient for an individual cavity	16 MV/m based on past VTS results	Requires radiation associated with the cavity measured outside the CM be < 50 mR/hr and the quench level be at least 0.5 MV/m higher than the operating gradient Usable gradient shall be defined as stable operation for at least 1 hour of c.w. operation.
Minimum CW voltage produced by an individual cryomodule	41 MV	The total CW voltage produced by an individual cryomodule shall be 41 MV and an average of cavity gradient ≥14.9 MV/m with 8 cavities operating simultaneously.
Minimum cavity gradient at onset of field emission	12 MV/m	The onset of measurable field emission shall be at a gradient of ≥ 12 MV/m
Captured dark current	<1 nA	The dark current as measured by Faraday cups at each end of a cryomodule at the minimum CW voltage as defined above shall be ≤1 nA when the cavities are operated in GDR mode with the relative phases set to accelerate speed of light electrons.
Average cavity Q_0 within a cryomodule	1.5×10^9 Nominal $= 2\times10^9$	Average Q_0 of cavities within a CM $\geq 1.5\times10^9$, measured at 13.4 MV/m
Cryomodule operating duration with RF power during test		Each cryomodule must operate at the minimum CW voltage or greater until the coupler temperatures achieve equilibrium or for a minimum of ten (8) hours continuously, whichever is less, to verify stable operation and confirm acceptable coupler heating
Cryomodule heat load during test at 8 cavities at 14.9 MV/m Q0 = 1.5E09 *2-phase pipe heat load capacity ~300 W (limitation is Kinney pump)*		Dynamic 2 K ≤ 189 W; Dynamic 5 K ≤ 8 W; Dynamic 45 K ≤ 92 W Static 2 K ≤ 7 W; Static 5 K ≤ 17 W; Static 45 K ≤ 123 W Total 2 K ≤ 117 W; Total 5 K ≤ 25 W; Total 45 K ≤ 215 W The impact of end caps in cryomodule testing is estimated to be <1 W
Cryomodule thermometry		All installed thermometry shall be verified functional by observing consistency in output with operational conditions. For sensors measuring identical locations on components within a cryomodule there shall be variation of no more than 0.2 Kelvin under the same conditions at each component and under static load with no power applied to the cavities or magnets
Cryomodule liquid level sensors		Liquid level sensors shall be verified functional by observing liquid levels and changes therein consistent with liquid supply rates and estimated boil-off rates
Cryomodule cryogenic valving		JT valve, CoolDown/Warm up valves shall all be verified functional during cryomodule operations by consistency with expectations for operational performance, in particular, no valve is to have ice form on the room temperature components.
Cavity tuning to resonance during test (slow tuner)		Each cavity must be able to be tuned to a resonant frequency of 3900.000 MHz with a minimum available tuning range of 0.750 MHz at 2 K
Fast tuner minimum range	1 kHz	resolution ≤ 1 Hz
Microphonics	30 Hz peak	The peak detuning per cavity shall be measured to be no more than specified when on resonance and powered.
Heater performance		All installed heaters shall be verified functional by measuring resistance of 45±6 Ω at 2 Kelvin. Heaters must be demonstrated functional in a cryomodule as verified by heating of the helium: • Six (6) of the eight (8) heaters on the helium vessels • Two (2) of the three (3) heaters on fill lines – double check from Fred's pt to pt • Both heaters on liquid level units
Fundamental power coupler 50 K coupler flange maximum temperature	150 K	
Fundamental power coupler warm part maximum temperature	450 K	
Cavity HOM coupler rejection of 3.9 GHz power, FP same upper power limit		$Q_{ext} \geq 3.8\times10^{10}$, maximum power measured at 3.9 GHz out of a single HOM coupler is 1 W at 14.9 MV/m
BPM electrical verification and signal balance		The BPM shall be verified electrically to be without shorts or opens, with cross-talk between electrodes ≤ -30dB. The difference in S-parameter (S21) between electrodes is < 1dB over a frequency range of 0.5 to 2.5 GHz
Cryomodule vacuum		Cryomodule beamline vacuum prior to cooldown 1×10^{-8} Torr Cryomodule insulating vacuum prior to cooldown 1×10^{-4} Torr Cryomodule warm coupler vacuum prior to cooldown 1×10^{-7} Torr Cryomodule beamline vacuum at 2 K 1×10^{-9} Torr Cryomodule insulating vacuum at 2 K 1×10^{-6} Torr Cryomodule warm coupler vacuum at 2 K 5×10^{-8} Torr

