CERN SPL Cavity Measurements Report

Alick Macpherson
on behalf of
CERNs SPL measurement team

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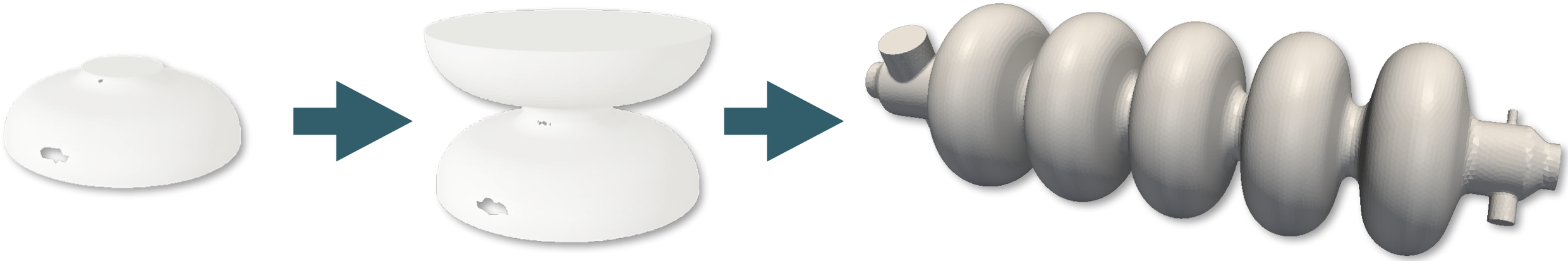
18 March 2015

Introduction

- **Cavity construction**
  - Trimming + Tuning Bench + Tuner Measurements
- **2 Kelvin Testing of Nb 5-cell Bare SPL Cavities**
  - Cavity Preparation Issues
  - 1st & 2nd cold Test of SPL_1
- **Schedule, Plans and Upgrades**
  - Objectives, Procedures and what happens next …

Cavity Construction: Trimming and Tuning

Trimming and Tuning: Target Frequency



$f_{\text{Pi Half cell}}$ = $f_{\text{Pi dumb-bell}}$ = $f_{\text{Pi cavity}}$

Setting the target frequency value for trimming

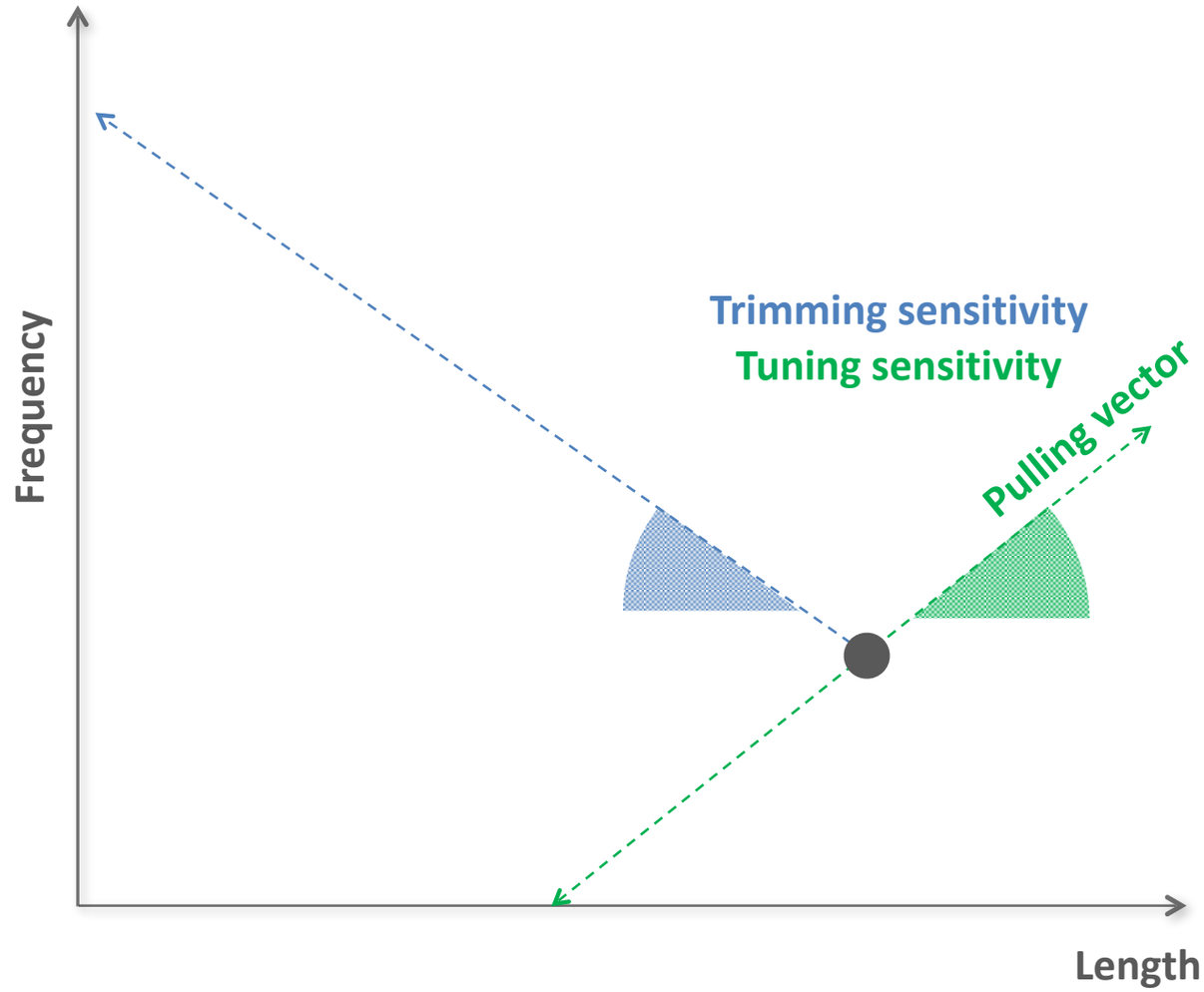
- 1. Cavity: f_π(2 K & under vacuum) = 704.400 MHz
- 2. Dumb-bell: f_π(300K & nominal length & vacuum) = 704.043 MHz
- 3. Dumb-bell: f_π(300K & nominal length & dry air) = 703.836 MHz
- 4. Dumb-bell: f_π(300K & nominal length + 5mm & vacuum) = 696.467 MHz
- 5. Dumb-bell: f_π(300K & nominal length + 5mm & dry air) = 696.286 MHz

Setting the target Cavity length:

- L = 1397.3 mm ± 3 mm at 300 K
- L = 1392.9 mm ± 3 mm at 2K

Frequency and length correction

- **Construction of 5 Cell Cavity**
  - Trimming: Trim dumbbell to get close to target frequency and length
  - Tuning: Plastically deform 5-cell cavity to required freq, length & field flatness
    - Caveat: In cryomodule, operate tuner in one direction (elastically deform)



