# LCLS-II Cryomodule Testing at Fermilab

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## Abstract

*Cold powered testing of all LCLS-II production cryomodules at Fermilab is complete as of February 2021. A total of twenty-five tests on both 1.3 GHz and 3.9 GHz cryomodules were conducted over a nearly five-year time span beginning in the summer of 2016. During the course of this campaign cutting-edge results for cavity Q0 and gradient in continuous wave operation were achieved. A summary of all test results will be presented, with a comparison to established acceptance criteria, as well as overall test stand statistics and lessons learned.*

## Introduction

LCLS-II is a next generation hard x-ray light source based on a superconducting RF electron linac operating in continuous wave regime.

The LCLS-II cryomodule (CM) design is cutting edge in terms of continuous wave (CW) operating gradient and Q0.

The scope of this paper focuses on test results only for Fermilab-built cryomodules and is an update to results shared at SRF2019.

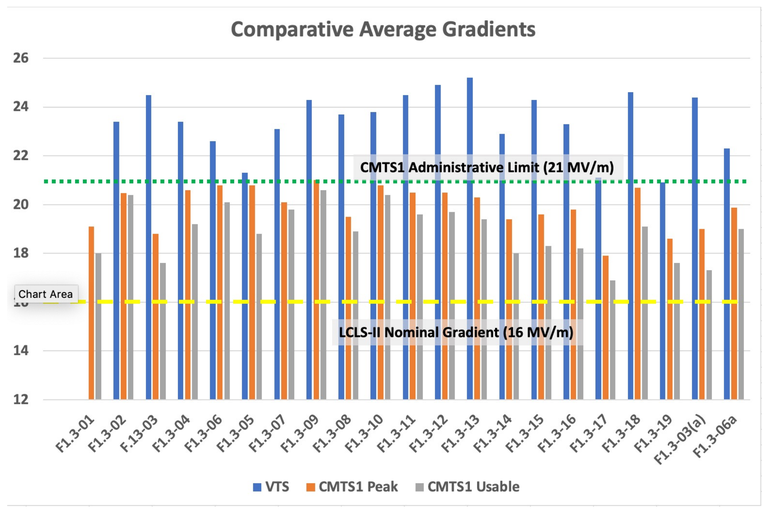
## Timeline

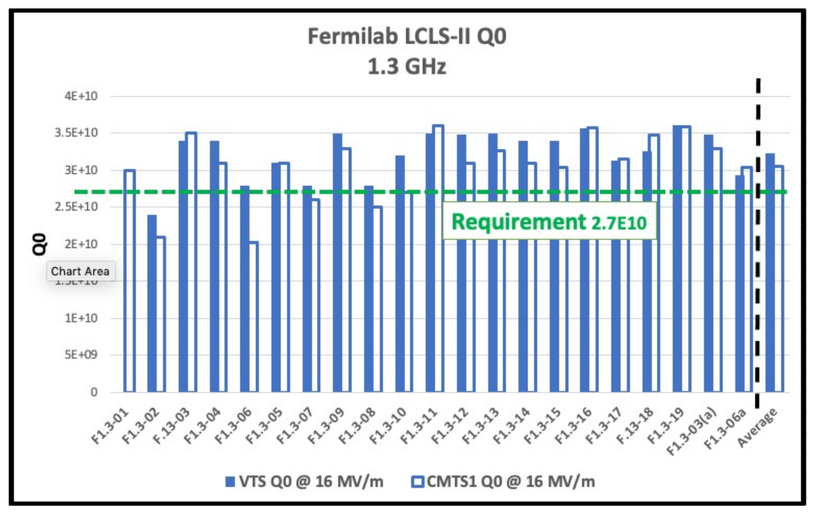
In general, the time required to install, cooldown, test, warmup and subsequently remove each cryomodule was in line with early estimates. Table 1 summarizes the average time duration for each step with separate counts for the 1.3 and 3.9 GHz CMs.

Notable is the time that the 3.9 CMs, particularly F3.9-02 spent at CMTS1. This duration was exaggerated by the work stoppage in early 2021 associated with the covid-19 pandemic. Testing time was also impacted due to the need to limit on-site staffing once the work stoppage was lifted.

| CM type | Installation & cooldown | Cold testing | Warmup & removal | Total days at CMTS1 |
|---|---|---|---|---|
| 1.3 GHz | 18 | 14 | 8 | 43 |
| 3.9 GHz | 19.75 | 38 | 6 | 104* |

