

PROVISION OF HIGH BETA CAVITIES FOR EUROPEAN SPALLATION SOURCE BY UKRI-STFC DARESBUURY LABORATORY

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Introduction

- Testing of 704 MHz high-beta SRF cavities for the European Spallation Source (ESS) facility in Lund, Sweden started in 2019
- Aim to deliver 84 cavities to Commissariat à l'Énergie Atomique et aux Énergies Alternatives (CEA) Saclay for cryomodule integration
- The requirements are:-

Parameter	Value
Geometrical β	0.86
Frequency (MHz)	704.42
No. of cryomodules	21
No. of cavities	4
Cryomodule length (m)	6.584
Nominal accelerating gradient (MV/m)	19.9
Nominal accelerating voltage (MV)	18.2
Qo at nominal gradient	5×10^9

- Estimated that the cavity test failure rate would be of the order of 30%
- Anticipated 115 and 120 cavity tests would be required
- To date 88 out of 89 ESS high-beta cavities have been fabricated in industry by Research Instruments (RI) in Germany
- Qualification cavity testing has been performed at:-
 - Daresbury Laboratory, STFC
 - Deutsches Elektronen-Synchrotron (DESY)
- STFC test facility
 - Cavities are tested horizontally
 - Cavities cooled by the filling the liquid helium jackets
 - 3 cavities tested in a single run
 - STFC radiation detectors are located ~25 cm from the cavity at either end of each cavity along the beam axis of the cavity
- DESY test facility
 - Uses the conventional complete bath immersion
 - 2 cavities tested in a single run
 - Radiation monitors positioned at the top and bottom ~ 2 m from the cavities of the test bunker on the vertical centre line