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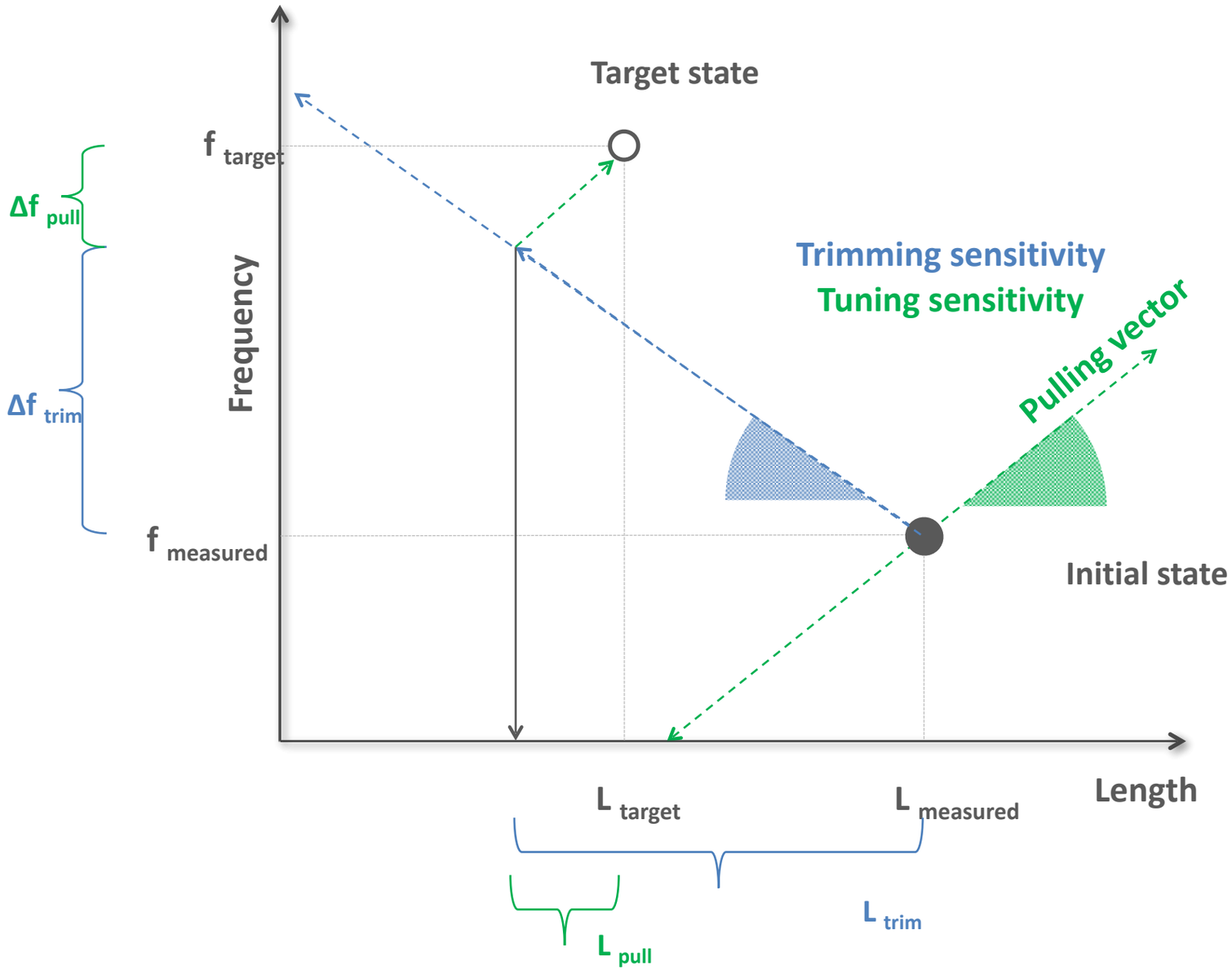
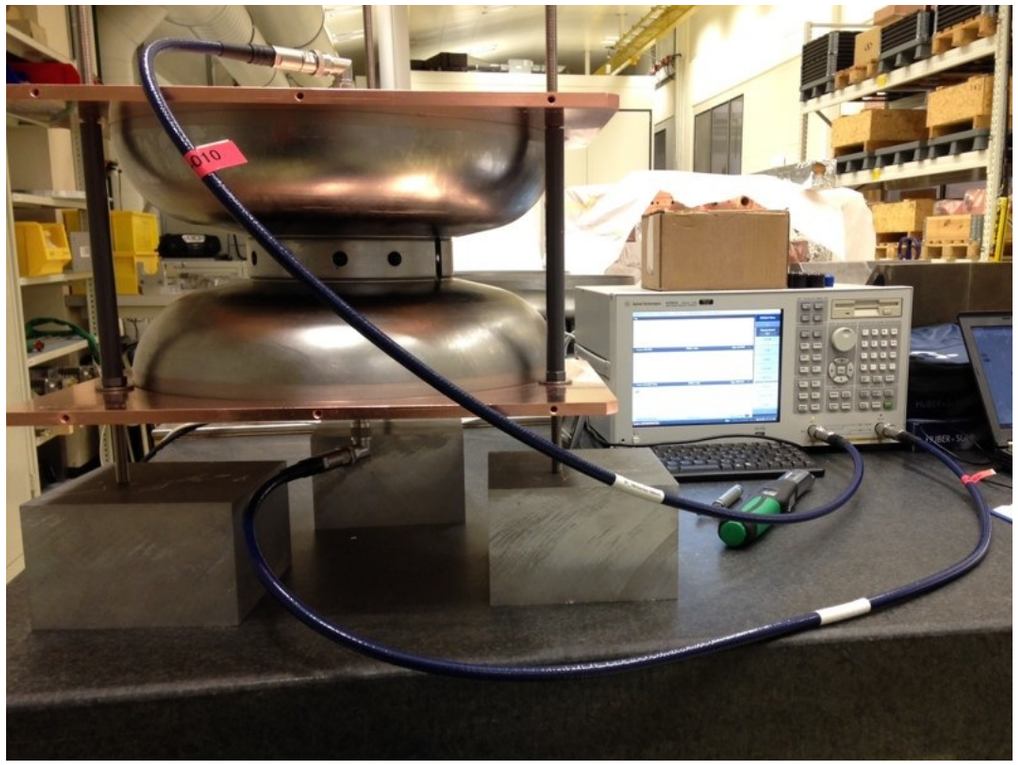
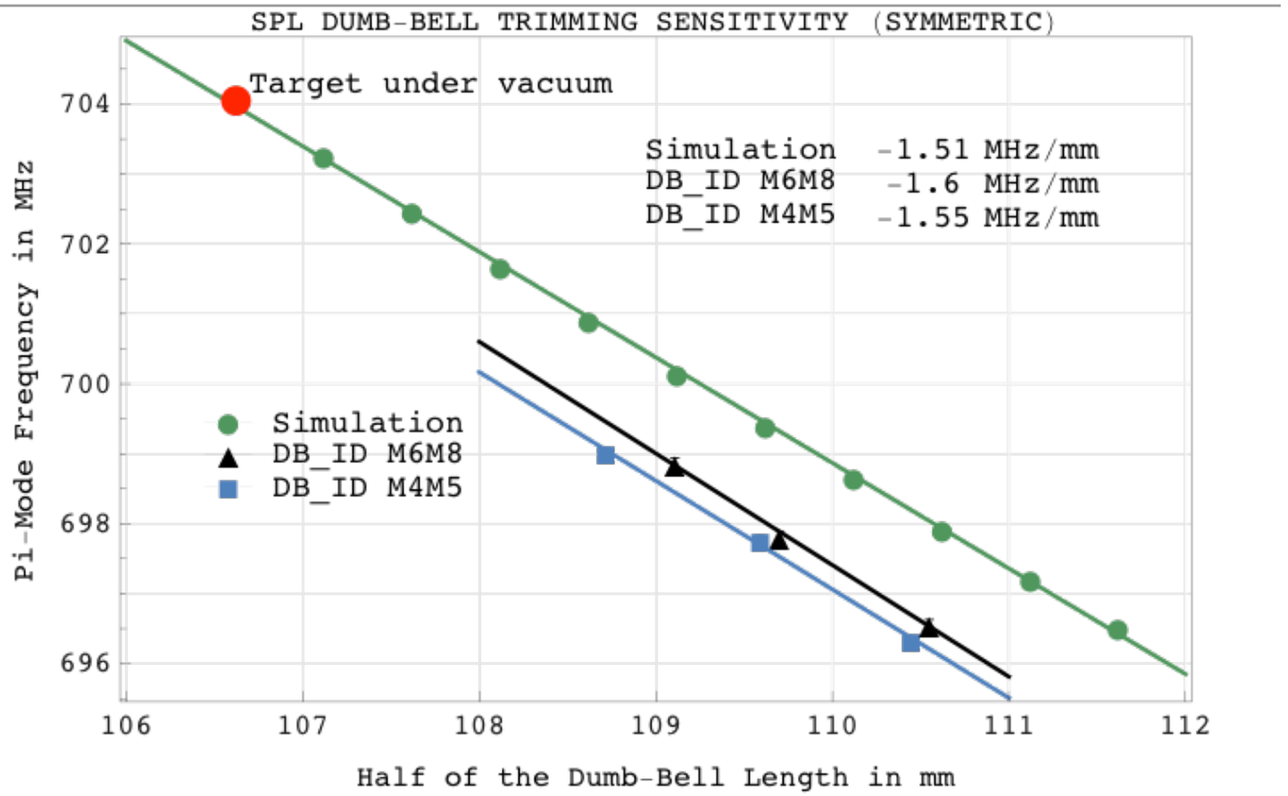
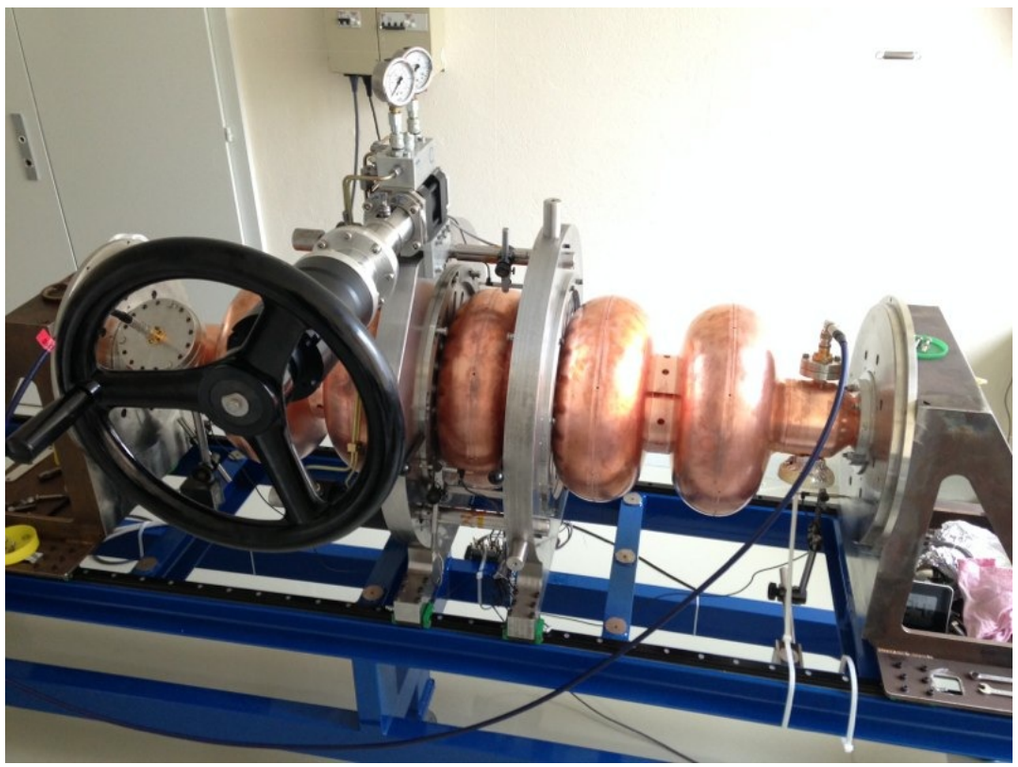
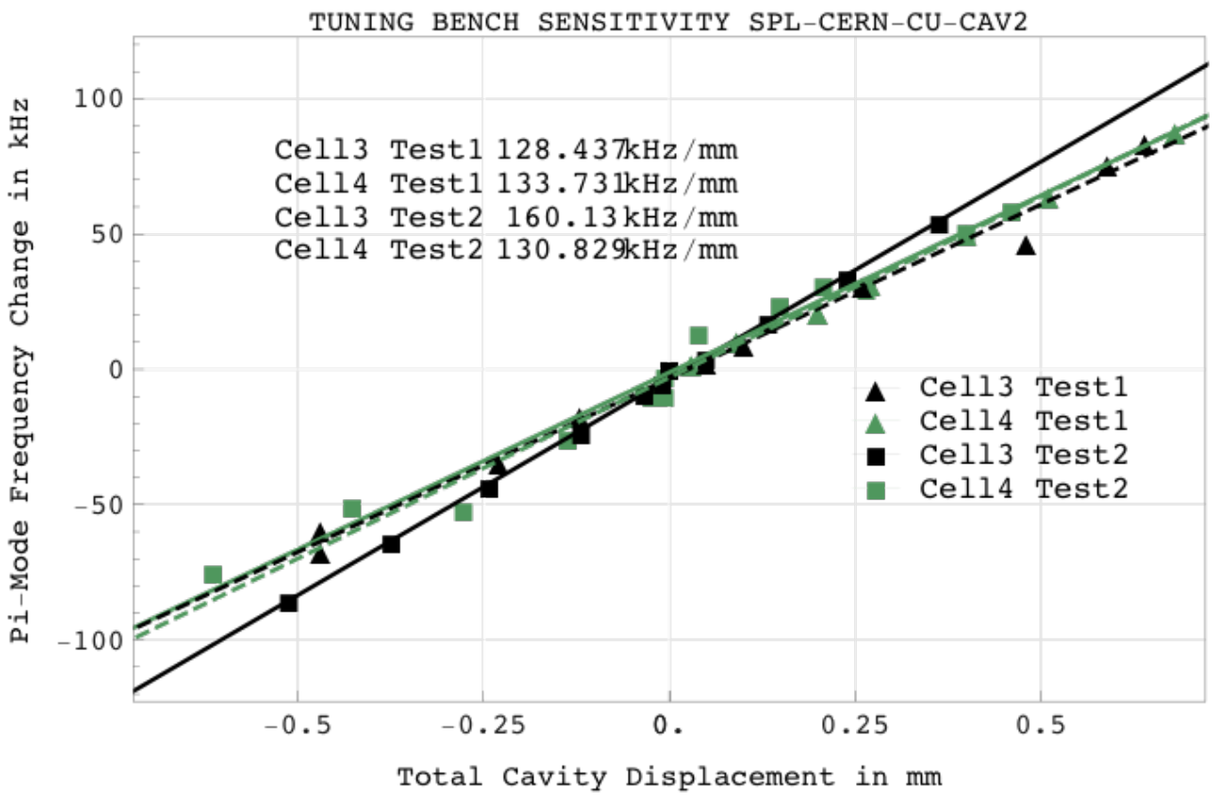


