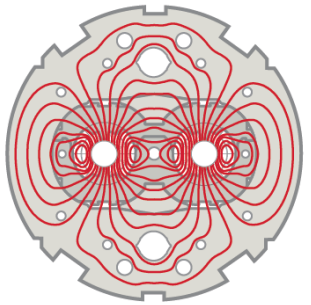



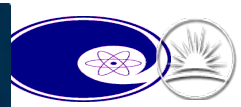
LARP

# Highlights of Crab Cavities performance test results

Alessandro Ratti – SLAC
For the global crab cavity team







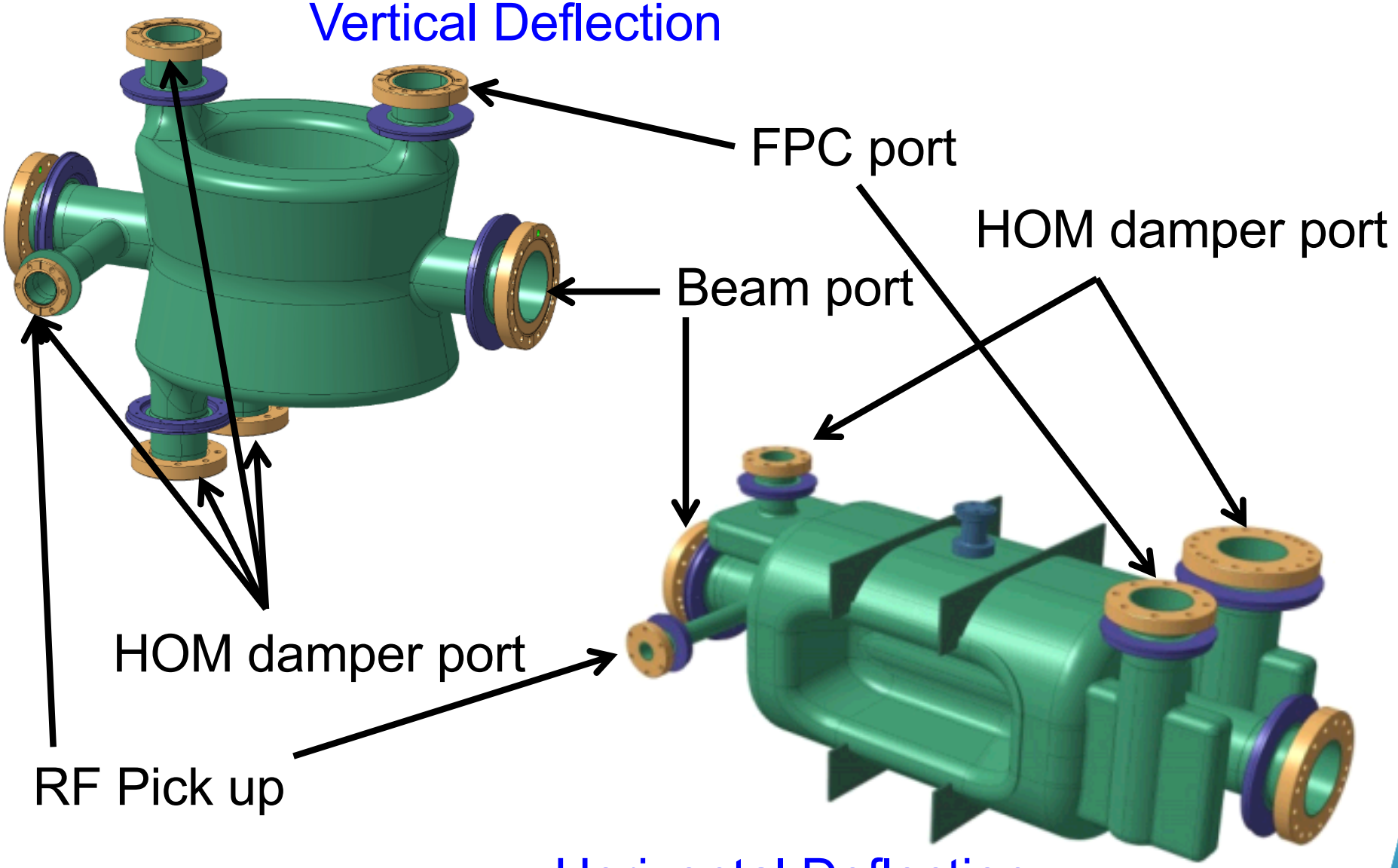

# Acknowledgments


- LARP
  - BNL – Q.Wu, S. Verdu-Andres, B. Xiao, J. Skaritka, Ilan Ben-Zvi
  - FNAL – L. Ristori
  - JLAB – A. McEwen, E. Daly, H. Park (also ODU)
  - LBNL – J. Qiang
  - ODU – J. Delayen, S. De Silva, H. Park
  - SLAC – Z. Li, A. Ratti
- Niowave
  - C. Boulware, T. Grimm, J. Yancey
- World Wide Collaboration
  - CERN – R. Calaga, O. Capatina, M. Garlasche', C. Zanoni
  - STFC – G. Burt, T. Jones, J. Mitchell, S. Pattalwar, N. Templeton,
- Many others are actively involved, in particular in the work centers of CERN and JLAB
  - and many contributed in the past

# Outline

- History of existing cavities tested by LARP
- Manufacturing of sub-assemblies by Niowave
- Final welding and testing at JLAB
- Vertical Tests of DQW
- Vertical tests of RFD
- Cavity performance
- Conclusions

# Crab Cavities for HiLumi



# JLAB Contribution

For both cavities and both designs:

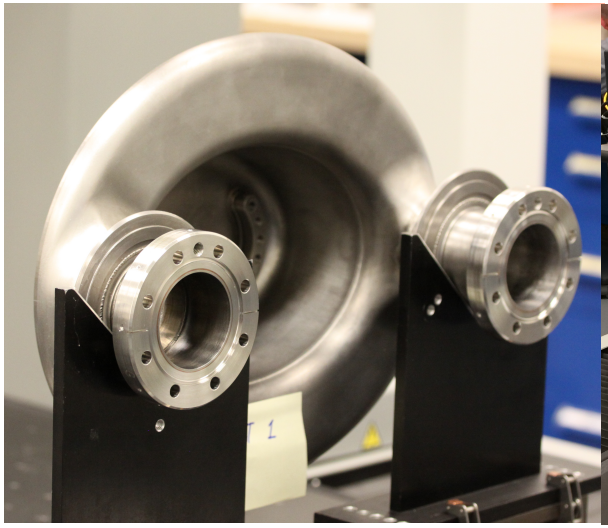
- Receive and inspect all parts
- Final frequency trimming
- Welding
- Chemistry processing
- Vertical Testing

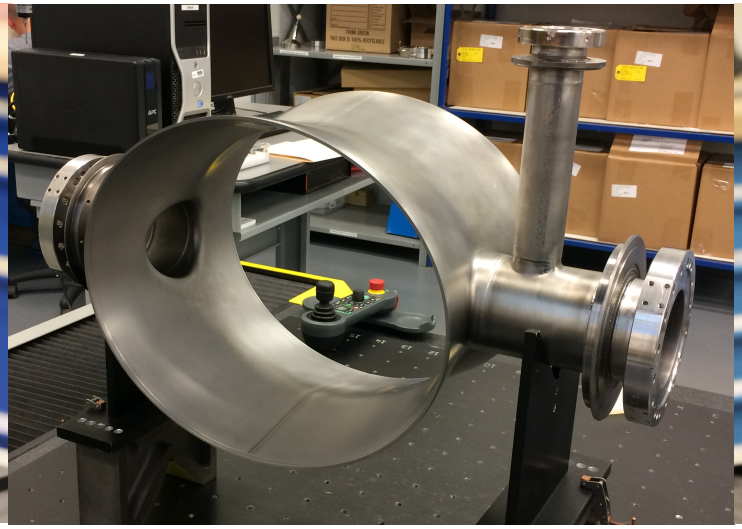
- Due to practical and schedule considerations, the initial inspections of the DQW cavities were completed at BNL and final trimming was completed at Niowave in collaboration with LARP and BNL personnel

