MOOBAU01 - Third Harmonic System at FERMILAB/FLASH

E. Harms, *on behalf of the 3rd Harmonic Collaboration*

A 4-cavity 3.9 GHz cryomodule has been constructed at Fermilab and delivered to DESY. Its intended use is to linearize the non-linear beam energy-time profile produced by the 1.3 GHz accelerating gradient and thus improve the operating characteristics of FLASH for its users. First cold testing of the module is expected in the near future prior to its installation. We will report on the performance of the cavities, assembly and transport of the module as well as anticipated testing, installation, and commissioning plans.

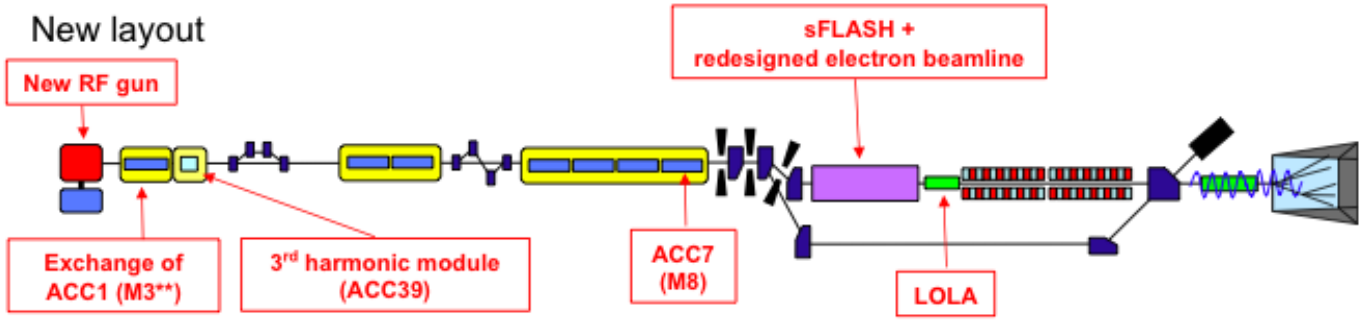
Introduction

- Fermilab has constructed a cryomodule containing four superconducting radio frequency (SRF) cavities operating at 3.9 GHz for the Free electron LASer in Hamburg (FLASH) facility at the Deutsches Elektronen-SYnchrotron (DESY) laboratory.
- This cryomodule, known as ACC39, was proposed to linearize the energy distribution along a bunch upstream of the bunch compressor.
- The four 9-cell cavities were designed to operate at 2 K in the TM_{010} π-mode at an accelerating gradient E_{acc} = 14 MV/m.

Number of Cavities	4
Active Length	0.346 meter
Gradient	14 MV/m
Phase	-179º
R/Q [=U^2/(wW)]	750 Ω
E_{peak}/E_{acc}	2.26
B_{peak} (E_{acc} = 14 MV/m)	68 mT
Q_{ext}	1.3 X 10^6
BBU Limit for HOM, Q	<1 X 10^5
Total Energy	20 MeV
Beam Current	9 mA
Forward Power, per cavity	9 kW
Coupler Power, per coupler	45 kW

The 3.9 GHz module - What is it - what will it do?