Trimming and Tuning Sensitvities

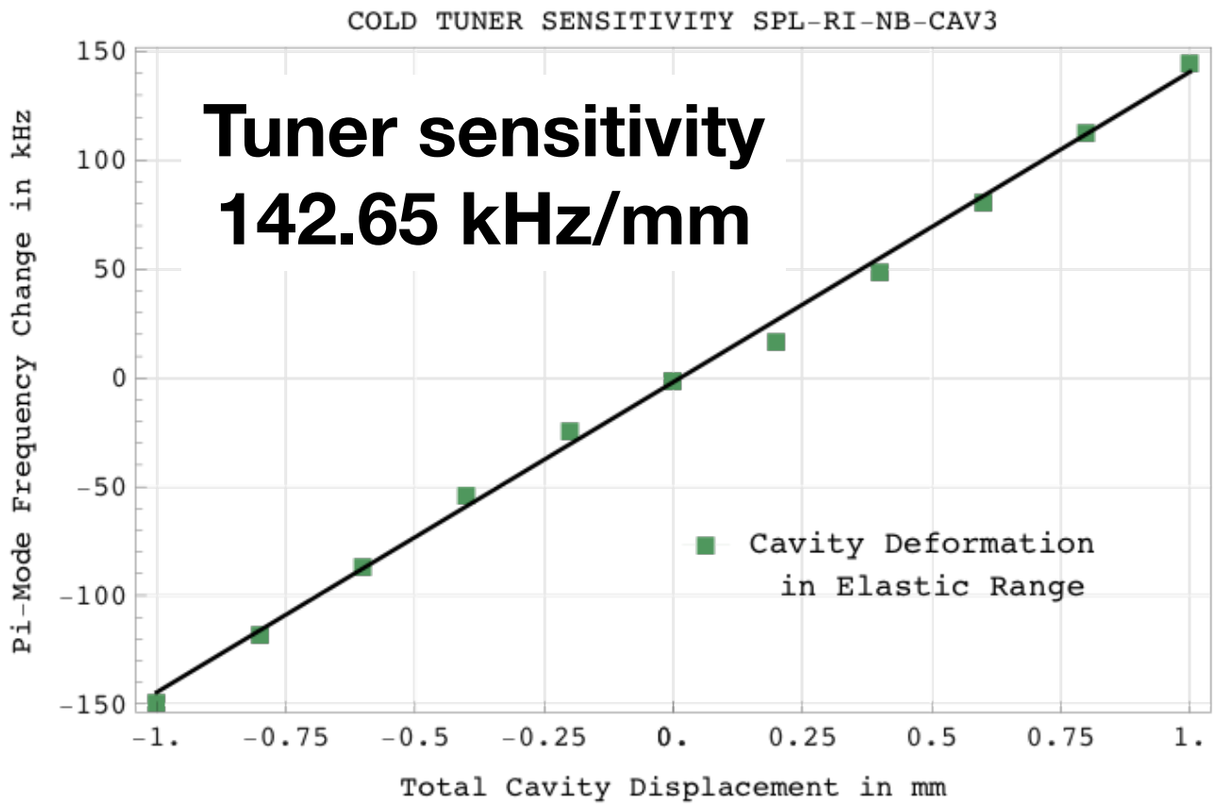


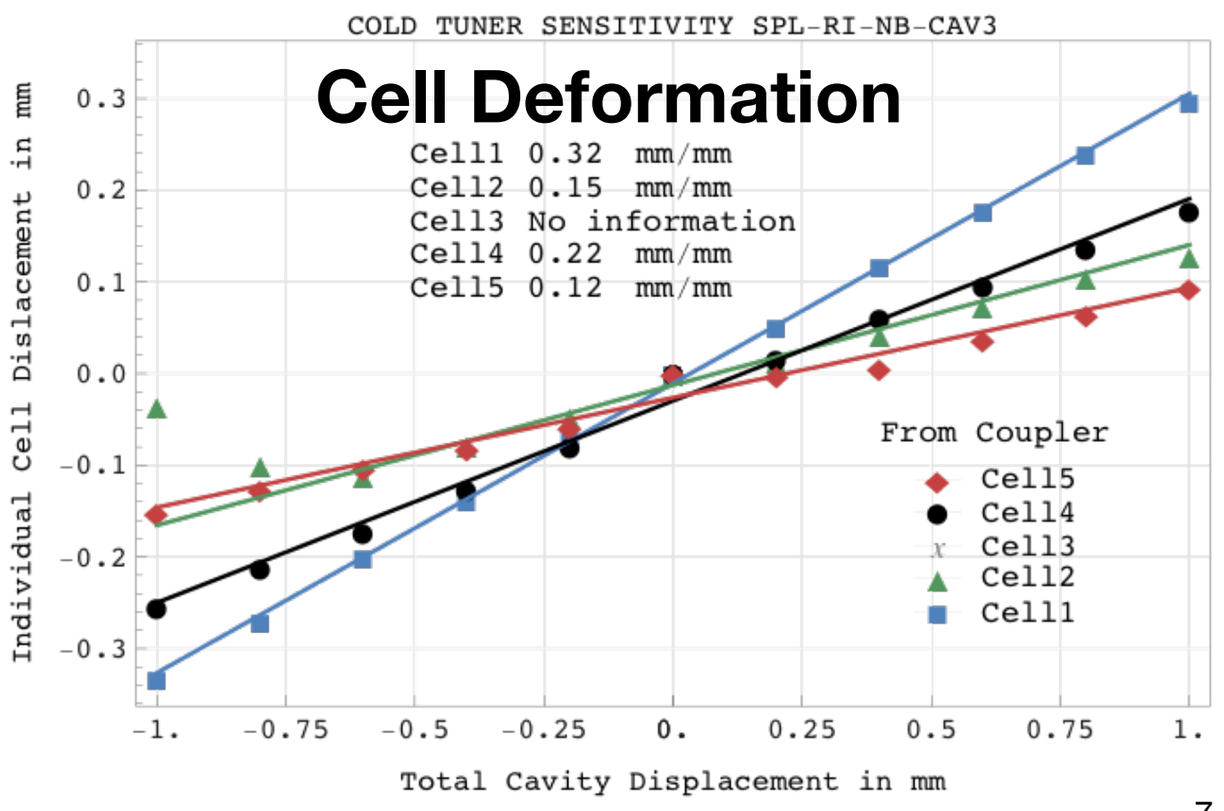




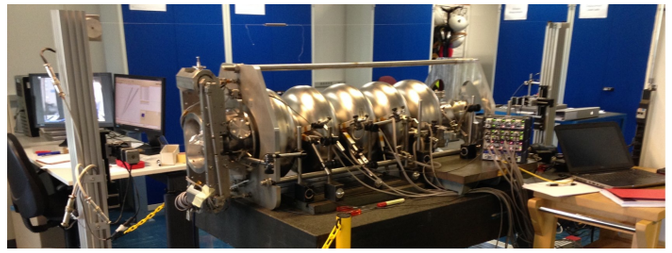


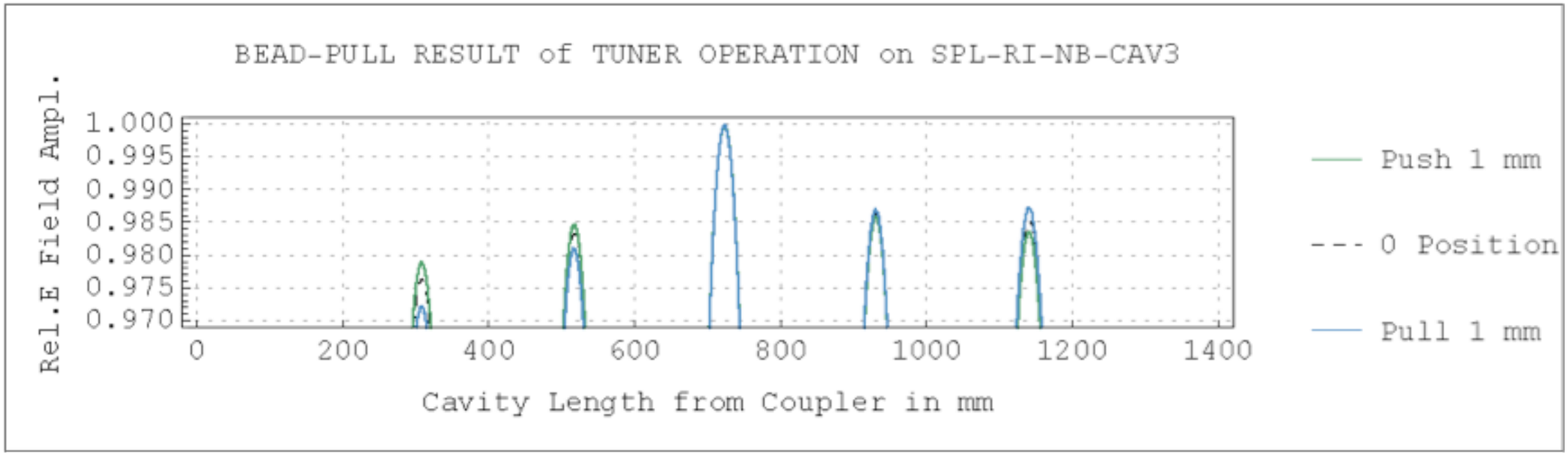
Tuner Measurements

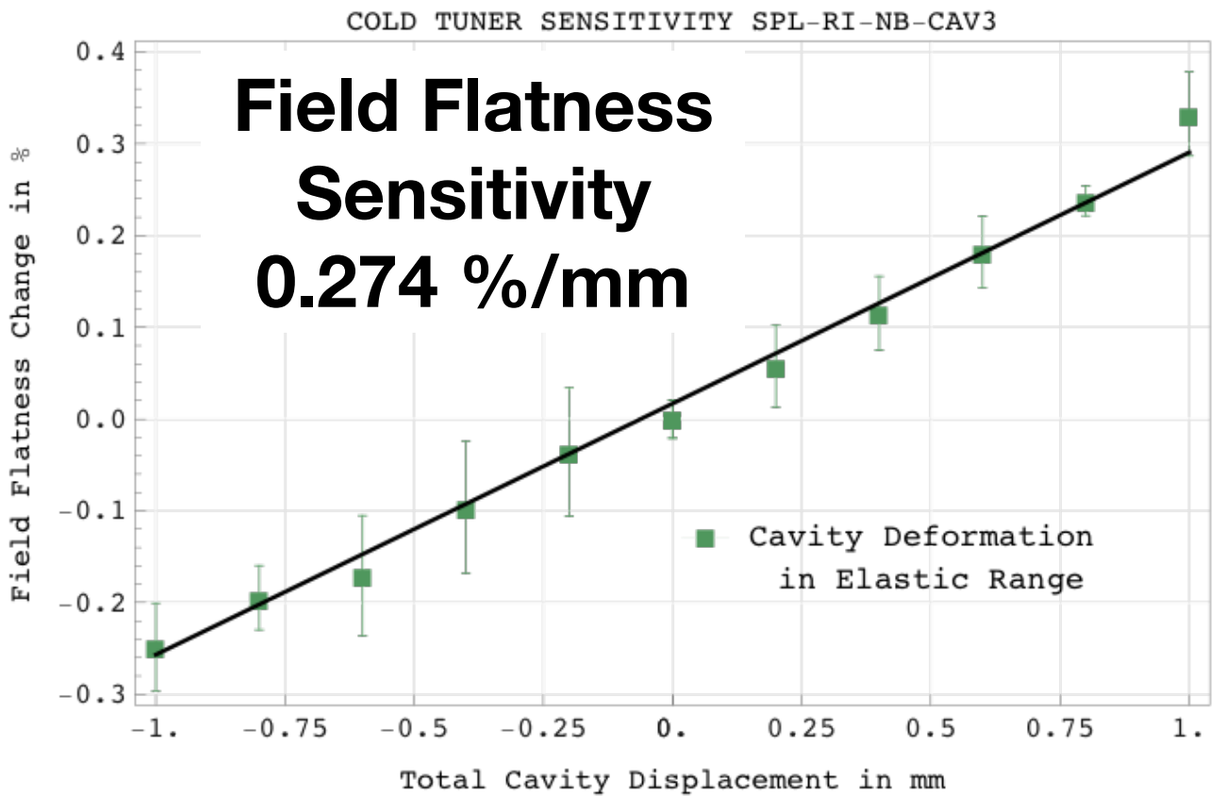


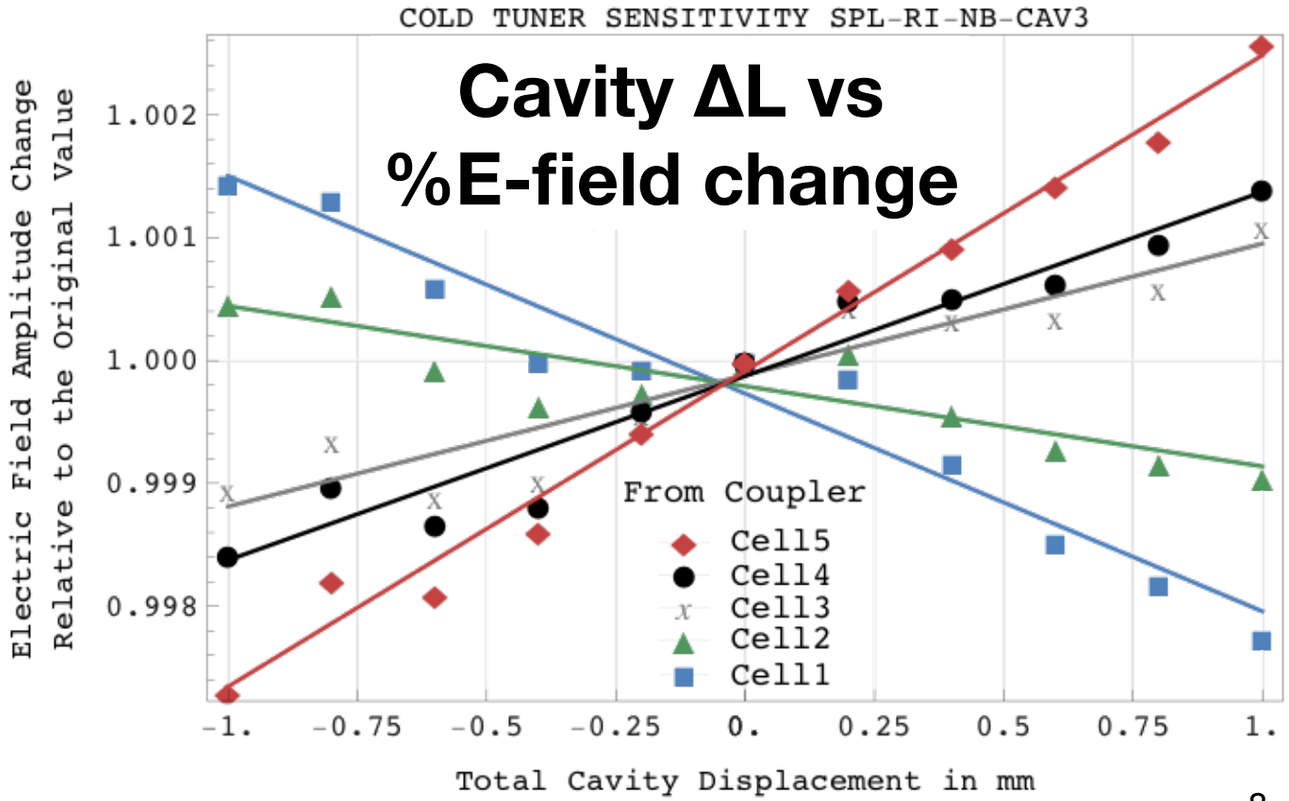


Tuner Measurements: Field Flatness

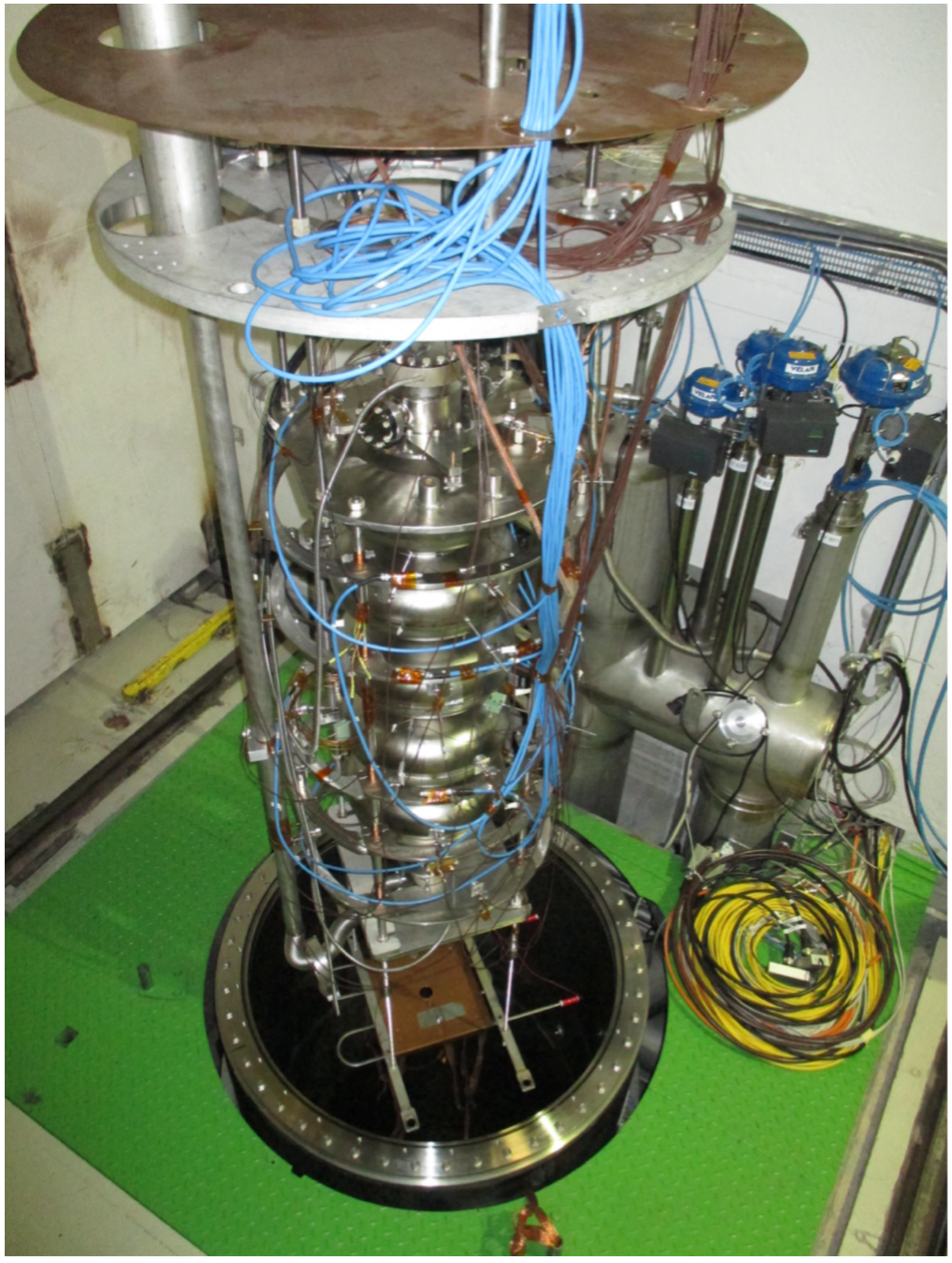








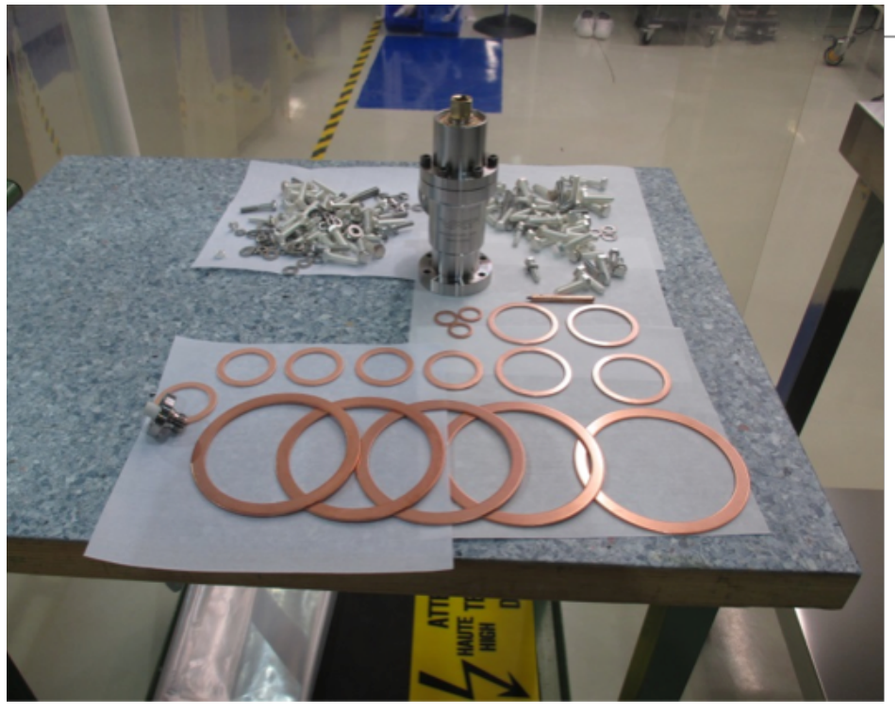
Cavity Cold Testing

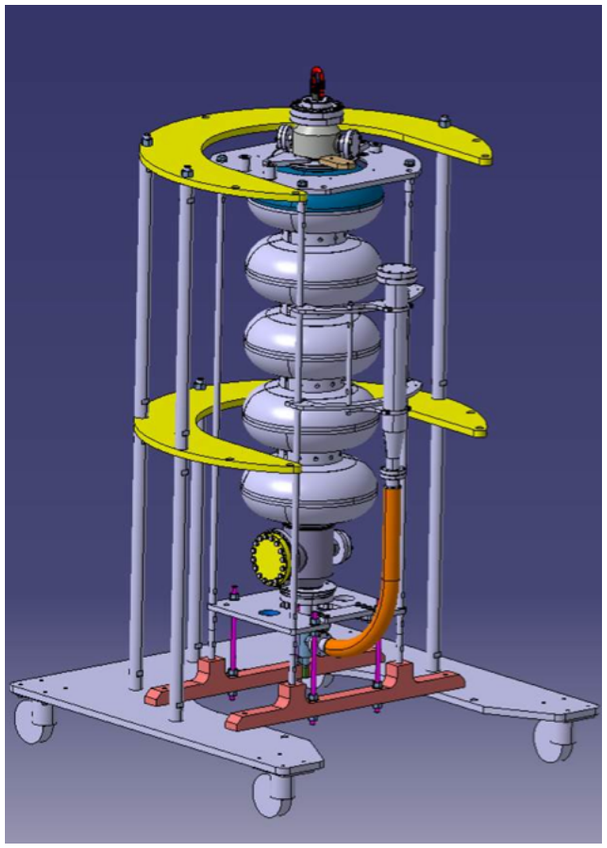


Cavity Preparation Steps

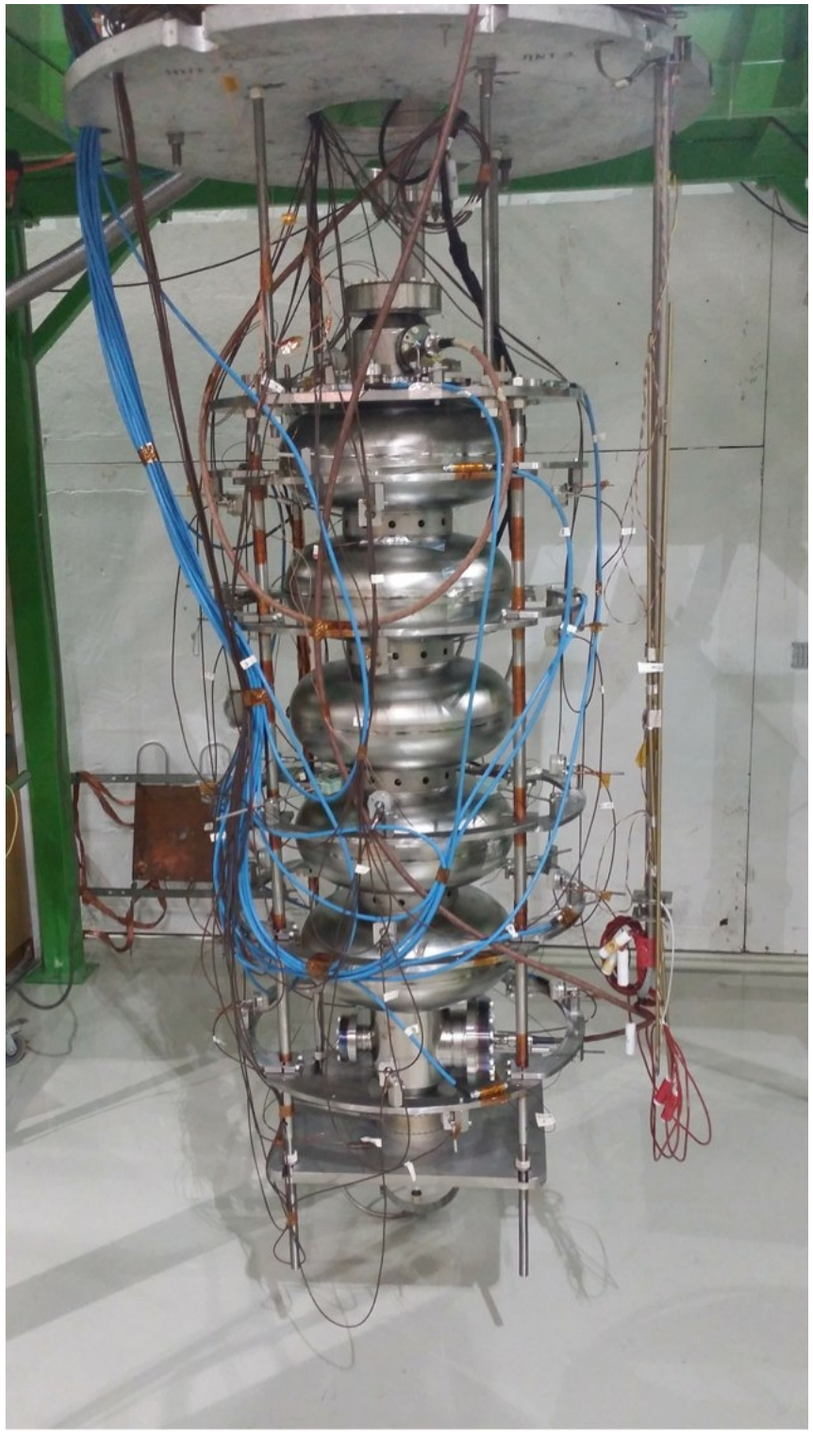
- **Chemistry:**
  - Electro polishing of 160 - 200 um
  - Heat treatment: 650 degree for 24hrs
  - Light Electro polishing of 10 - 20 um
- **HPR at 100bar with ultra pure water**
  - Conductivity >18MΩ/cm TOC < 16 ppb Water Temperature : 26°c
  - Drying in hot nitrogen atmosphere then 12 hrs in laminar clean air flow
- **Cavity Assembly and Pump down**
  - Done in ISO-4 cleanroom. Pump down within 36 hrs after end of HPR
- **120 deg C Bakeout.**
  - Duration: was ~12 hrs. Now 48 hrs
  - RGA on cavity vacuum (for comparison with RGA after cold test)
- **Mounting on Insert and assembly into cryostat**
  - Bakeout of vacuum pumping line before opening cavity valve.
  - Mounting of diagnostics