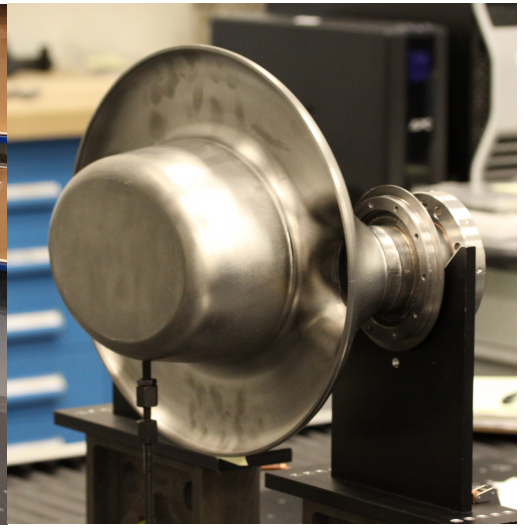
# DQW and RFD processing

- Niowave-produced cavities have parallel paths
  - RFDs received from Niowave go to JLAB for final machining, thinning, trimming and processing
  - DQWs received from Niowave go to BNL for dimensional measurement, shipped back to Niowave for thinning and final machining, then back to JLAB for welding, processing and testing.
- All four cavities (2+2) arrived at JLAB by October 2017
- In light of CERN's ongoing development of DQW cavities, it was important for LARP to remain ahead of CERN in processing and testing the DQW cavities
  - Fed useful information and experience back into CERN's process
  - BNL staff was particularly engaged in the processes on both sides of the ocean