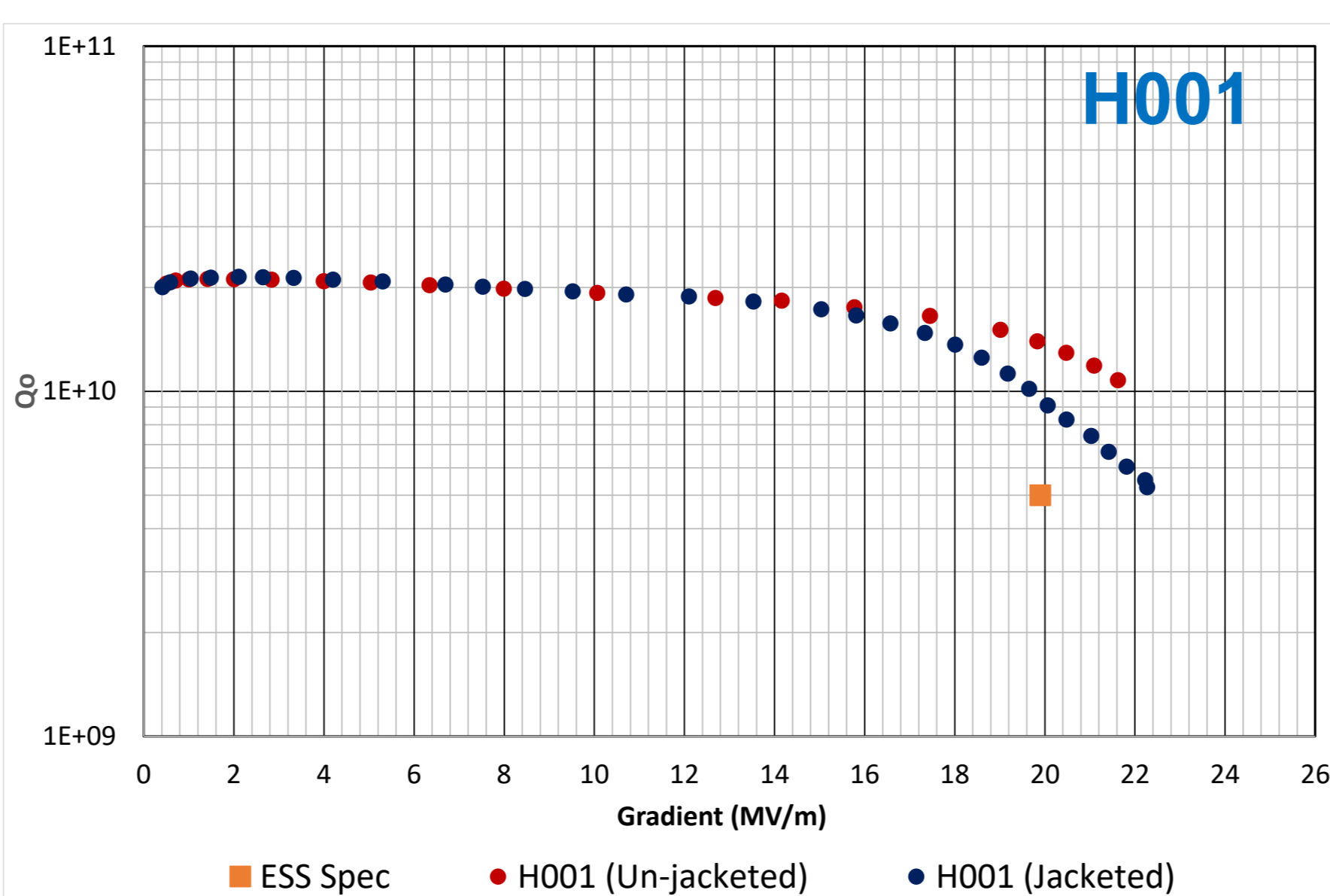


Cavity Performance