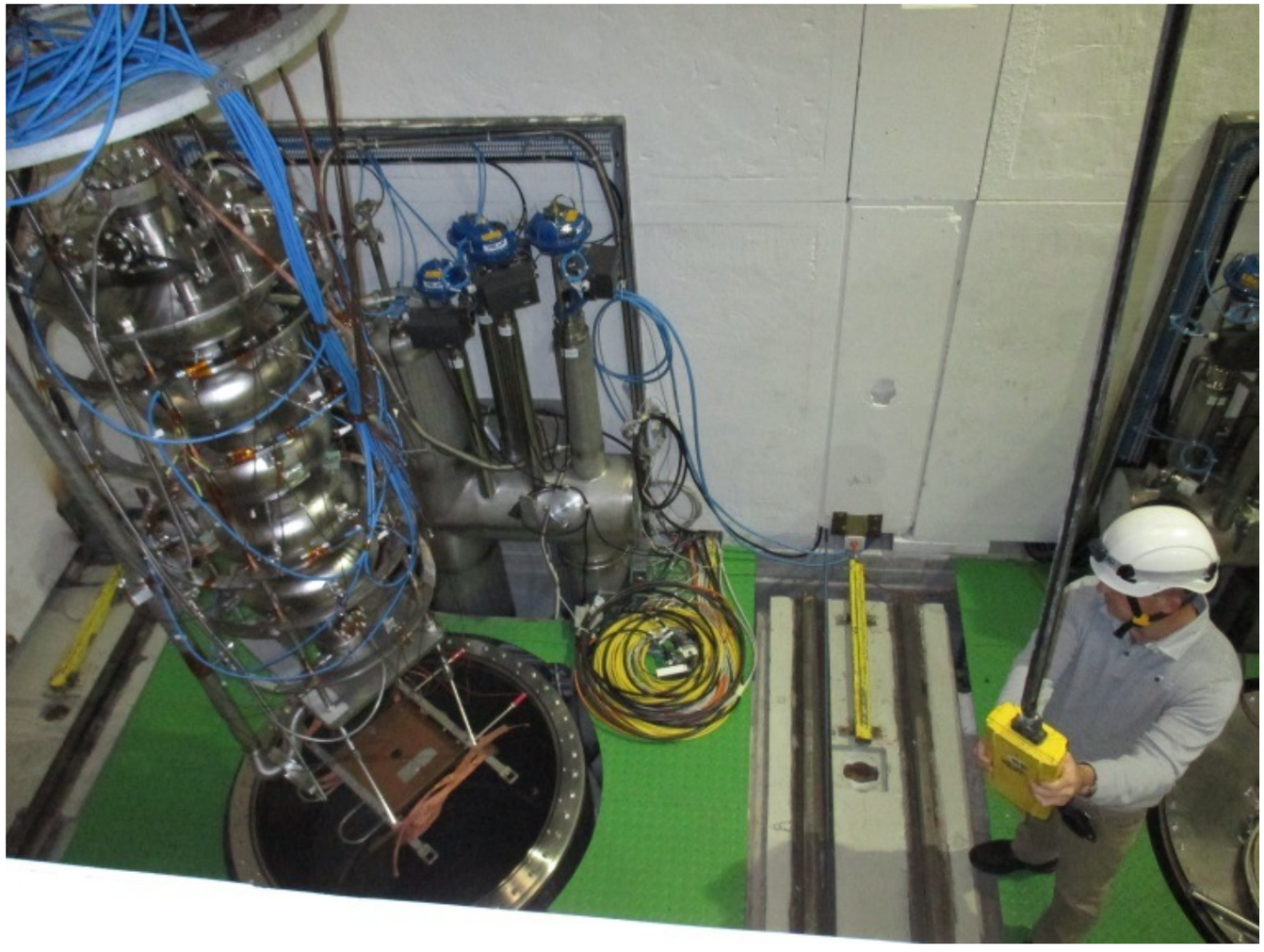
Cavity Preparation



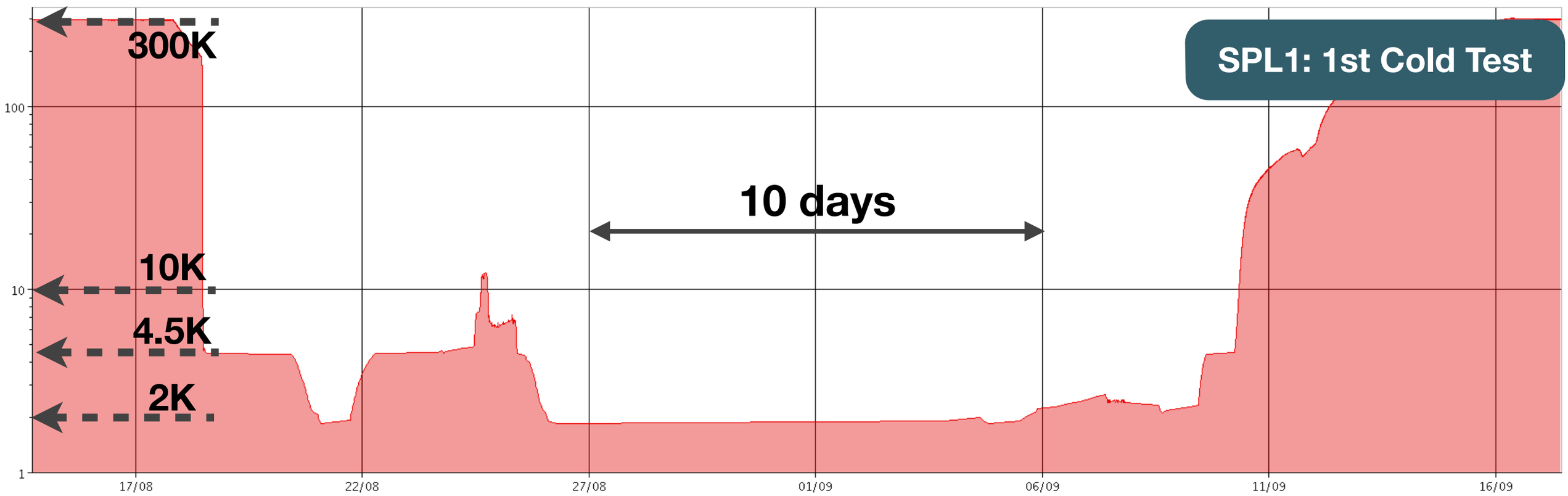




Assembled Insert

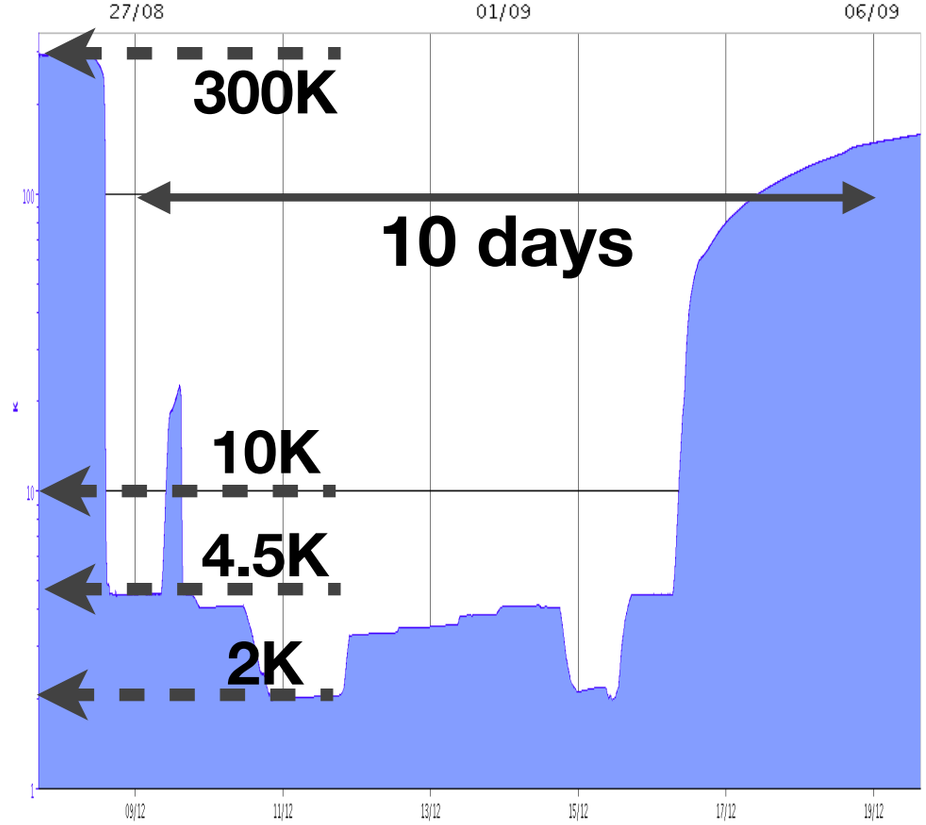




SM18 SPL Cold Tests in 2014



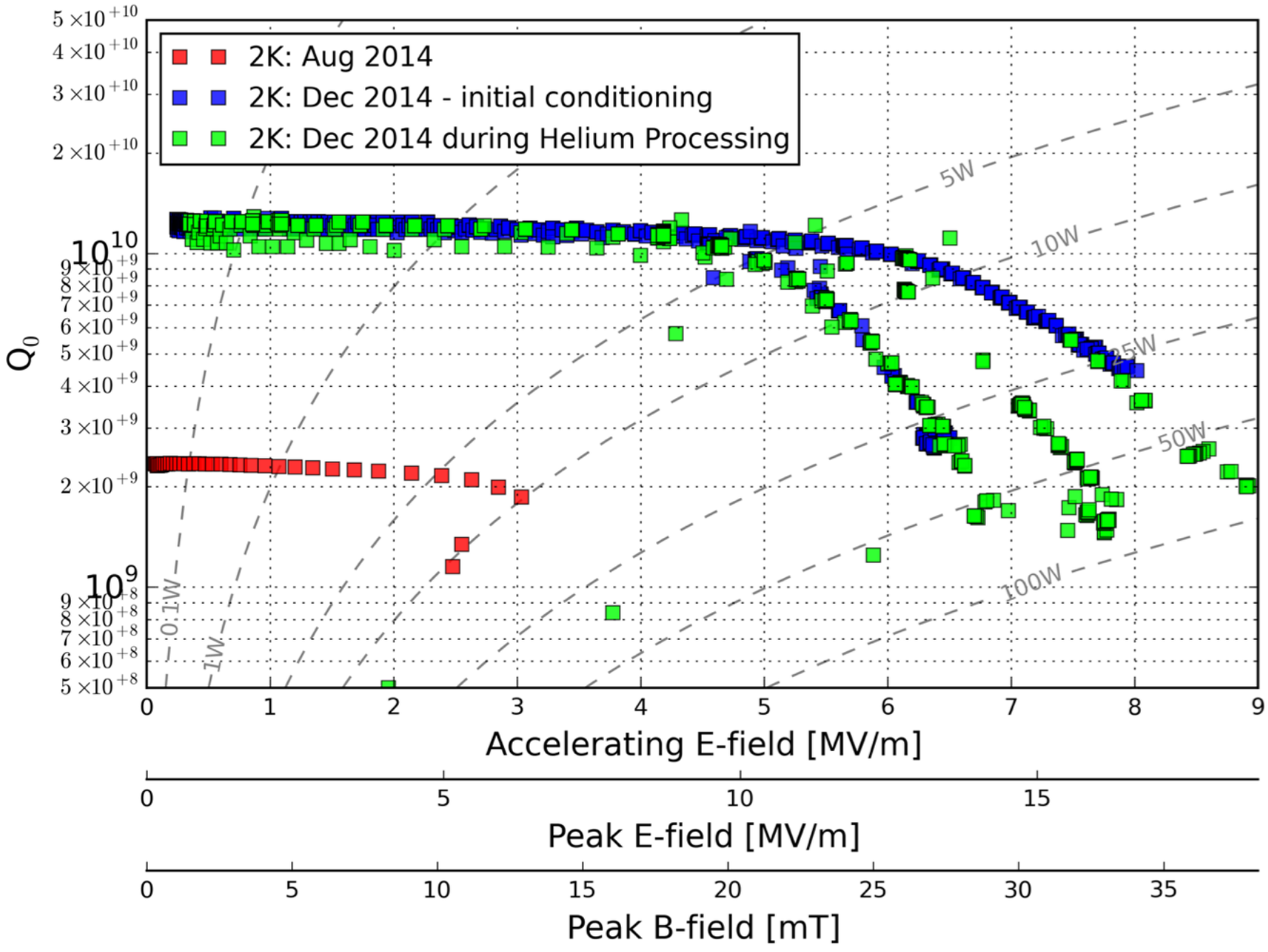
SPL1: 1st Cold Test



SPL1: 2nd Cold Test

Summary Results from the two cold tests

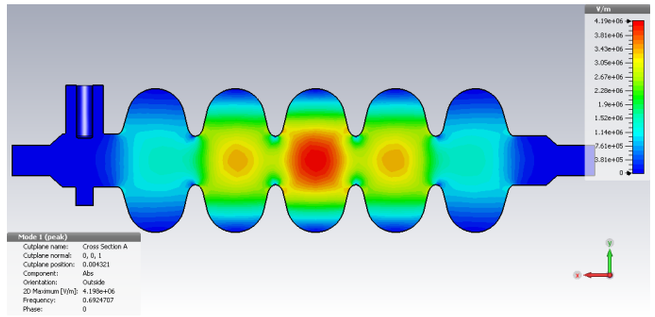
- **1st Cold Test: Q0 limited due to valve contamination and incomplete HPR**
  - Residual Surface Resistance @ = 94 ± 3 nOhms
- **2nd Cold Test: Gradient limited due field emission**
  - Residual Surface Resistance = ~18 nOhms



1st Cold Test: Passband Frequencies

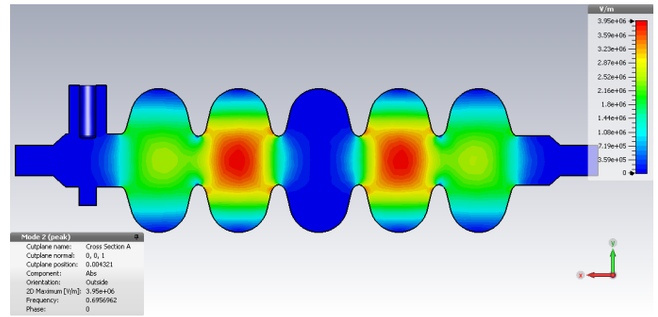
$\frac{1}{5}\pi - mode$

Simulated (2K): 692.470 MHz
Measured (4.5K): 692.062 MHz
Measured (1.8K): 692.293 MHz



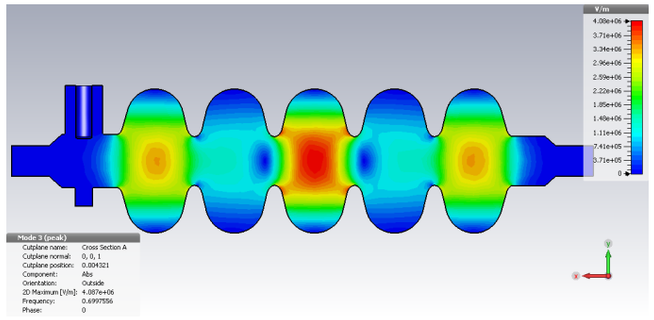
$\frac{2}{5}\pi - mode$

Simulated (2K): 695.696 MHz
Measured (4.5K): 695.277 MHz
Measured (1.8K): 695.500 MHz



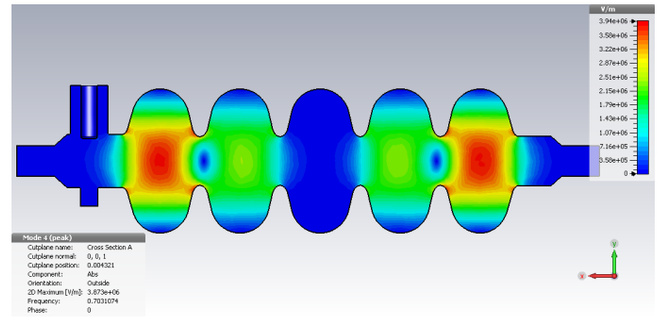
$\frac{3}{5}\pi - mode$