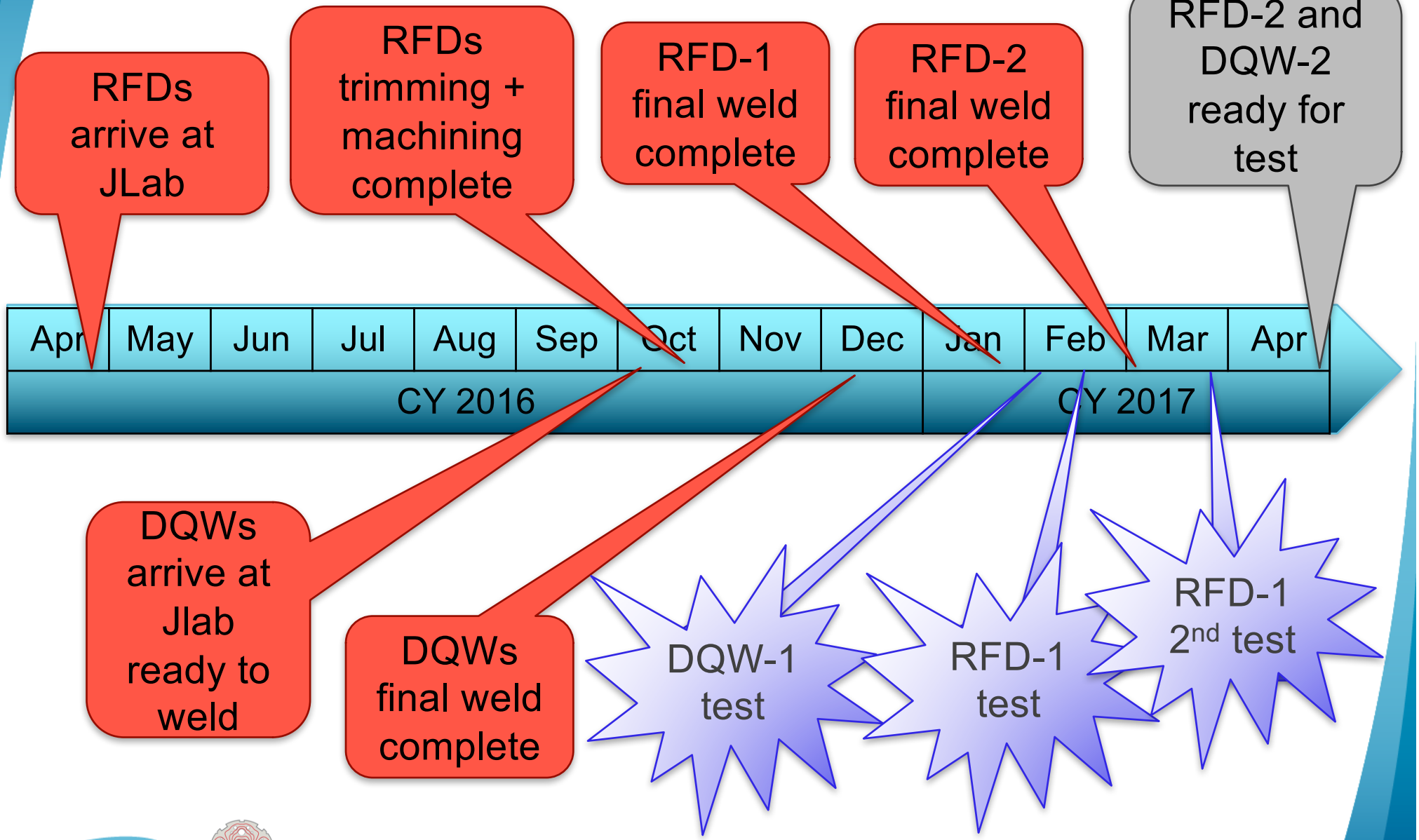
# DQW and RFD sub-assemblies





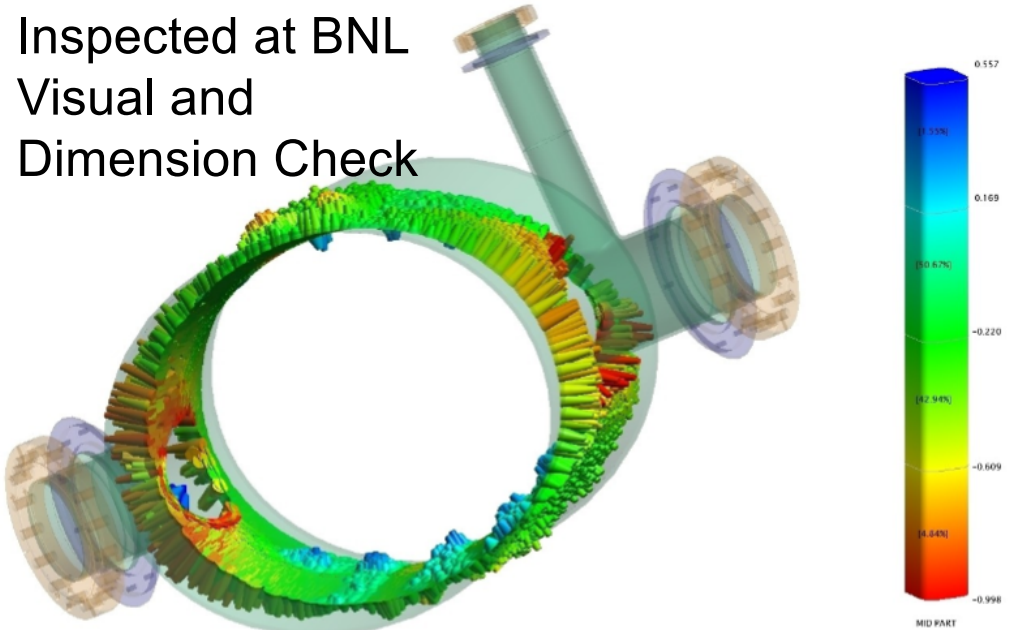


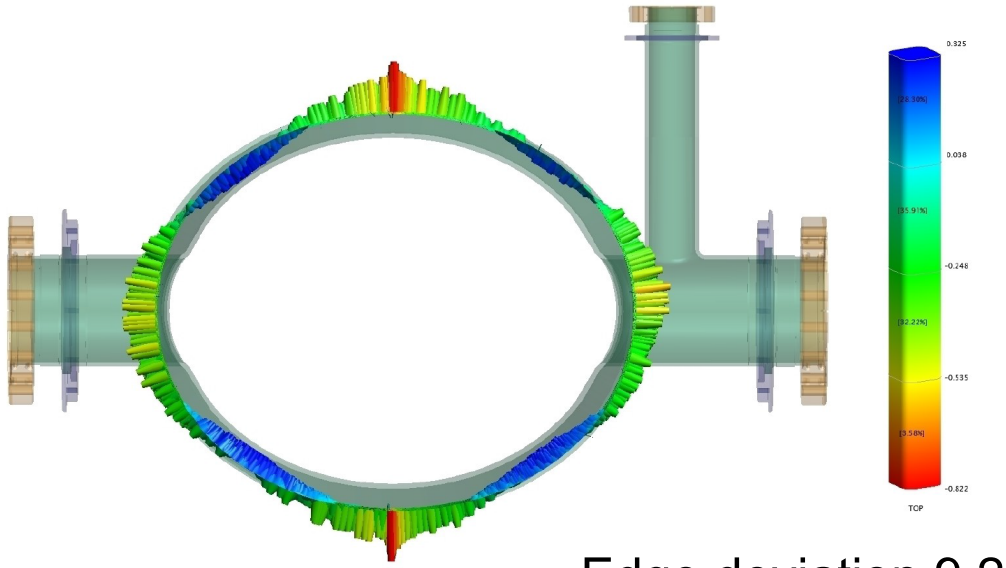
# Timeline at JLAB



# DQW Received at BNL on Jun 26, 2016

Inspected at BNL
Visual and
Dimension Check




| All Vectors Summary: Vector Group ANALYSIS::MID PART | | | | |
|---|---|---|---|---|
| Statistic | dX (mm) | dY (mm) | dZ (mm) | Mag (mm) |
| Min | -0.781 | -0.849 | -0.674 | -0.998 |
| Max | 0.754 | 0.907 | 0.491 | 0.557 |
| Average | 0.006 | 0.002 | 0.001 | -0.227 |
| StdDev from Avg | 0.216 | 0.211 | 0.056 | 0.207 |
| StdDev from Zero | 0.216 | 0.211 | 0.056 | 0.307 |
| RMS | 0.216 | 0.211 | 0.056 | 0.307 |
| Tol Range | | | | -0.400 |
| | | | | 0.400 |
| In Tol | | | | 8010 (80.6%) |
| Out Tol | | | | 1930 (19.4%) |
| Count | 9940 | | | |

Profile spec ≤ 0.8 mm

| All Vectors Summary: Vector Group ANALYSIS::TOP | | | |
|---|---|---|---|
| Statistic | dX (mm) | dY (mm) | MagXY (mm) |
| Min | -0.822 | -0.566 | -0.822 |
| Max | 0.810 | 0.517 | 0.325 |
| Average | 0.006 | -0.002 | -0.131 |
| StdDev from Avg | 0.218 | 0.153 | 0.232 |
| StdDev from Zero | 0.218 | 0.153 | 0.267 |
| RMS | 0.218 | 0.153 | 0.267 |
| Tol Range | | | -0.400 |
| | | | 0.400 |
| In Tol | | | 5569 (87.0%) |
| Out Tol | | | 834 (13.0%) |
| Count | 6403 | | |