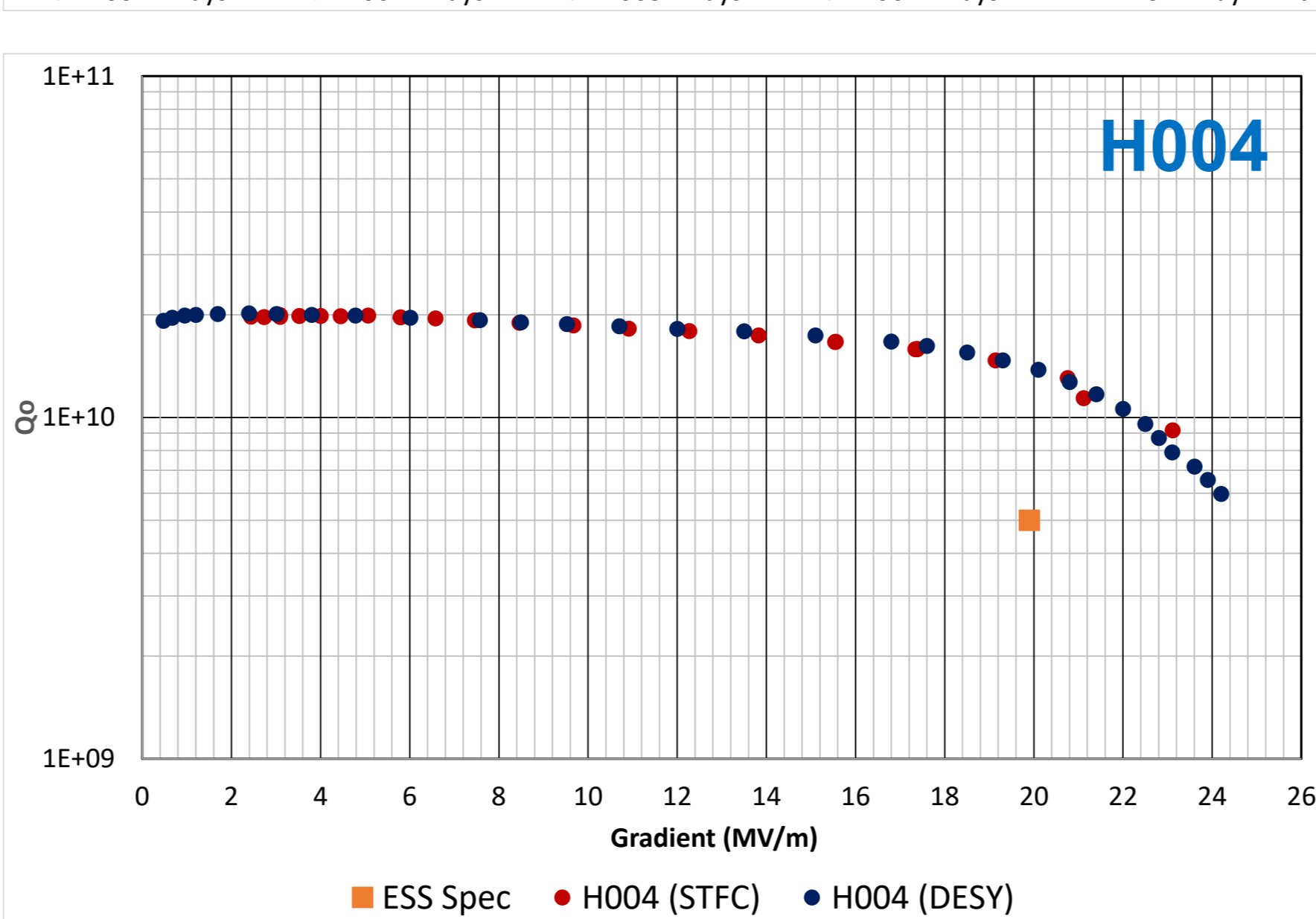