Simulated (2K): 699.756 MHz
Measured (4.5K): 699.464 MHz
Measured (1.8K): 699.382 MHz



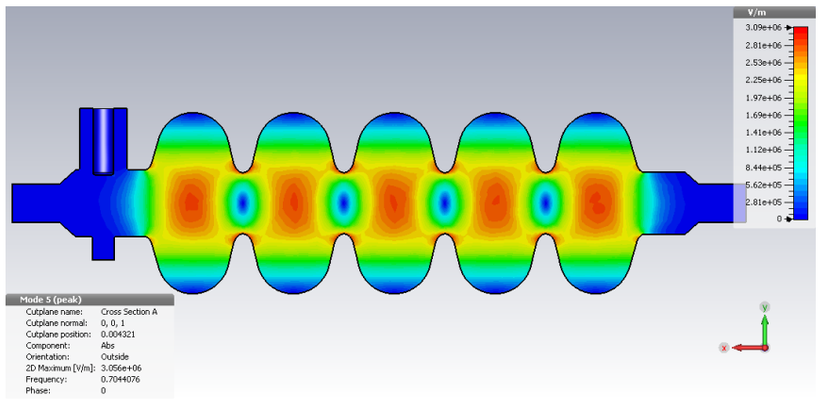
$\frac{4}{5}\pi - mode$

Simulated (2K): 703.107 MHz
Measured (4.5K): 702.773 MHz
Measured (1.8K): 702.992 MHz



$\pi - mode$

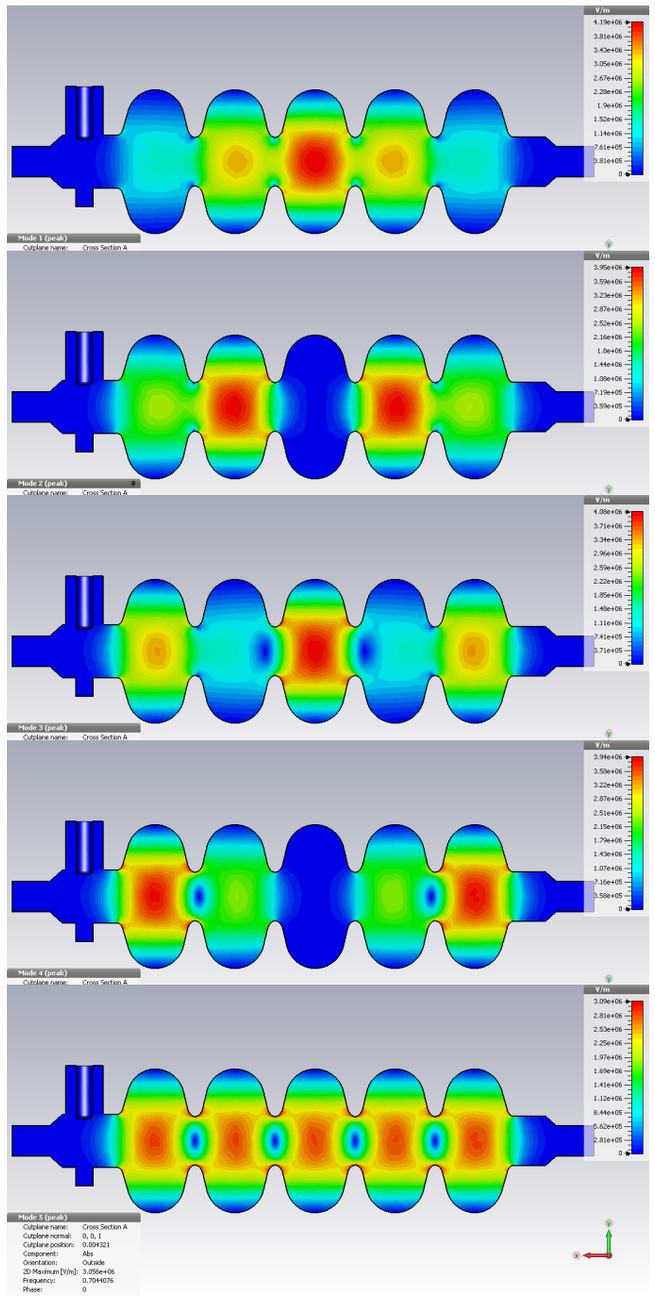
Simulated (2K): 704.408 MHz
Measured (4.5K): 704.219 MHz
Measured (1.8K): 704.432 MHz



1st Cold Test: Passband Mode Measurements

- **1st Cold Test: Dominated by low gradient and high field emission**
  - Use passband modes to look for problems

- **Mode 1**
  - Multi-pacting at low stored energy.
- **Mode 2**
  - Multi-pacting at low stored energy. **Processable**
  - Electron loading at higher stored energy
- **Mode 3**
  - Moderate levels of field emission (200usv/hr)
- **Mode 4**
  - High levels of field emission (> 3 mSv/hr)
- **Mode 5**
  - High levels of field emission (> 3 mSv/hr)



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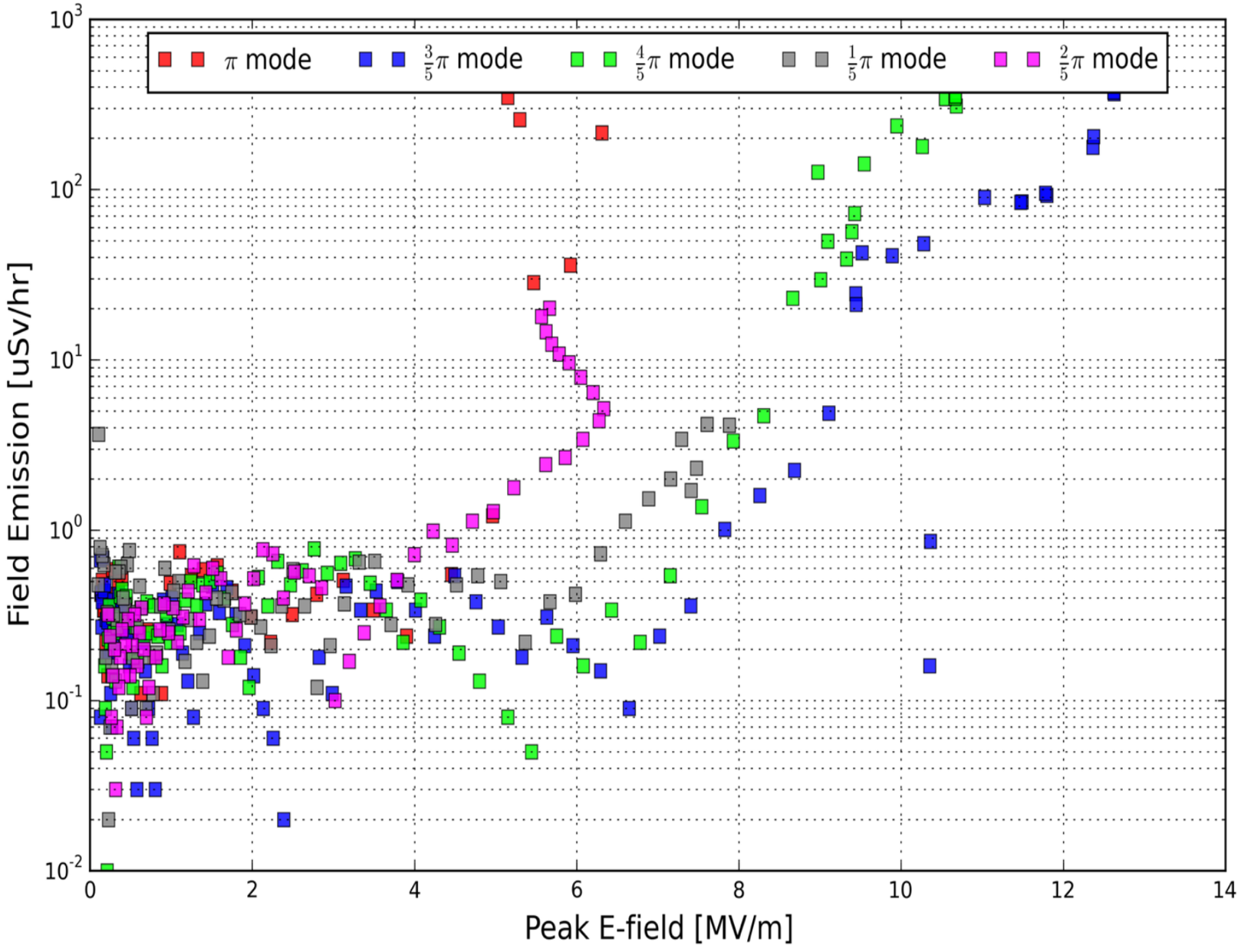