Edge deviation 9.293 mm down from the edge

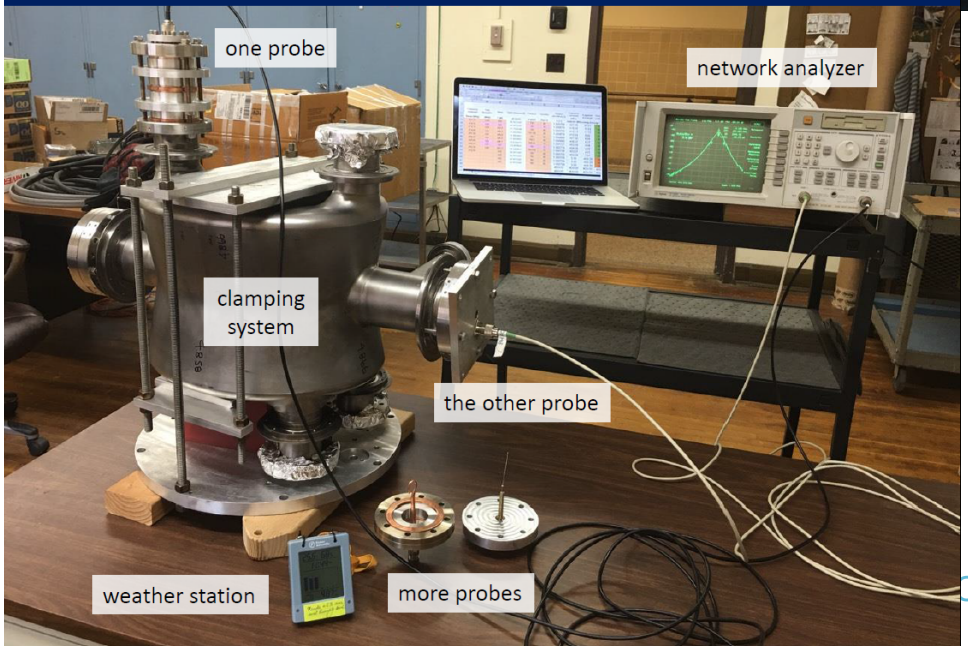


Q. Wu - BNL

# DQW n 1 Final Trimming at Niowave

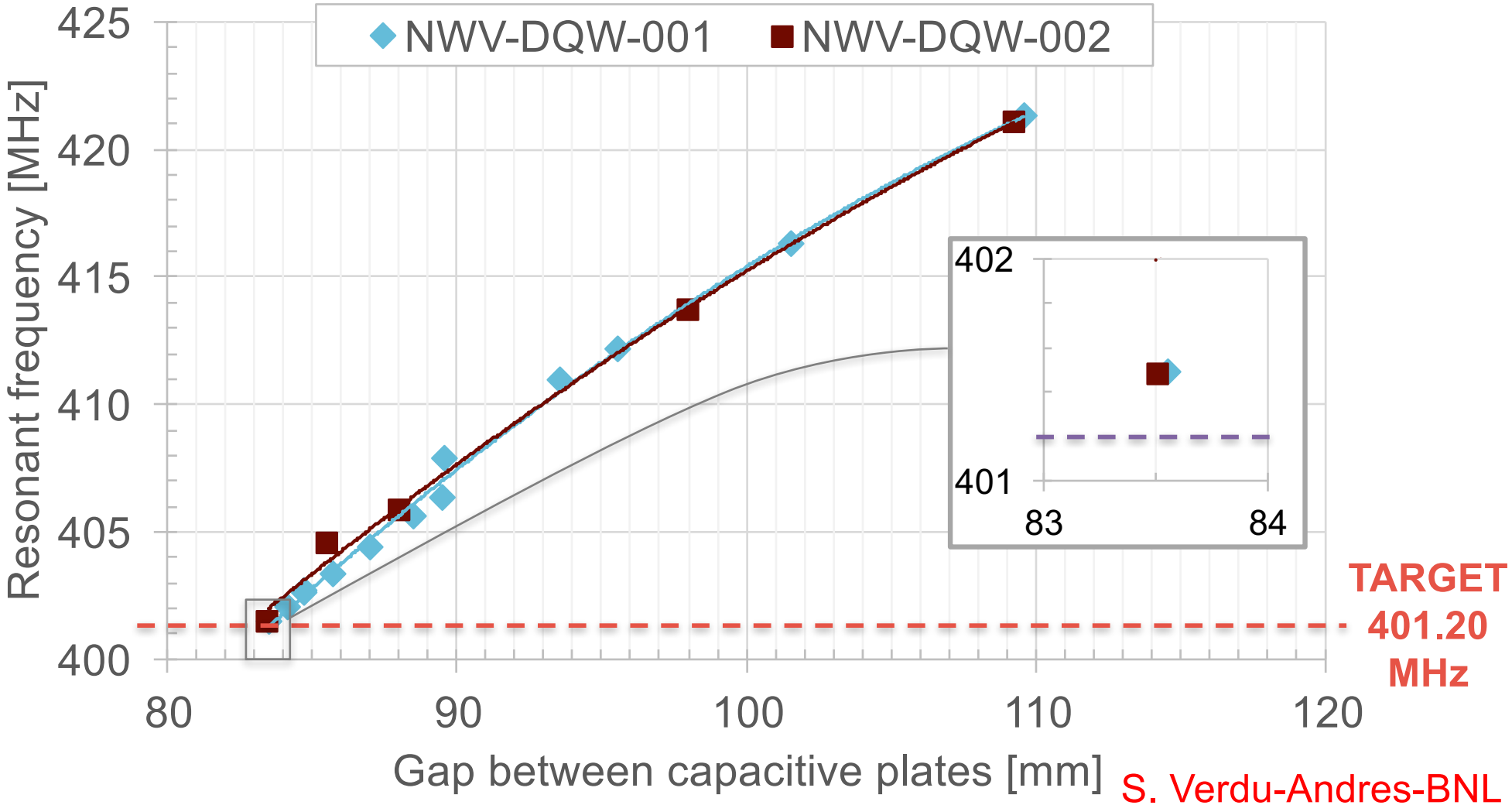
15 Sep 2016

Trim tuning at Niowave – *frequency check setup*




# DQW Tracking Trim Tuning

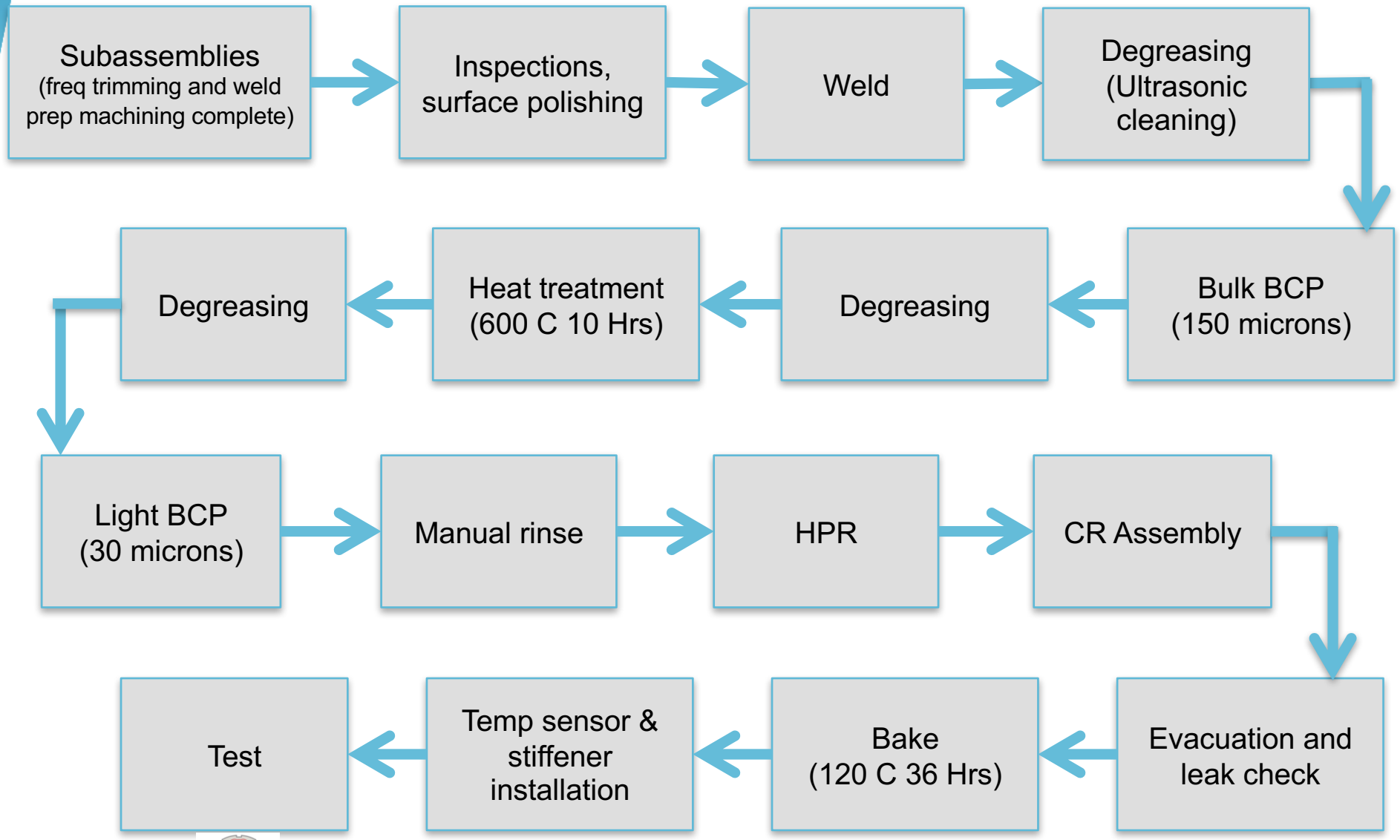
- **Good reproducibility**: both cavities follow the same behavior
- Measured trim tuning sensitivity, 0.9-1.0 MHz/mm-gap, close to predicted by simulations, 0.98 MHz/mm-gap (using 2nd order polynomial fit)
- Accepted cavities are about 0.2 MHz above from target frequency