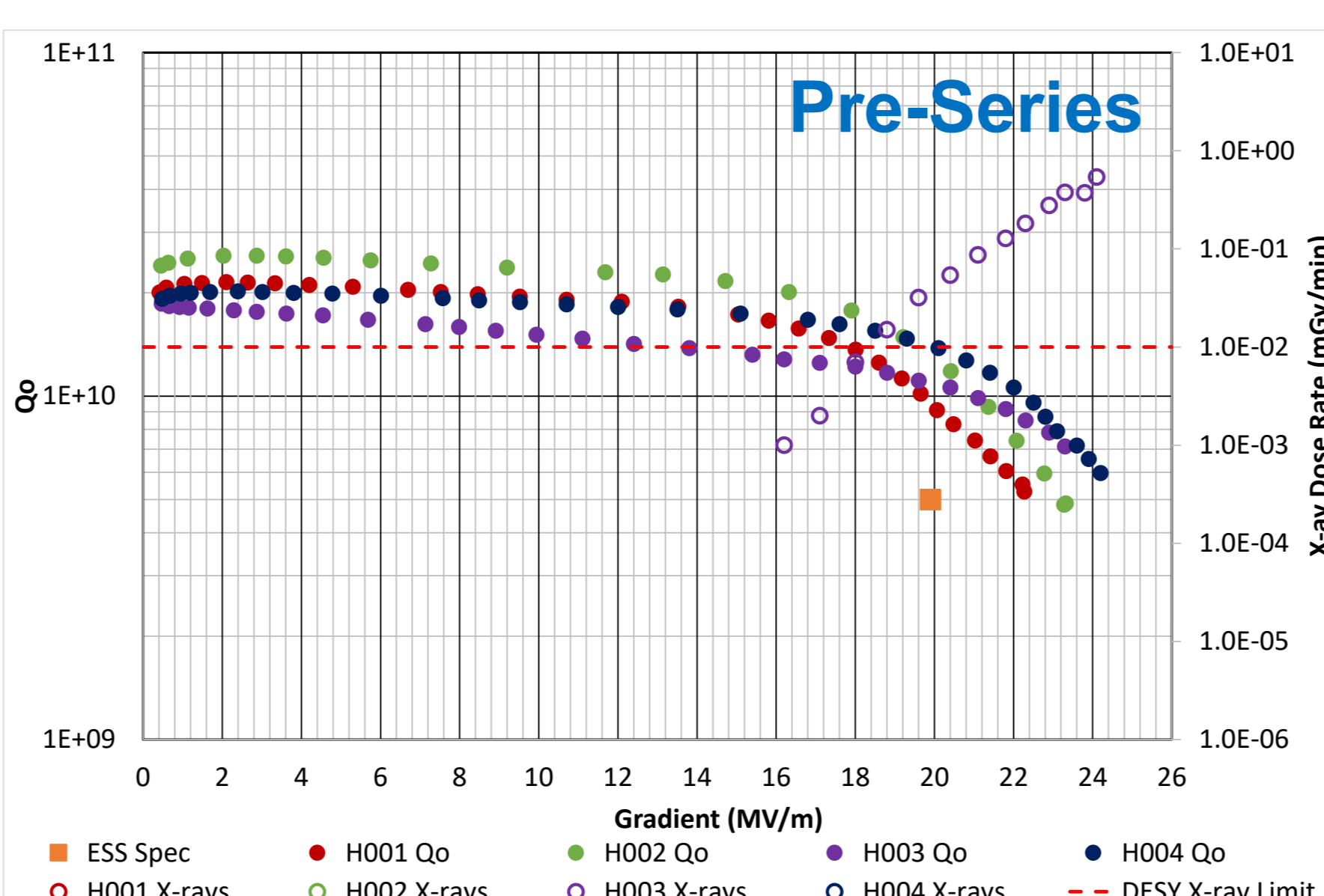
Pre-Series Cavity Performance