## Performance – 1.3 GHz



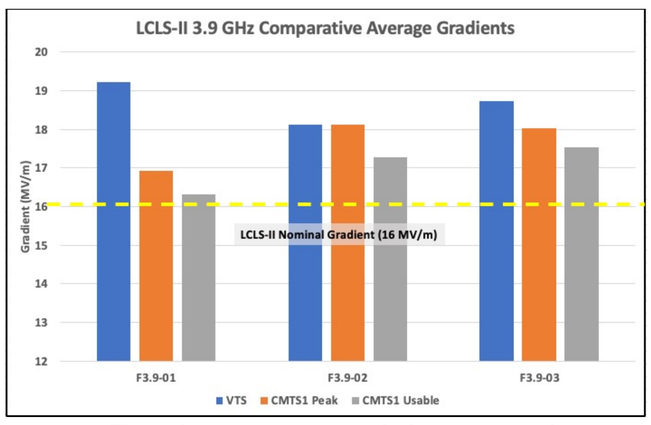



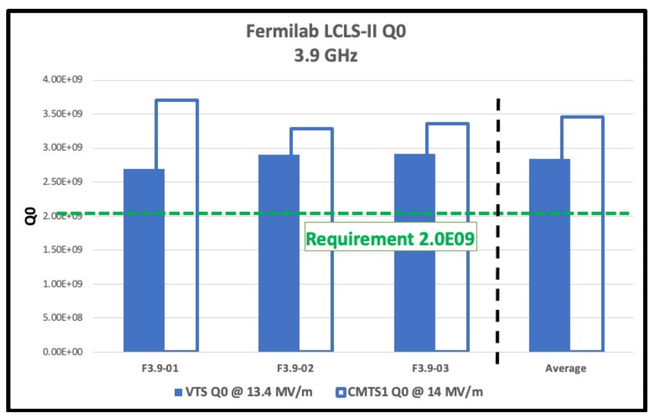

For all cryomodules tested, average achievements (compared to specification) are:

**Maximum voltage = 164.8 (128) MV, 'Usable Voltage' = 157.5 (128) MV**

**Q0 = 3.06 (2.7) E+10**

## Performance – 3.9 GHz

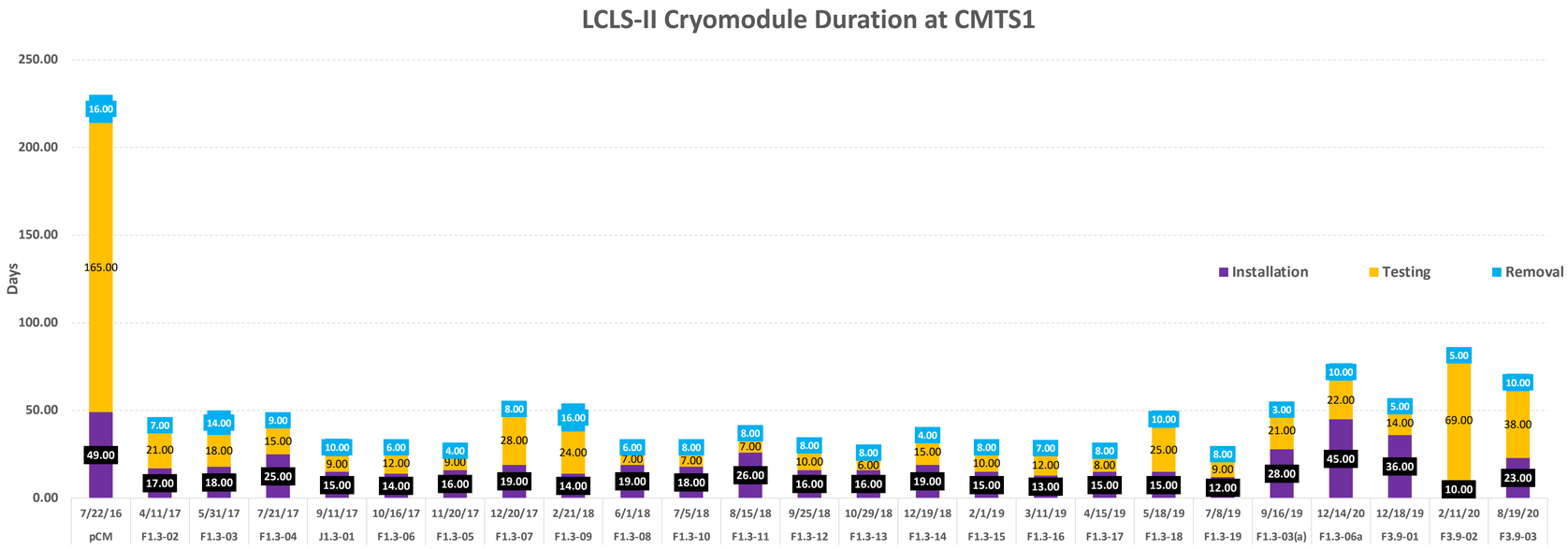



For the 3 cryomodules tested, **average achievements** (compared to specification) are:

**Maximum voltage = 48.5 (41) MV, 'Usable Voltage' = 46.4 (41) MV**

**Q0 = 3.45 (2.0) E+09**




## Summary

The campaign to cold test all cryomodules built at Fermilab for LCLS-II has come to a successful conclusion and all devices are now delivered to SLAC having met and oftentimes exceeded performance specifications. The design choices made in adapting TESLA style cryomodules for cw operation were validated. The experience gained with these series of tests will benefit LCLS-II commissioning and operation and are already informing follow-on projects, especially SRF-based ones. Most significantly this effort was carried out safely with only one technical incident affecting the cryoplant occurring.

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