S. Verdu-Andres-BNL

# Process Flow – DQW

Inspection and frequency measurement between each step



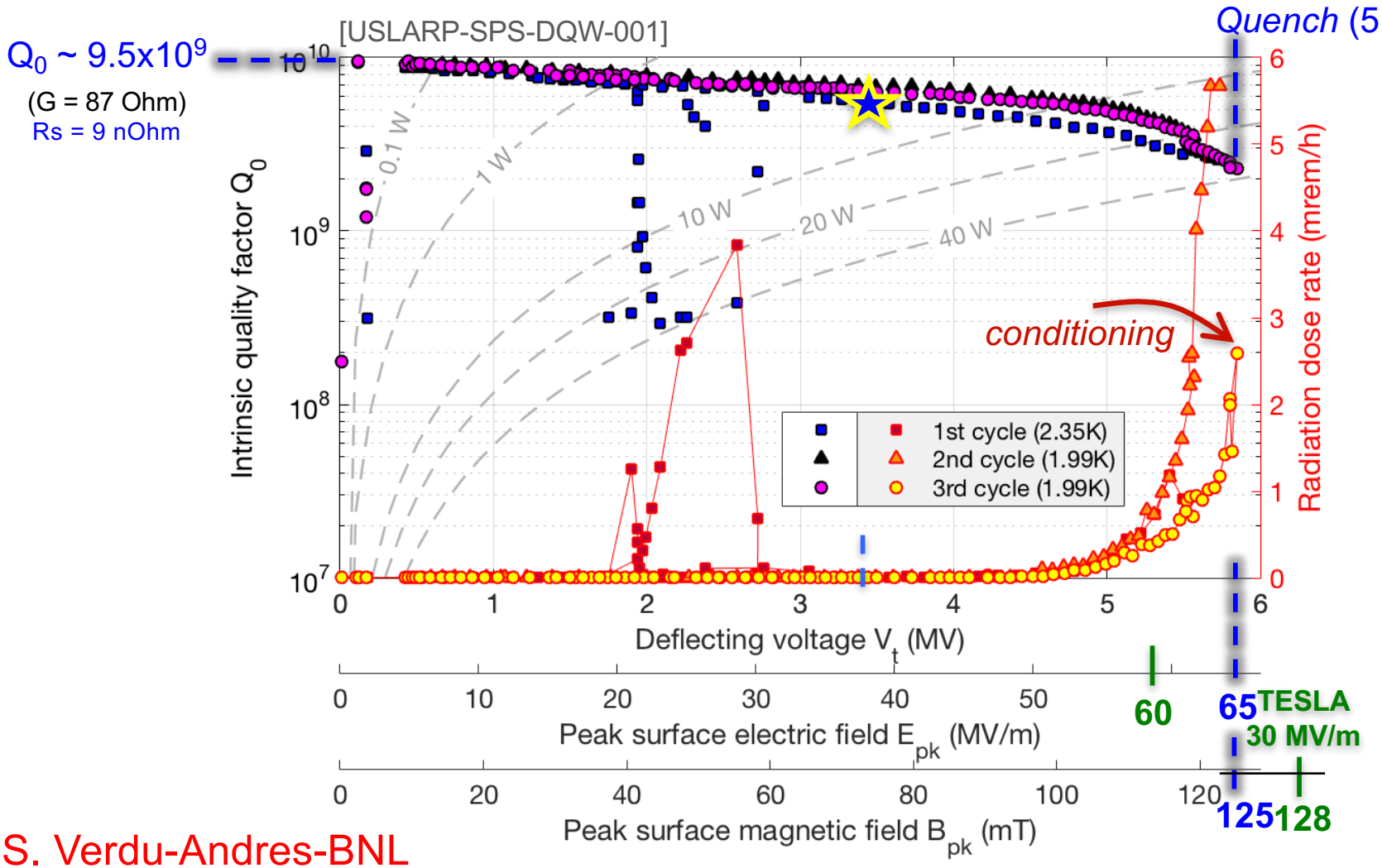



HK Park - JLAB

# SPS DQW crab cavity: performance

**Confirms enhanced nominal deflecting voltage** (Feb 2017)

- Reached **$V_t$~5.8 MV** before quench (CERN cavity confirmed 5.1 MV a few weeks later)
- No detectable field emission well beyond operating gradient



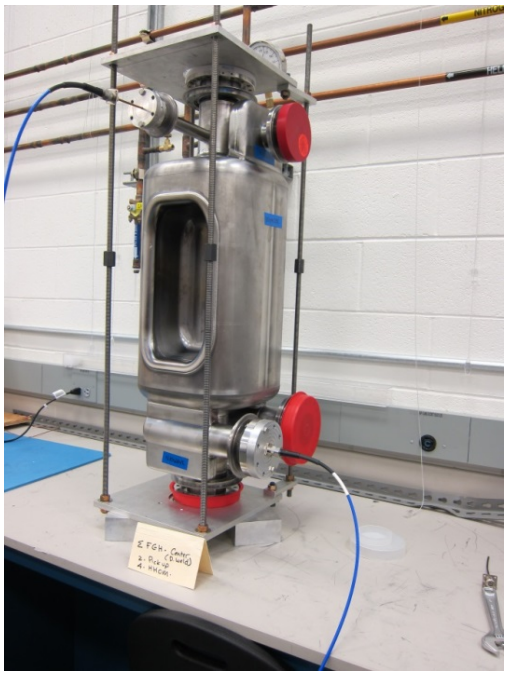

S. Verdu-Andres-BNL

# SPS DQW Tests - Comments

- Cavity arrived at JLAB ready to weld
- Remained ahead of CERN's production feeding useful information, details and lessons learned to the processes at CERN
- Excellent performance exceeds all previous results
- DQW2 being prepared for re-testing
  - First attempt was unsuccessful due to setup problems