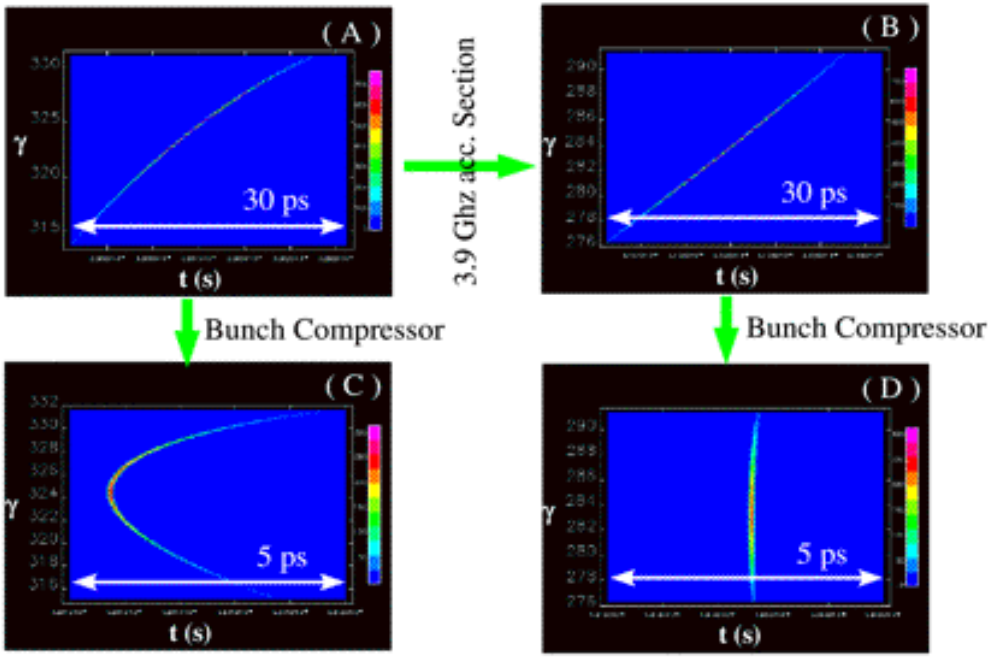
- The 3.9 GHz module, ACC39, will be installed in the DESY FLASH injector just after the 1.3GHz ACC1 (first) cryo module.
- It will be used in conjuction with this module in order linearize the bunch energy vs. time over the bunch length.
- This in turn should make “bunch compression” to very short bunches with high peak currents more efficient, or a more controlled longer bunch charge distribution.
- The SASE FEL operation should become more efficient and stable seeded operation (sFlash) possible.
- This is an important proof of principle not only for FLASH and XFEL but also for accelerator-photon physics, and a learning experience.

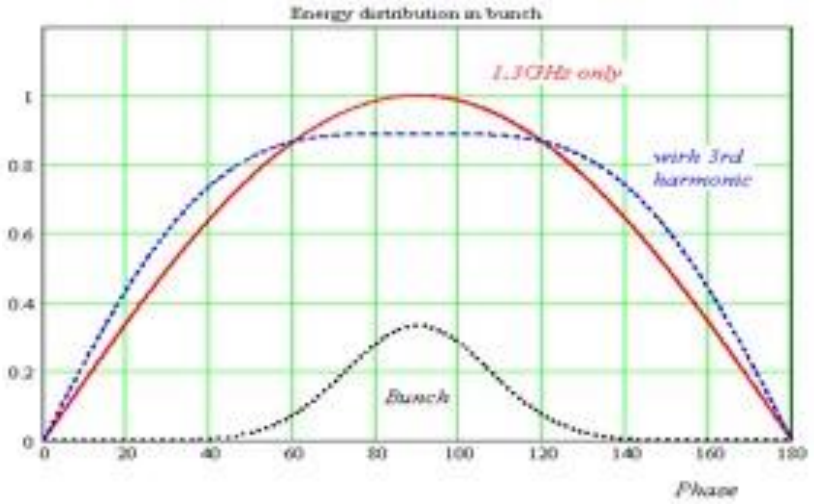


Bunch Compression with 3.9 GHz Module

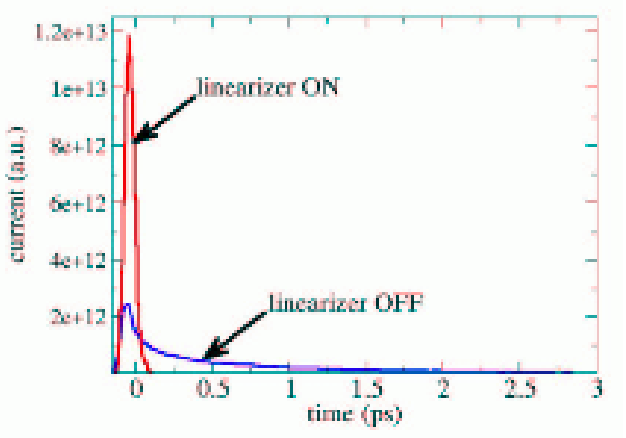
After acceleration w/o

After compression w/o



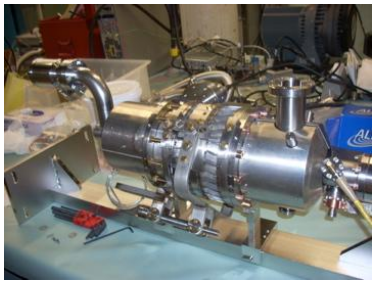


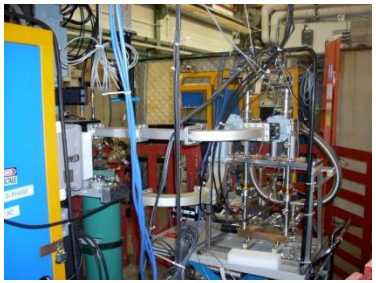
Effect of third harmonic on 1.3 GHz waveform