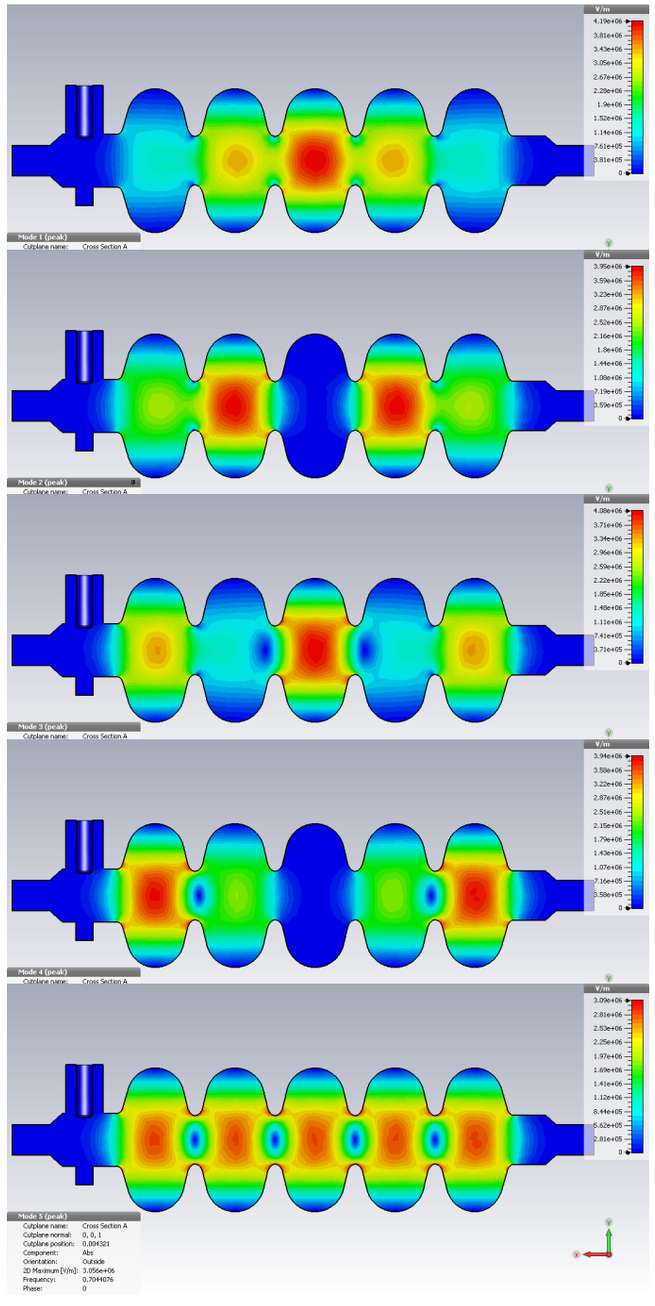

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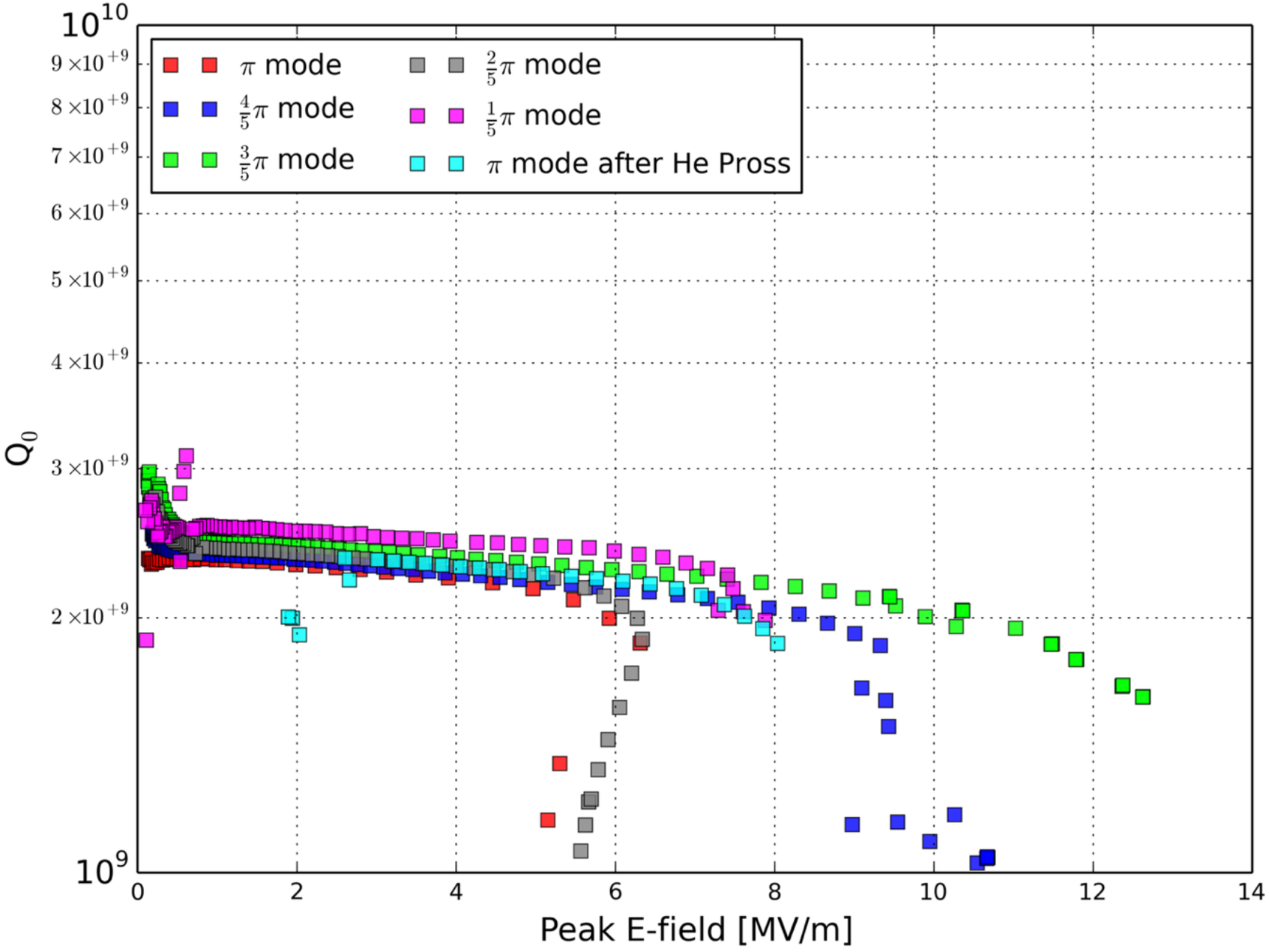