# Niowave RFD Cavities at JLAB

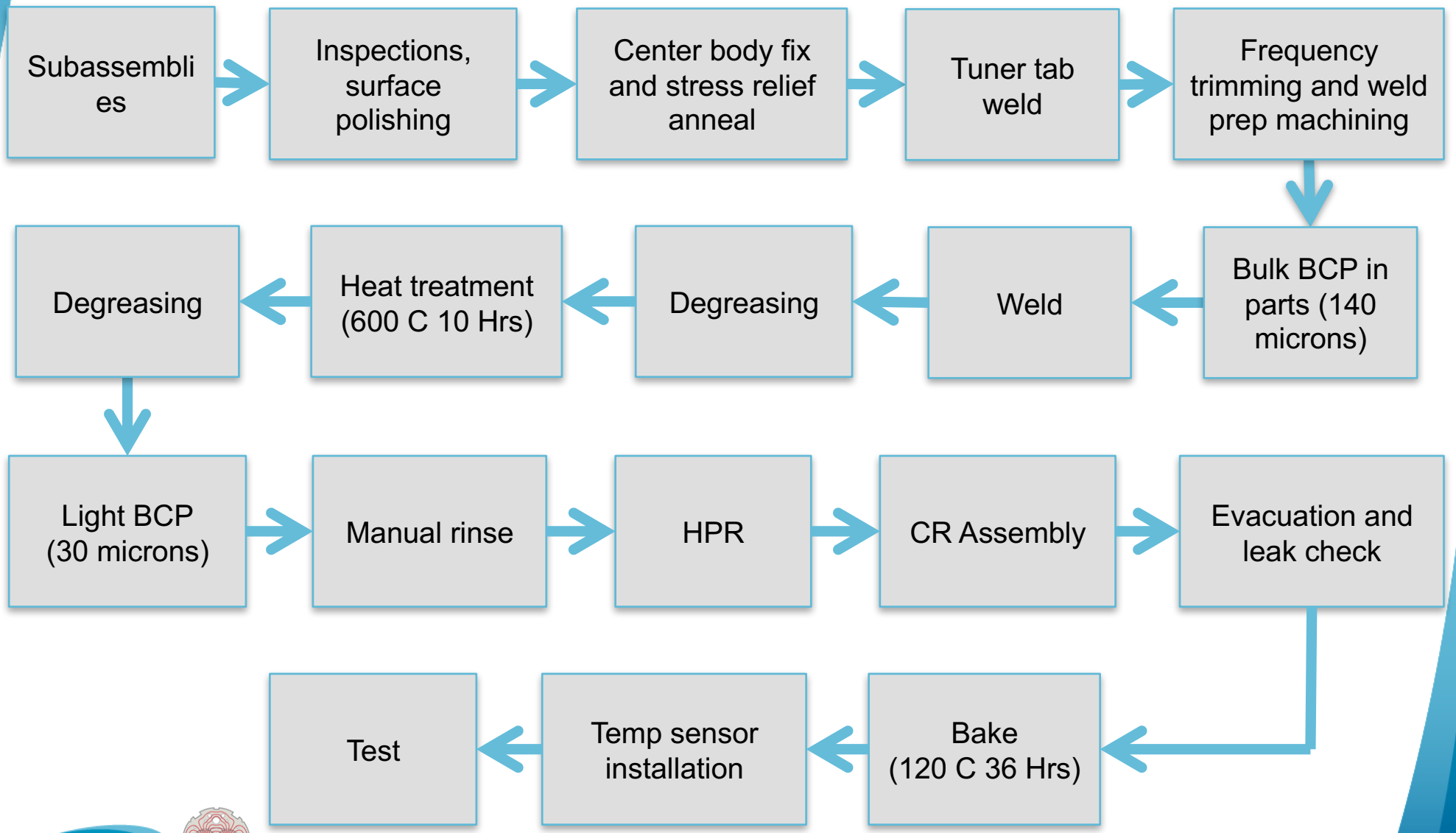
- Two cavity sub assemblies arrive at JLAB