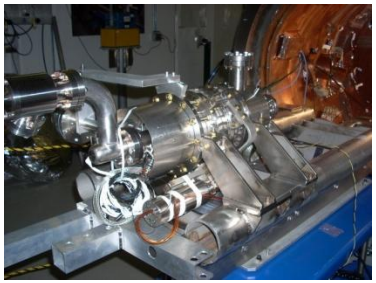


With 3rd harmonic

from P Piot



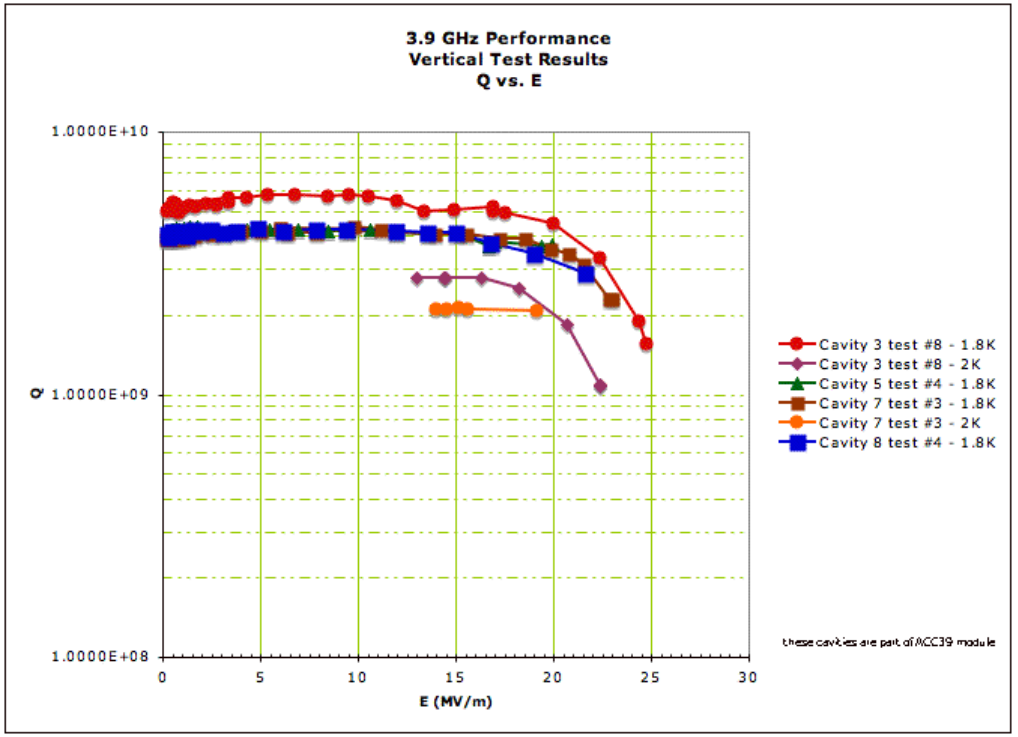




Cavity	Assembled by	Completion date	Test results and status
#1: 2-leg HOM	Fermilab	January 2006	Never tested: HOM membrane break during cleaning - Used as horizontal test prototype
#2: 2-leg HOM	Fermilab	February 2006	- Best vertical test: 12 MV/m limited by HOM heating - Fractured Formteils - Repair attempted
#3: 2-leg trimmed HOM	Fermilab JLab	August 2006	- Best Vertical test: 24.5 MV/m, achieved after HOM trimming -Horizontal testing: 22.5 MV/m limited by quench - Part of final string assembly
#4: 2-leg trimmed HOM	Fermilab JLab	March 2007	- Best Vertical test: 23 MV/m - Horizintal testing: 18 MV/m limited by quench
#5: 2-leg trimmed HOM	Fermilab JLab	May 2007	- Best Vertical test: 24 MV/m - Welded into Helium vessel - Horizontal testing: 22.5 MV/m limited by quench - Part of final string assembly
#6: 2-leg trimmed HOM	Fermilab JLab	May 2007	- Best Vertical test: 22 MV/m - Faulty welds repaired - Awaiting final vertical test with HOM feedthroughs
#7 single-post HOM	Fermilab JLab DESY	November 2007	- Best Vertical test: 24.5 MV/m - Welded into Helium Vessel - Horizontal testing: 26.3 MV/m limited by quench - Part of final string assembly
#8 single- post HOM	Fermilab DESY	October 2007	- Vertical test: 24 MV/m - Horizontal testing: 24 MV/m limited by quench - Part of final string assembly