- Qualification testing of the 4 pre-series cavities, H001 – H004, was performed at DESY
- Cavities were tested un-jacketed and then jacketed so as to validate the industrial cavity manufacturing processes
- Manufacturing hold points were used to evaluate the readiness of processes
 - Buffer chemical processing (BCP) niobium (Nb) removal rate
 - High-pressure rinse (HPR) process
 - Final light 20 μm BCP etch and the tank integration processes
- The BCP process on cavity H001 was performed in 3 steps
 - A 45 μm removal run to determine the etch rate. Measured by:-
 - A sample test piece of Nb
 - Weighing the cavity before and after processing
 - Ultrasonic thickness measurement
 - A second 45 μm etch followed 90 μm etch verified the etch rate
 - Removal rate of 1.1 – 1.2 $\mu\text{m}/\text{min}$

- After a high pressure rinsing (HPR) the cavity was then successfully tested un-jacketed at DESY
- A second cavity test was then performed after
 - The installation of the helium jacket
 - A 20 μm light BCP etch
 - A HPR for 12-hours.

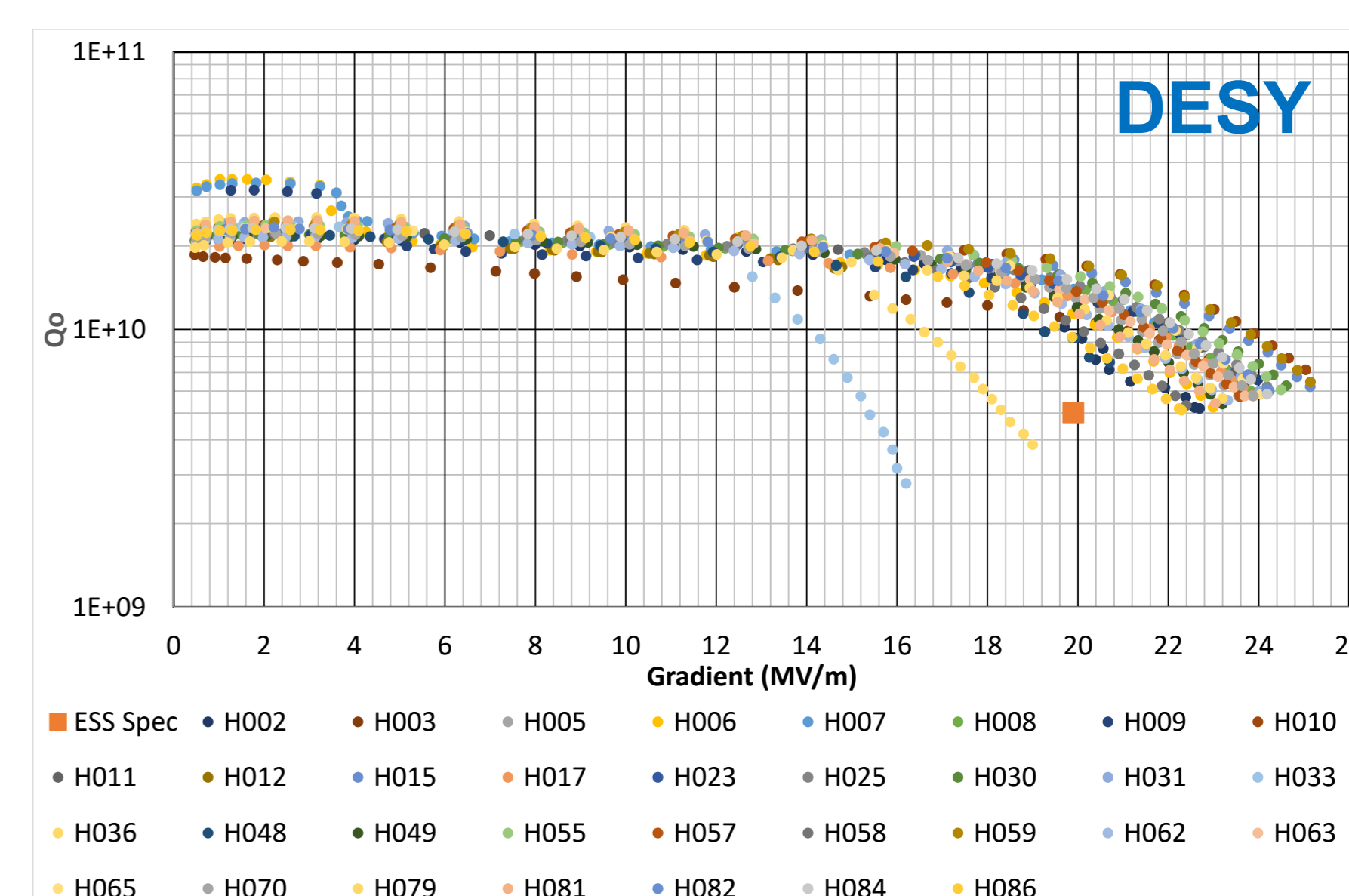
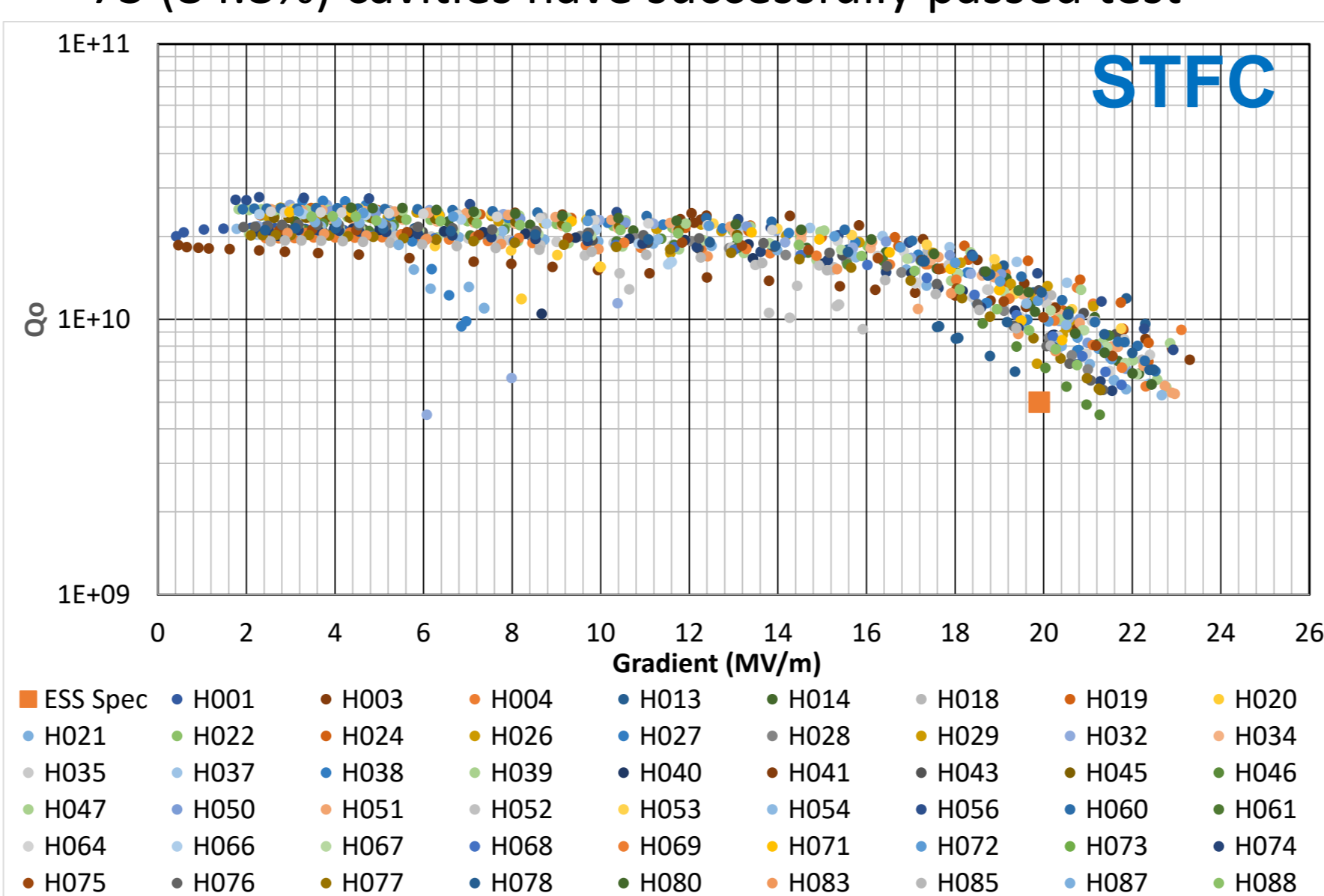