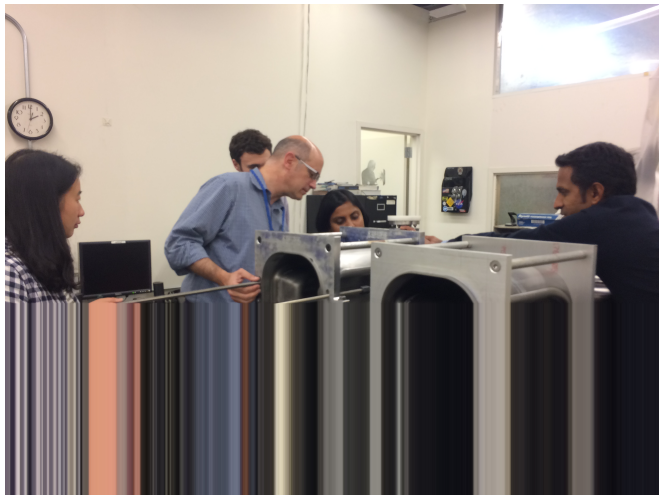

28 April 2016

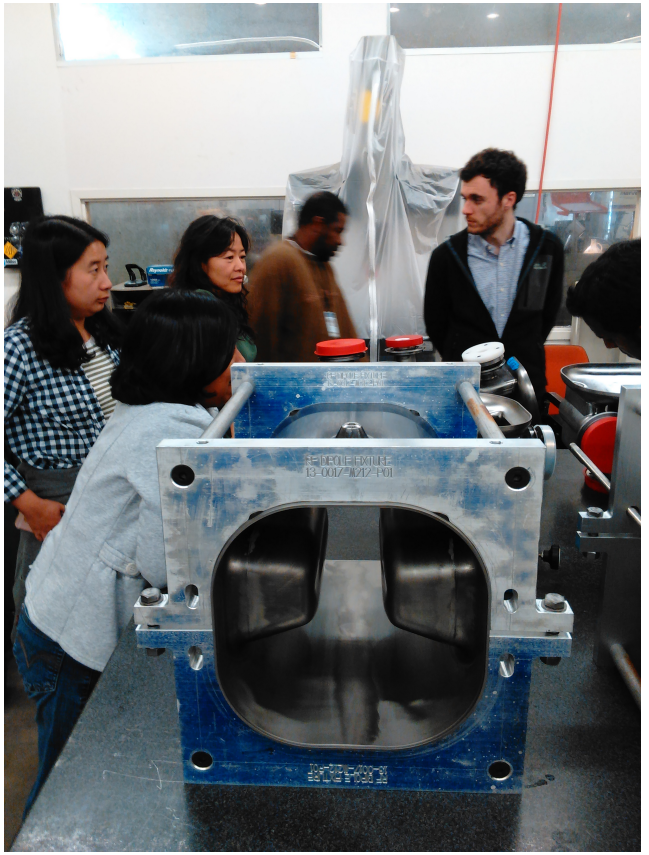
# Process Flow – RFD

Inspection and frequency measurement between each step



# RFD final Machining at JLAB





BNL
CERN
LU/STFC
JLAB
ODU
SLAC

contributed

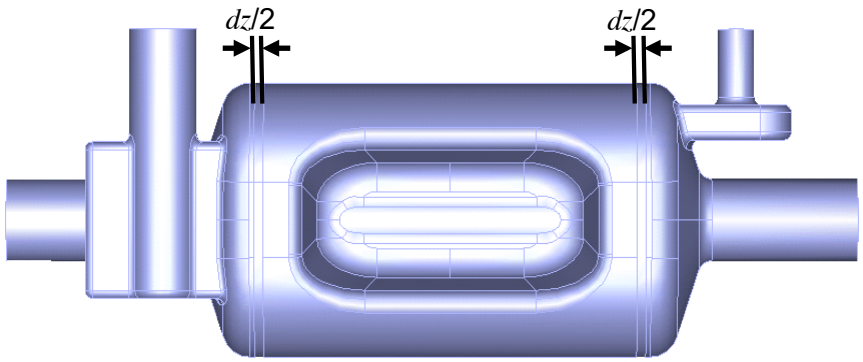
27 Oct 2016

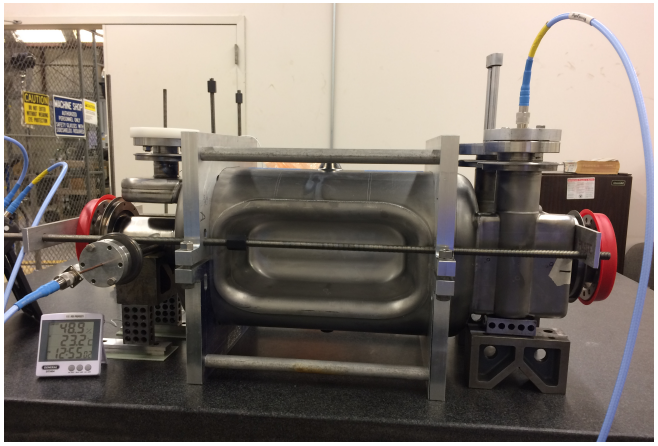
# SPS-RFD Cavity: Trimming Sensitivity

- Trimming sensitivity for RFD cavities

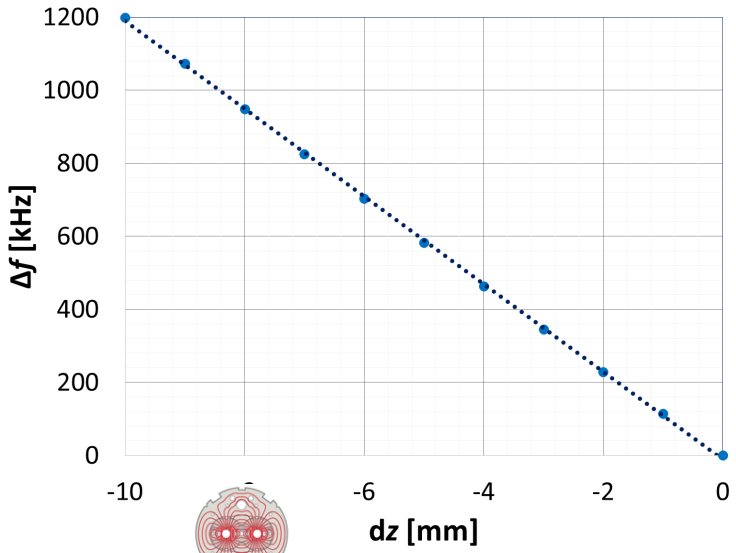
  $df/dz$ = -119.85 kHz/mm

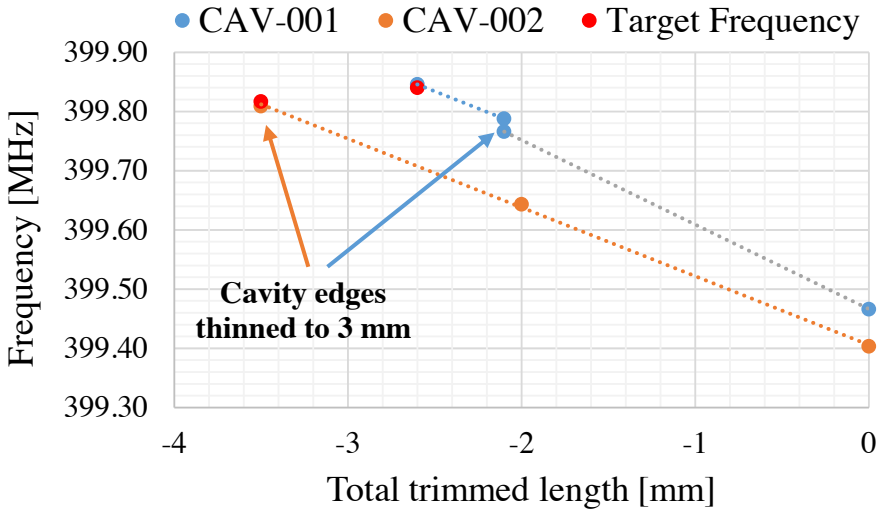
- Measured sensitivity:
  - CAV001: -129.3 kHz/mm
  - CAV002: -116.1 kHz/mm



Good agreement with simulations



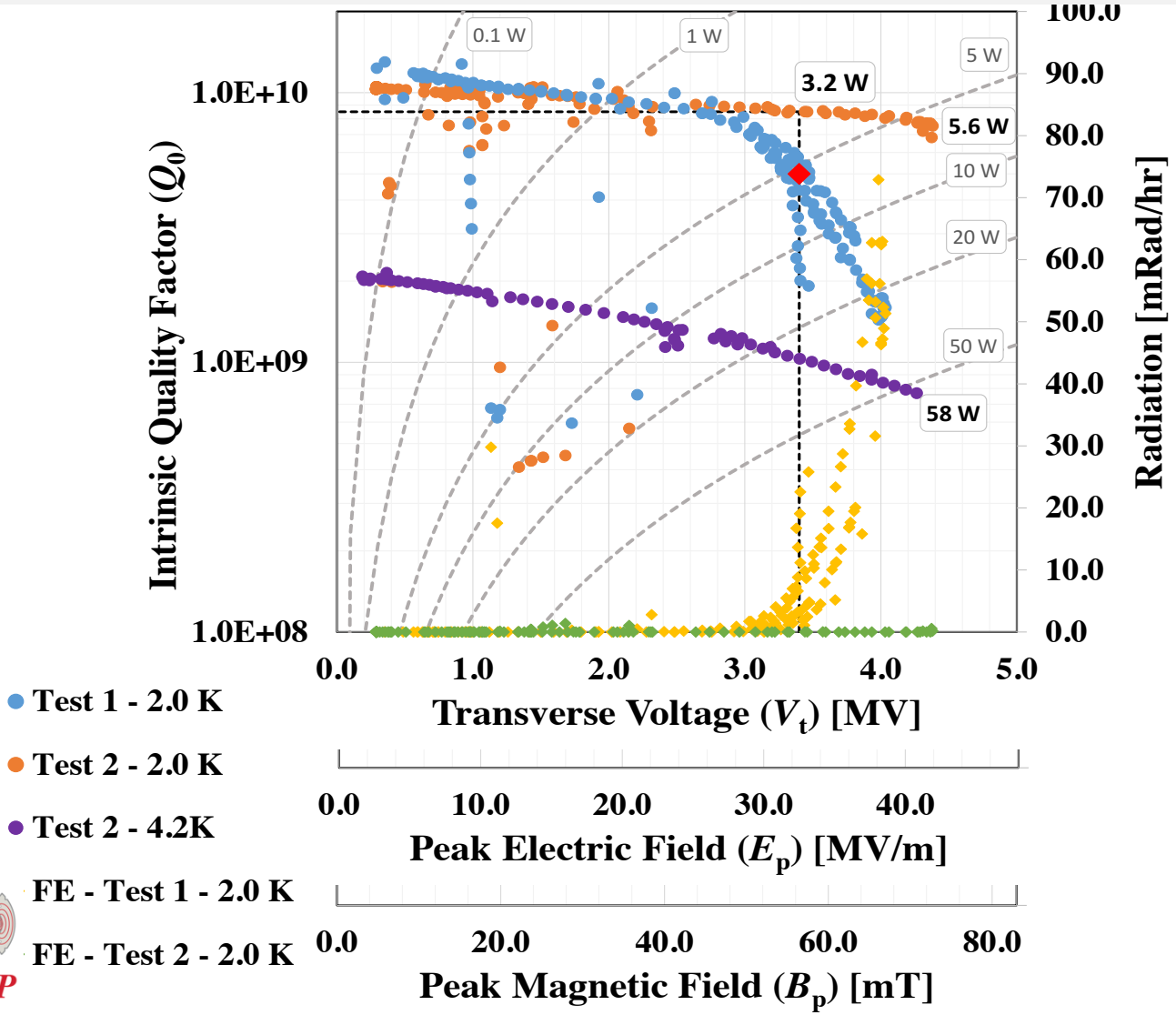
# RFD Processing - Notes

- Additional step needed in the beginning to correct the frequency of one center assembly
- Processed bulk BCP before final weld
- Final welds had some areas that appeared not fully penetrated upon visual inspection
  - Welds repeated with higher e-beam current
- First test of RFD1 gave satisfactory, yet marginal results
  - In particular with field emission
  - Additional cycle of light BCP gave much improved results
- RFD2 being prepared for re-testing
  - First attempt was unsuccessful due to setup problems