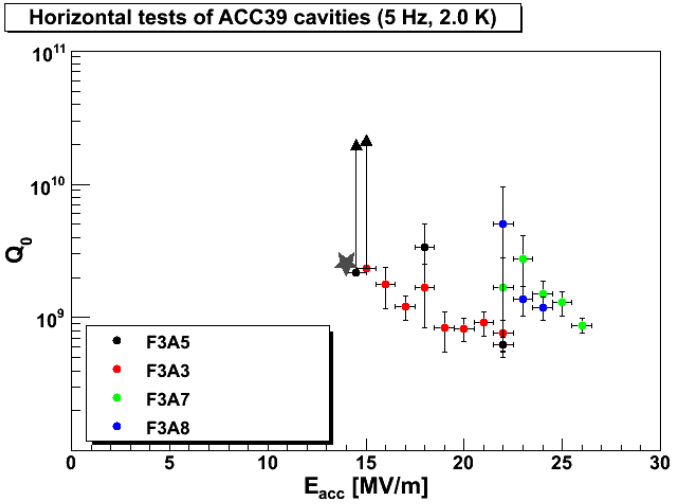
Vertical Testing

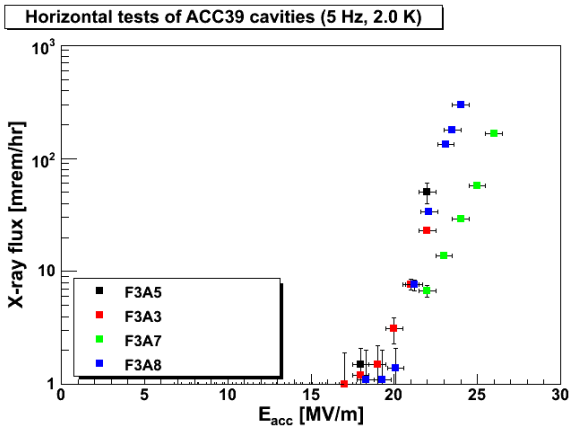
- All fabricated cavities tested at the A0 vertical test stand as 'bare' cavities
- To date there have been a total of 67 tests performed. The cavities selected for inclusion in the string were tested an average of seven times each – two undergoing only four tests and Cavity #3 subjected to ten.
- Those welded into helium vessels were given an additional test prior to dressing to ensure that the welding process did not significantly degrade each cavity's performance.
- As conditions allowed, tests were conducted at both 1.8K, the default A0 vertical test stand operating temperature, and 2K, the FLASH operating temperature.
- Two production cavities, #'s 4 and 6 have yet to be fully qualified as spares.

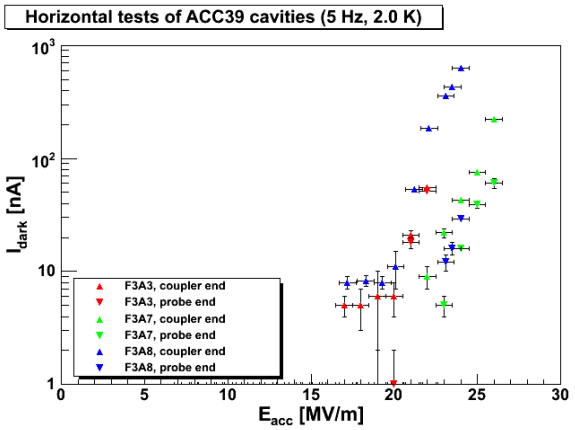


Horizontal Testing

- Five cavities are now welded into helium vessels and have undergone Horizontal tests at the Fermilab Horizontal Test Stand (HTS) located in the former Meson Detector Building (MDB) as complete 'dressed' cavities outfitted with magnetic shielding and blade tuners.
- All tested cavities have reached gradients of at least 18 MV/m, with most achieving a gradient in excess of 22 MV/m.
- Of the four selected for ACC39 string assembly, all reached at least 22 MV/m.