LCLSII-4.1-PR-0097-R2: 3.9 GHz Physics Requirements (4/7/2016)

LCLSII-4.1-FR-0096-R1: 3.9 GHz Functional Requirements Specification (12/8/2016)

Test stand operation

- 1.3 GHz cryomodule testing has already demonstrated mature and proven applications
- Adaptable for 3.9 GHz testing
- Techniques and test sequencing evolving for optimum throughput

Testing differences/similarities with 1.3 GHz

Simplifications

- QL set, fixed couplers
- No magnet
- Flux expulsion not needed
- Fast cooldown not necessary
- Cro vacuum connections identical
- Radiation monitoring/faraday cups unchanged

Potential Challenges

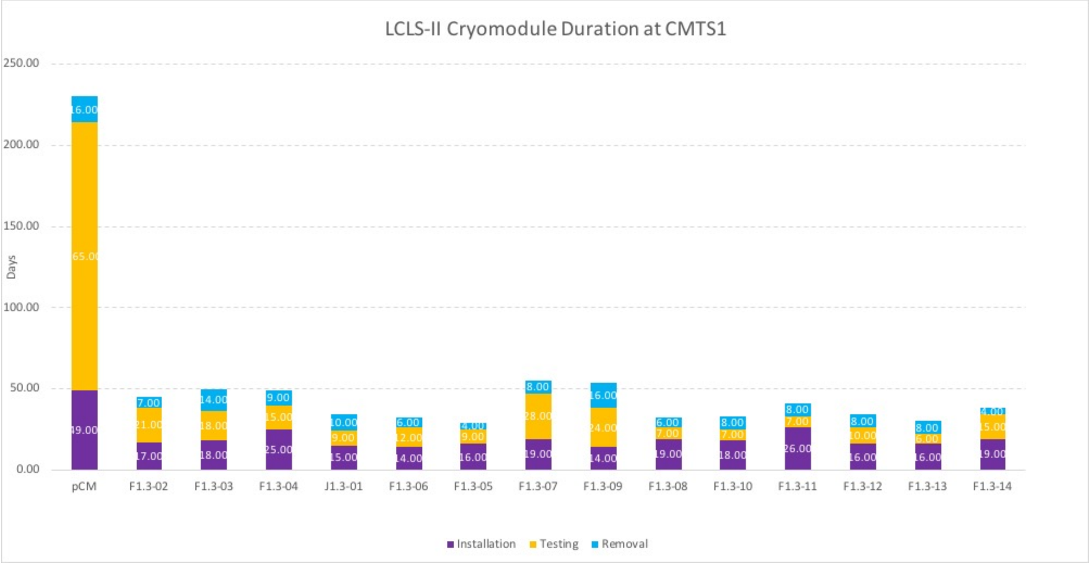
- LLRF
- Blade vs. end lever tuners
- Microphonics

Lessons learned

- CMTS1 is a proven, reliable test bed
  - Necessary modifications understood
  - Majority of the changes are mechanical
  - 8-cavity cryomodule makes change-over simpler
  - Staff continuity
- Learn from past experience
  - Test stand already commissioned
  - Alignment
  - Cryo heat exchanger failure
  - Microphonics mitigation
  - Post-test leak check
  - 3.9 GHz for FLASH (and XFEL) experience
    - don’t assume ‘success is in the bag’

Response to charge

- Q5: Is the design likely to meet performance expectations?
  - Early results from single cavity testing
  - CMTS1 performance to date
  - Strong, experienced team
- Q8: Have lessons learned from the 1.3 GHz cryomodule quality assurance, assembly and test been applied?
  - Following on to experience of testing 19 modules over 3 years already



Summary

- Preparation for testing 3.9 GHz cryomodules begun
  - Regular (at least bi-weekly) dialogue
  - Test documents under development largely based on existing PRD and FRS
  - ESH&Q already engaged
- RF hardware in hand and being assessed
- 1.3 GHz testing a valuable experience
  - Excellent results achievable on schedule
  - Production mindset being embraced

Thank you for your attention – Questions?

Back up slides