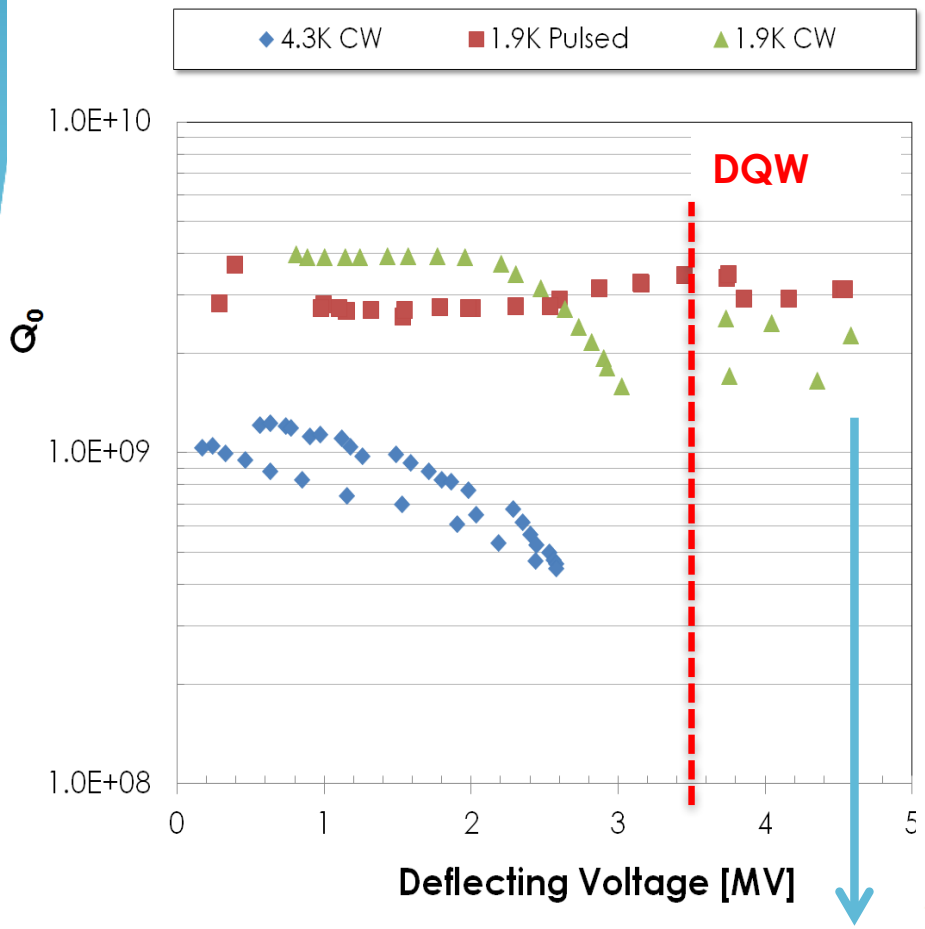
# SPS RFD Crab Cavity: Performance

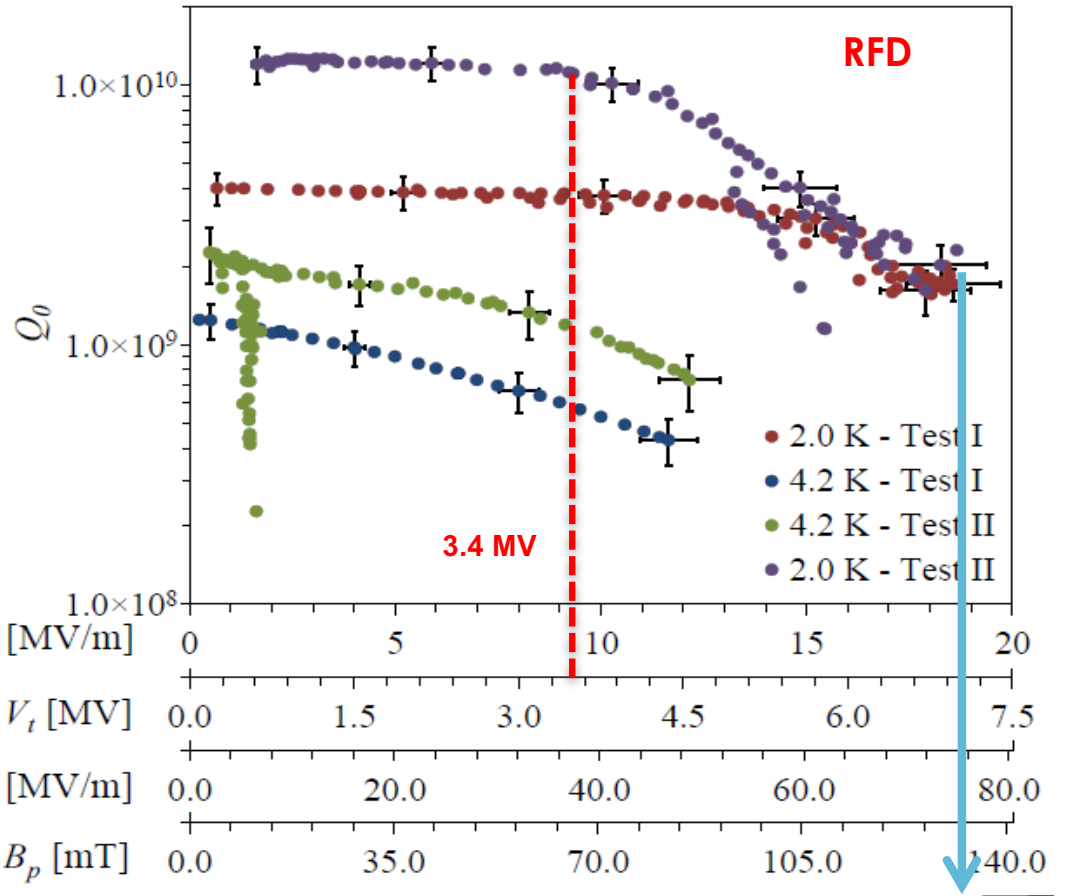
**Meets HL-LHC requirements for field and $R_s$**

- Reached **$V_t$~4.4 MV** before quench
- No detectable field emission until quench field



# DQW and RFD PoP Test Results (~2013)




4.6MV quench

7 MV quench

# SPS Prototype Testing - Comments

- When combining results from the PoP program and the SPS prototypes of DQW and RFD, both cavities reached excellent results:
  - Max $B_p$ >125 mT
  - Quenched at >> 5MV
  - Very limited field emission
- Indication of solid electromagnetic design
  - Quenches with no field emission often indicate surface defects and not EM design limitations
  - Processing generally helps
- Both design are fully capable to deliver the performance required by HL-LHC
  - As always (in SRF) the devil is in the details
    - Cavity manufacturing, processing and surface treatment
- More details on CC studies and analysis in WP4 and WP2/WP4 breakc

# Ongoing and Future LARP Plans

- Continue and complete testing of all bare cavities
- Test cavities with HOMs where possible
- Move tested cavities from JLab to BNL and FNAL for further testing
- Collaborate with CERN and support its development of RFD cavities towards the SPS tests post LS2 (and post LARP)
- Contribute to the definition and planning for the pre-series and series
- Support the SPS test with planning, RF measurements and MDs, analysis and synthesis
- Start planning for HL-LHC AUP with the limited availability of M&S funding within the LARP program and support the transition to the US construction project.

# Conclusions

- Niowave produced cavities were completed and tested at JLAB
- Good test results give valuable indications the project is on the right track to meet cavity objectives
- More testing to come on RFD2 and DQW2
- Plan to perform RF field measurements after successful vertical testing
- LARP plans to continue supporting crab cavity development and testing in support of AUP and HL-LHC

# Questions