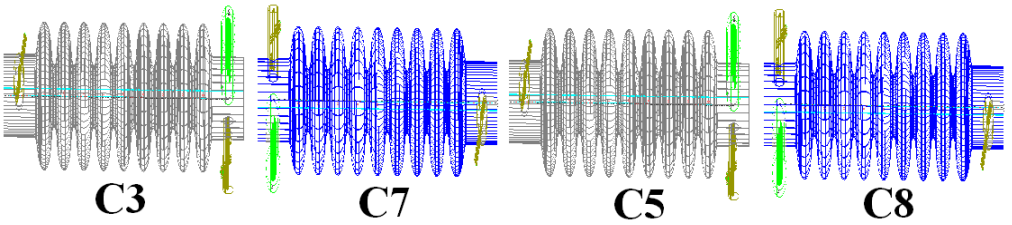




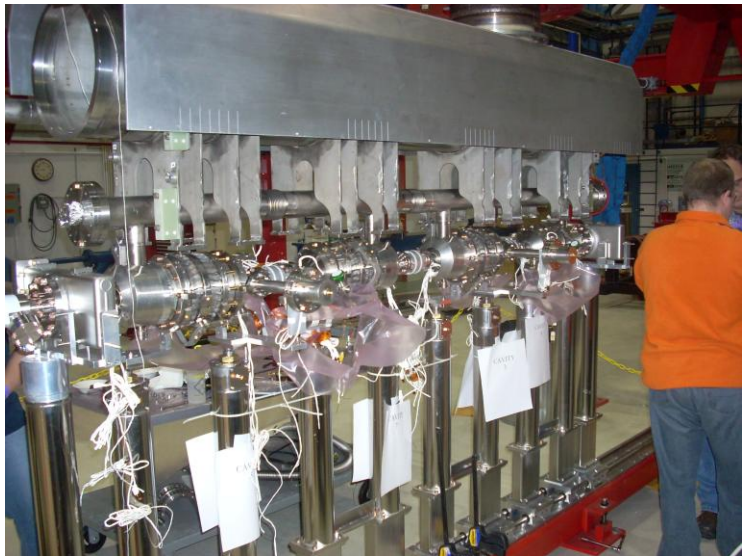


String Assembly

- Two of the cavities contain the original 2-post Formteil Higher Order Mode (HOM) couplers while the remaining two were fabricated with the re-designed single-post Formteil.
- Assembly was such that the cavities alternate with styles of Formteil motivated by a desire to equally distribute HOM frequencies along the beam pipe.
- Assembly from 11 December 2008 - early January 2009.
- String leak checked, mated to 300 mm gas return pipe, Ti return pipes welded.
- Transport to ICB for Cold Mass Assembly on 6 February 2009.
- Assembly was loaded onto the shipping fixture designed for the complete module and outfitted with vibration and g-force sensors to measure the response during truck transport.
- The adequacy of the transport design was confirmed.

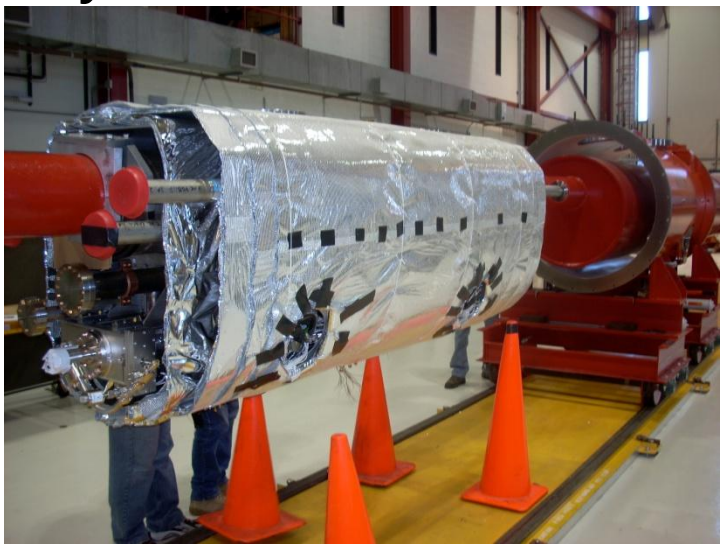


Mixed. Each beam pipe has both type of HOM couplers. Some D2 path band modes of the 2nd cavity (#7) is trapped.