- Cavity H002 was released for production
 - 2 times 90 μm BCP etch removal runs.
 - No degradation in the Q performance after jacketing
- H003 and H004 were released for processing
 - 2 times 90 μm BCP etch removal runs.
 - No degradation in the Q performance after jacketing
- All cavities met Q versus gradient performance
- H003 exhibited field emission above a gradient of 16 MV/m
 - An investigation of the cavity showed that it had a stain on the beam pipe, the root cause of which was not determined.
- H004 tested at STFC showed excellent correlation with DESY results

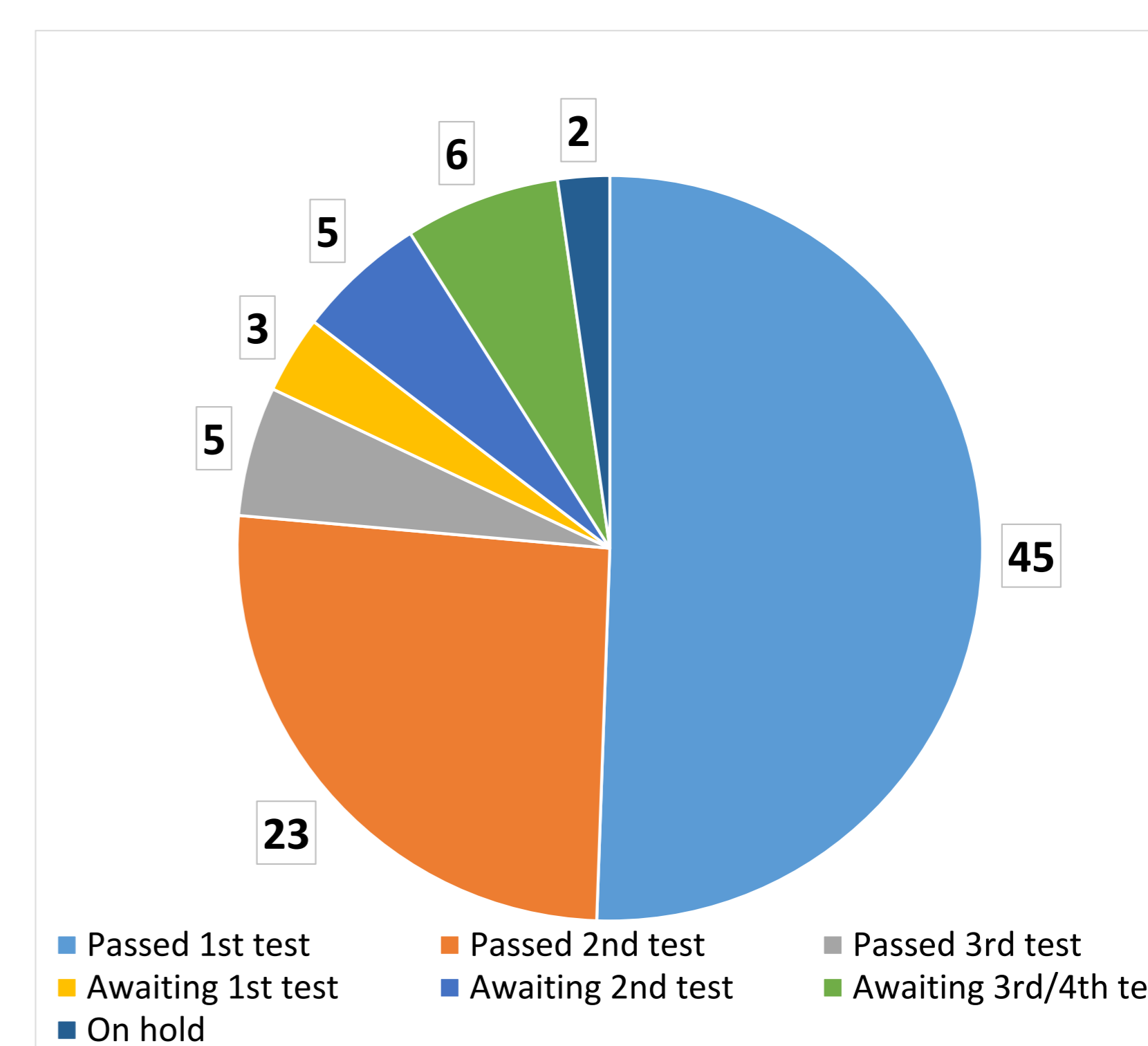


Production Cavity Performance

- 142 jacketed cavity tests have been performed
- 86 cavities have been tested at least once
- 45 (52.3%) cavities having successfully passed test first time
- 73 (84.8%) cavities have successfully passed test



- First 18 cavities tested only 5 cavities passed - a 28% pass rate
- Main failure reason for the 13 cavities was due to field emission
- Halted the production and testing of cavities for a review
- No on-site quality assurance and control (QA/QC) performed in this initial phase due to the COVID lockdown
- Improvements identified:-
 - Doubling the time for the final HPR to 24 hours
 - Inclusion of a Teflon disk on the bottom beampipe flange during coupler assembly to prevent the ingress of particulates



- First time yield increased to 67%, a significant improvement.
- Further reprocessing of failed cavities
 - 5 cavities have passed a third test
 - 6 cavities still awaiting additional processing
- H003 and H012 are on hold after additional BCP processing
 - H003 still exhibits field emission
 - H012 has quenched on both tests at ~15 MV/m.
 - Further BCP processing of these cavities would mean that the frequency would be outside the tuner range

Summary and Future Work

At the beginning of the project, it was estimated that between 115 and 120 cavity tests would be required as part of the delivery of 84 cavities to CEA Saclay, however to date 142 cavity tests have been performed and 86 cavities have been tested, with 73 cavities having successfully met performance requirements. Because of the field emission problems, it was necessary to revisit the manufacturing processes for the cavities and implement improvements to increase the testing yield to acceptable levels. This has identified the need for a more robust cavity qualification process as part of the pre-series evaluation and for a more stringent QA/QC monitoring for future similar SRF projects. The project is continuing with the aim of completing the final cavity tests in October 2023 to enable delivery and cavity integration at CEA Saclay.