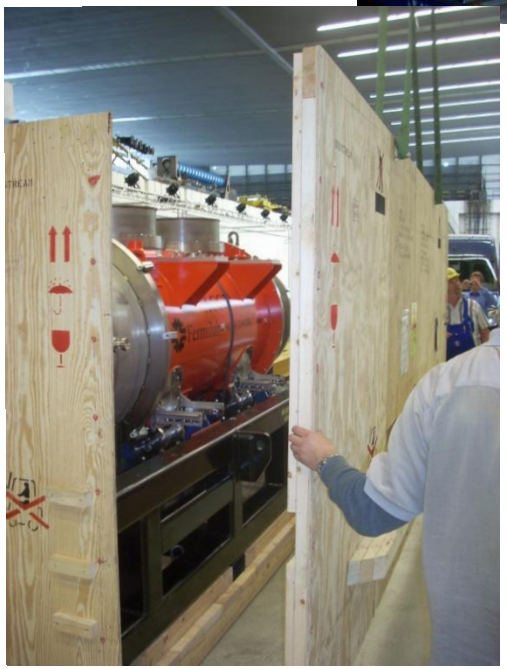
Cold Mass Assembly

- The final major assembly work at Fermilab was the Cold Mass assembly including
  - encasing the cavity string in 4K shield and 10 layers of MLI
  - 80K thermal shield and 30 layers of MLI
  - All additional piping installed
  - Entire assembly was then inserted into its vacuum vessel
  - Final alignments performed.
- Instrumentation cabling routed, terminated, and checked for functionality
- Final quality assurance checks including
  - vacuum leak checking
  - test fit of warm part input couplers
- All external joints verified leak tight
- Vacuum vessel was slightly pressurized to 50 mbar with dry nitrogen just prior to shipment
- Review of the Operation Readiness



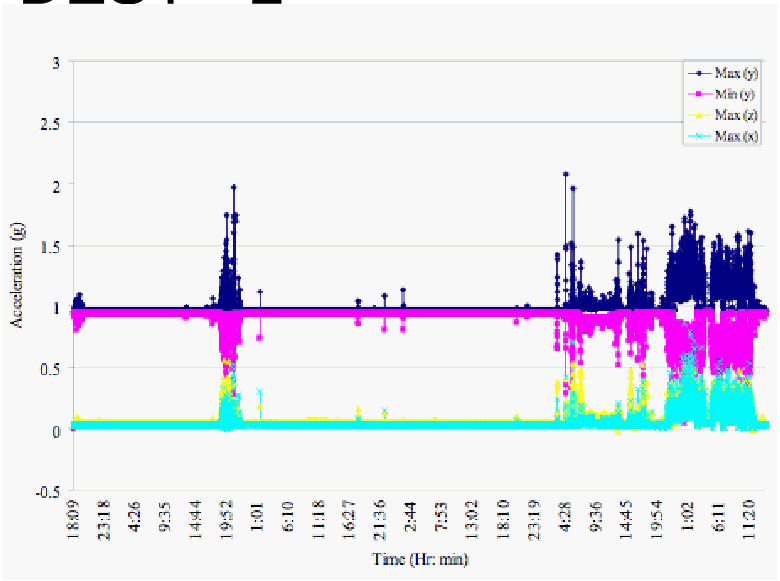
Transport to DESY

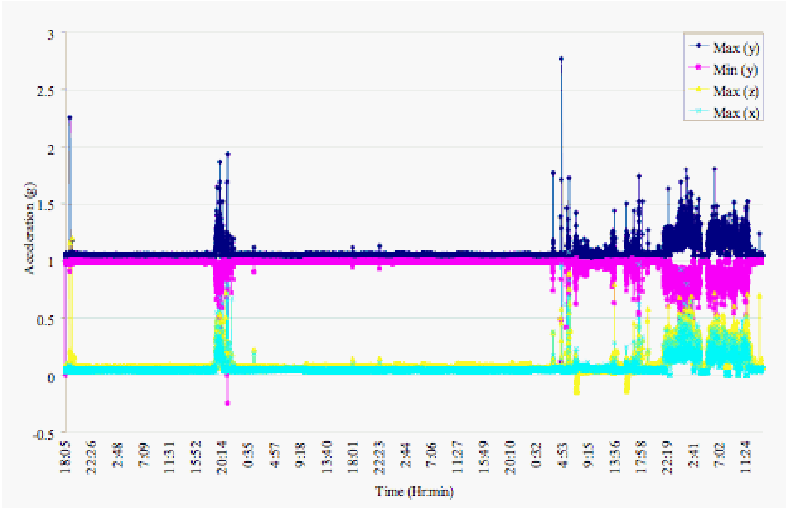
- Completed module departed Fermilab on 24 April 2009
- Delivered to DESY four days later.
- Transport was accomplished
  - Via truck from Fermilab to Chicago O'Hare airport
  - Air cargo transport to Paris, Charles de Gaulle airport
  - Overland transport via truck from Paris to Hamburg
- All critical transfer points were witnessed by Fermilab as well as DESY personnel once the module arrived in Europe.



Transport to DESY - 2

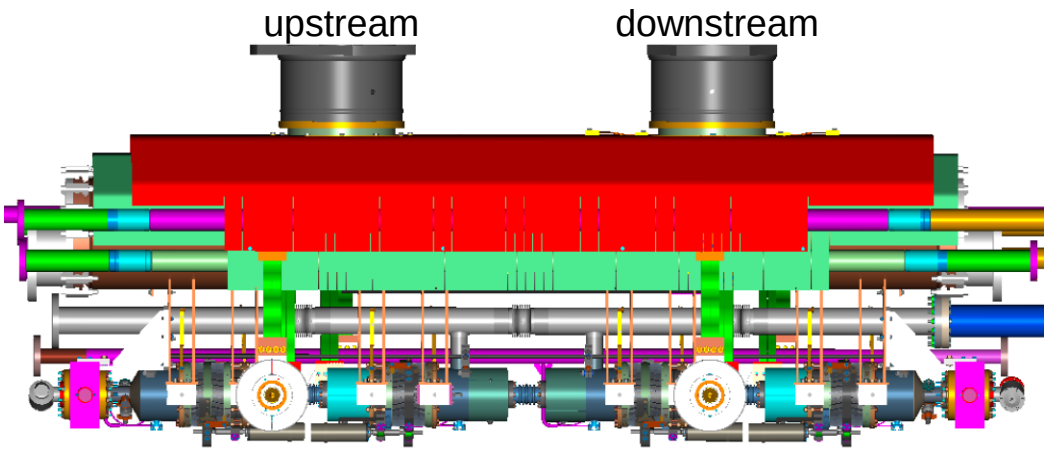
- The choice and placement of diagnostics to monitor shock and vibration during transport done with deliberation.
- Acceleration of the cryomodule during all phases of transport was maintained at or below 1.2 g in all planes – well within the specified criteria.
- Cavity string was shipped under vacuum; instrumentation was installed during cold mass assembly to allow one to monitor the vacuum pressure prior to, during, and after shipment.
  - 4.8 X 10^{-4} Torr prior to departure (two weeks after active pumping was ceased)
  - 7.7 X 10^{-4} Torr upon arrival in Paris and thereafter





Checkout & Preparation for Testing at DESY

- Post-transport checkout to verify
  - vacuum leak tightness
  - Alignment - no significant misalignment of the cavity string occurred during transport.
- Misalignment of some needle bearings necessitated the partial disassembly of the module.
- Longitudinal realignment of the cavity string ~4mm upstream of its initial location with respect to the fixed support post.



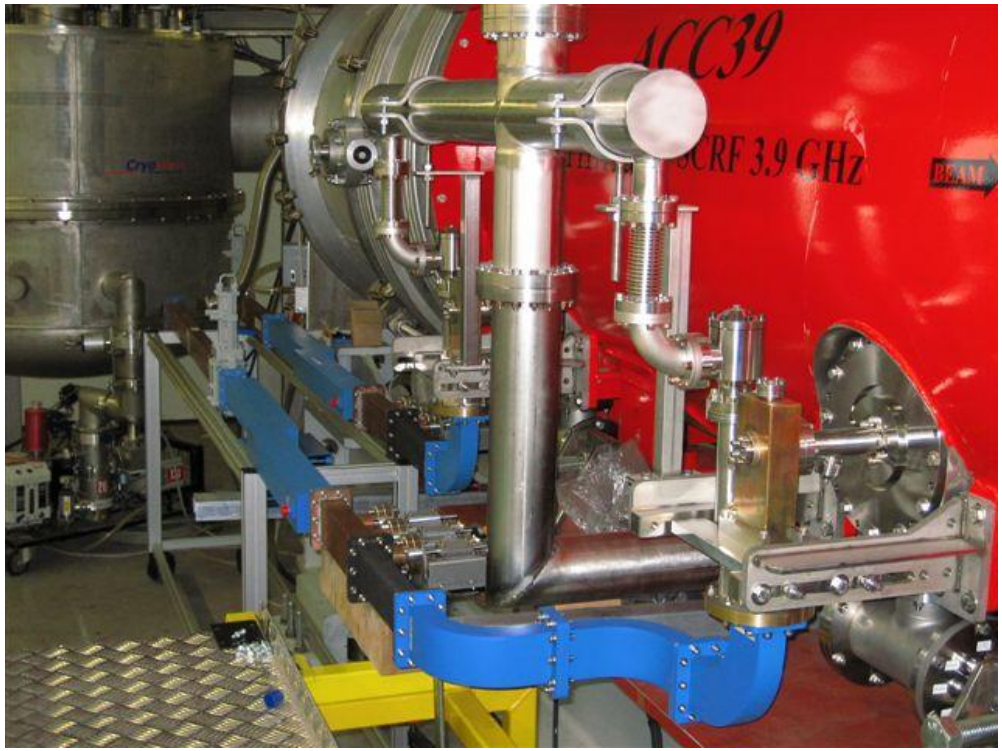
String shifted by 4.0 mm upstream

Checkout & Preparation for Testing at DESY - 2

- Faulty thermometry splices were similarly discovered and corrected.
- Warm ends of the input couplers installed and verified leak tightness once the re-alignment was completed.
- External electrical connections to internal instrumentation and tuner motors operated and verified.
- Two checks of the string alignment and the cavities relative to each other. Deviation found to be less than 0.1mm, within specification, as compared to Fermilab exit data.
  - Cavity targets as a group - maximum difference 0.16mm
  - Relative to cold mass - maximum difference 0.28mm
  - Measurement accuracy ~0.15mm
  - Gate valve motion ~0.7 mm.
- Frequency spectrum and HOM notch frequencies measured and compared with Fermilab exit data - ok.

Next Steps

- ACC39 is now installed on CMTB.
- Warm Input coupler conditioning planned for next week.
- Cool down for powered testing at CMTB to follow.
- Powered testing through October.
- Installation in the FLASH enclosure will coincide with the scheduled maintenance period – now planned for December 2009.
- Technical commissioning is scheduled for March 2010.
- Commissioning with beam to follow.



ACC39 Schedule Highlights

- 2002 — TESLA Facility Phase 2 Report with 3.9 GHz module for bunch compression (TESLA-FEL 2002-01)
- 2002-3 — Cavity design documents (TESLA-FEL 2002-05, 2003-01/FNAL TM 2210)
- 2005 — DESY-FNAL MOU on 3.9 module
- 2006, 03-06 — C1,C2 failures, Multipacting & HOM wall thickness
- 2006, 08 — C3 fabrication finished - first usable cavity
- 2007, 05 — C3 good vertical test after HOM formteils cut, 24MV/m
- 2007, 10 — C5 vertical tests with HOM feed-throughs complete 19MV/m
- 2008, 02-09 — C5 in horizontal test stand (HTS)
- 2008, 04 — C5 achieved 22.5MV/m in HTS
- 2008, 12 — C7 last cavity of four removed from HTS
- 2009, 01 — String assembled in MP9 CR
- 2009, 02 — Cold mass to ICB
- 2009, 04 — Module finished and shipped to DESY
- 2009, 09 — ACC39 installed in CMTB

Summary

- Fermilab has now successfully completed construction of a Superconducting RF module containing four 3.9 GHz cavities each of which have achieved a gradient in excess of 22 MV/m and met all other design criteria.
- The module was transported to DESY and is now installed on DESY's Cryomodule Test Bed in preparation for warm coupler conditioning and cold powered testing.
- Installation and beam commissioning in DESY's FLASH free electron laser is expected to follow beginning in late 2009.
- This effort has proven to be far more than merely a scaled version of a 1.3 GHz TESLA module.
- With this work largely complete, Fermilab has gained valuable experience in designing, fabricating, and assembling SRF devices as well as building up the necessary expertise and infrastructure.
- A collaborative effort especially with colleagues from DESY, Jefferson Lab, Cornell, Argonne, INFN - Milano.

Acknowledgements

- Many thanks to all members of the Third Harmonic Collaboration
  - DESY, Argonne, Jefferson Lab, INFN
  - Colleagues at Fermilab