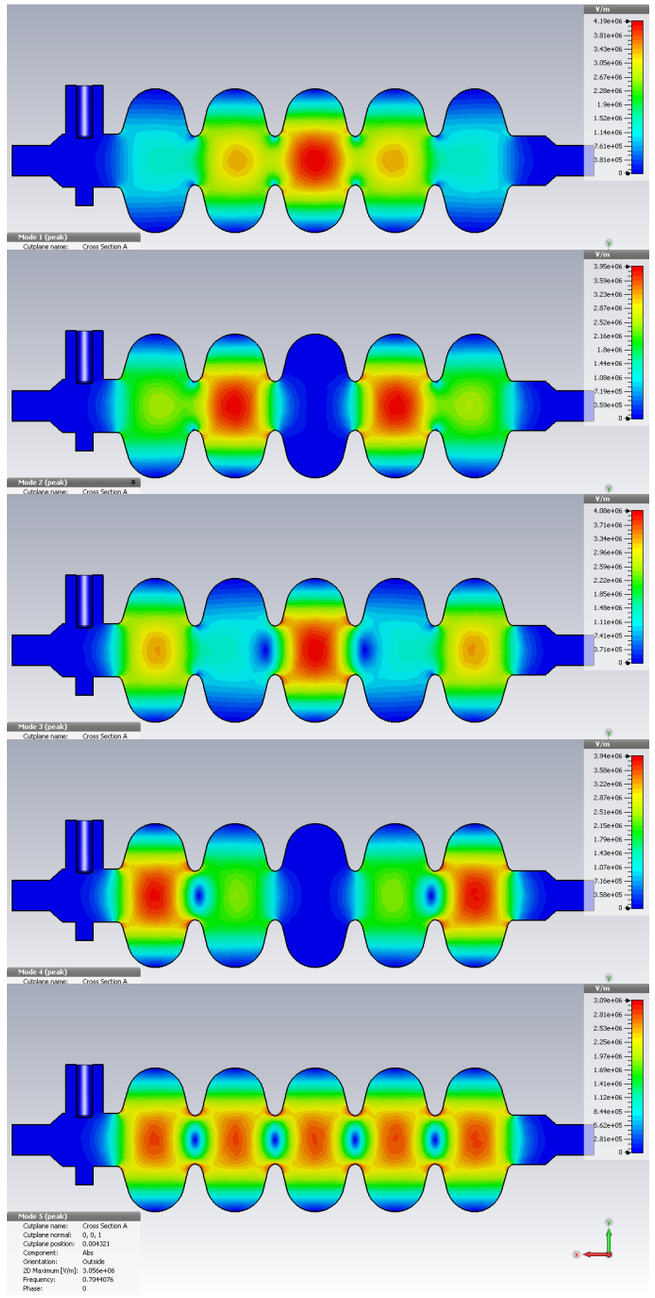

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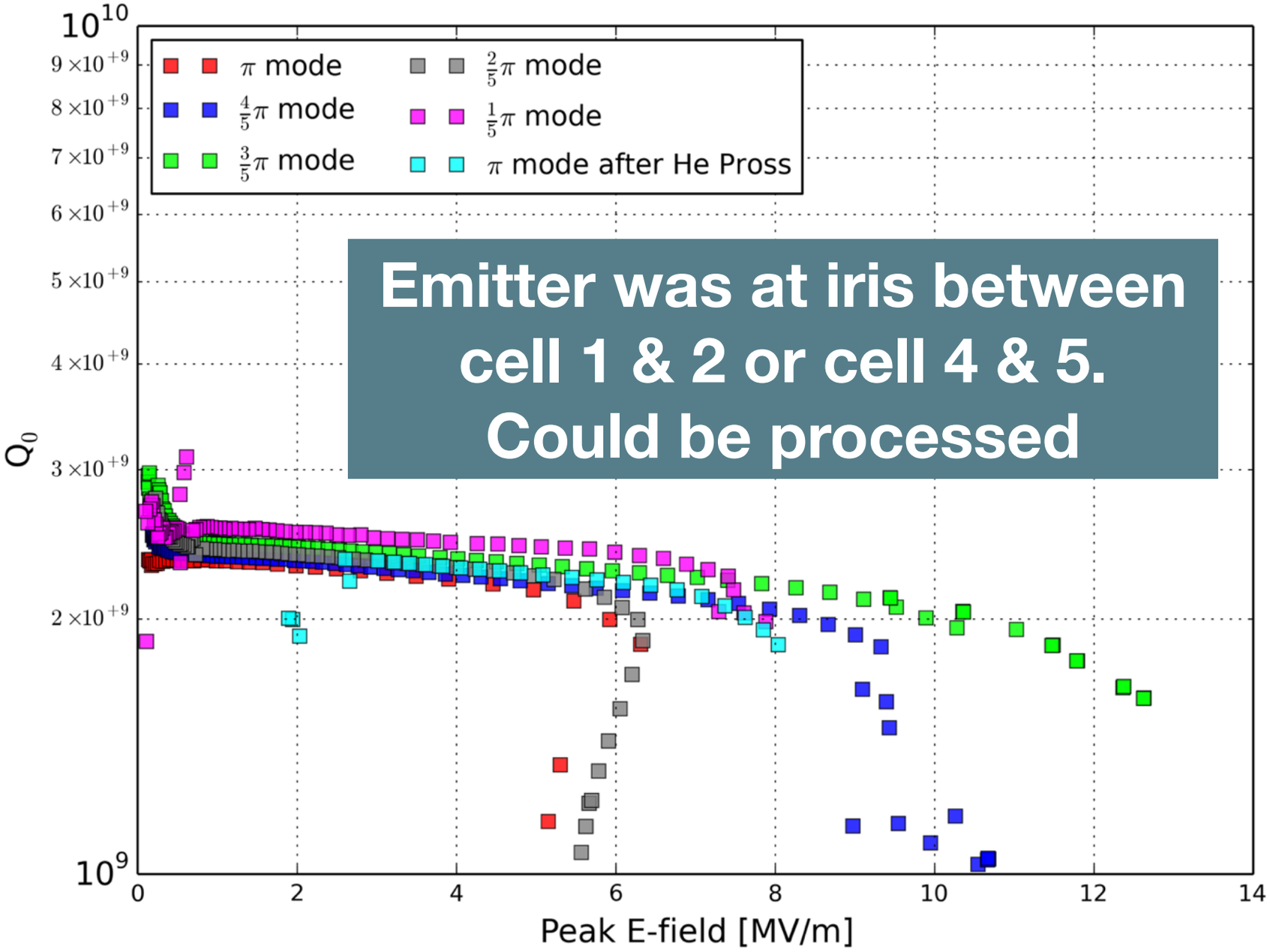
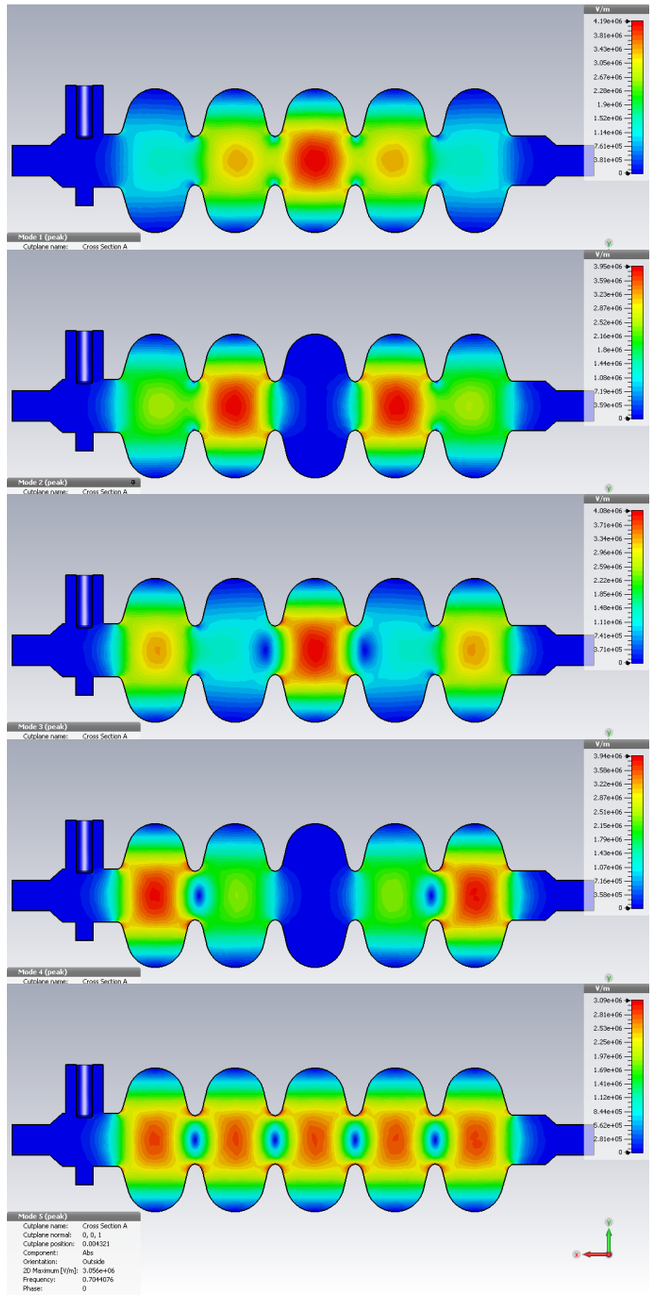


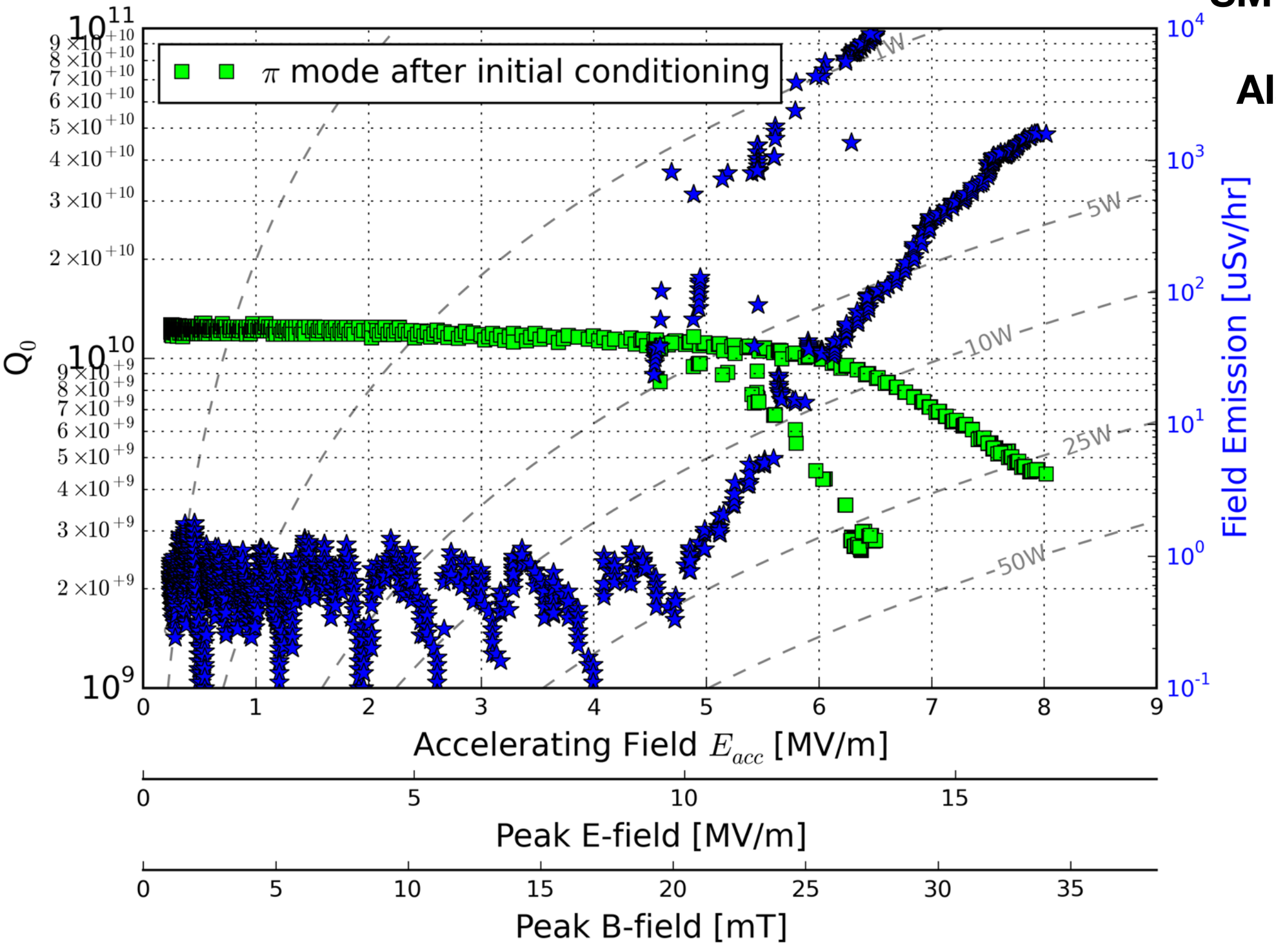


2nd Cold Test: Getting better…

- **Q_0 much improved but still too much field emission …**

SM18 Radiation

Alarm & Veto



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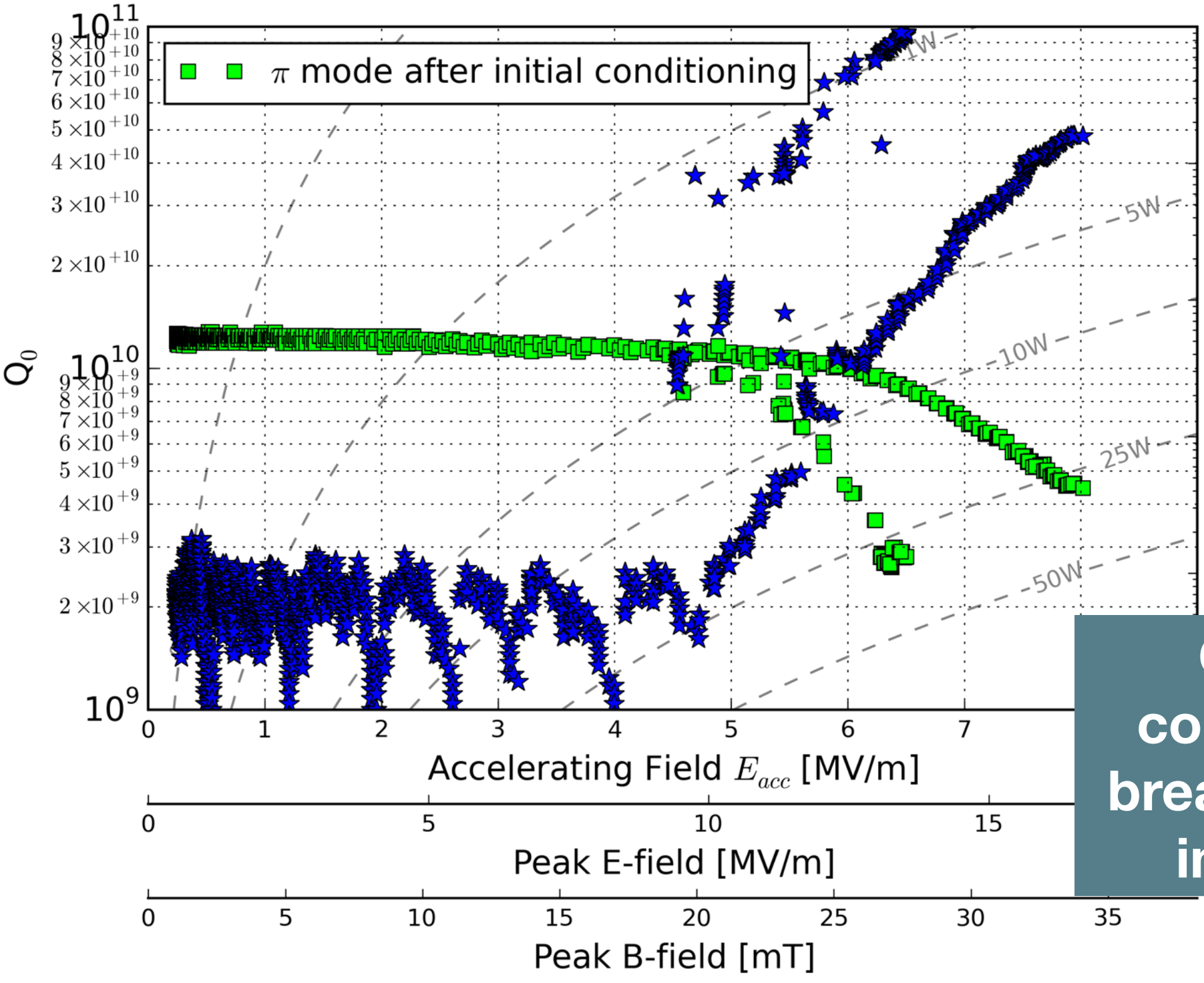
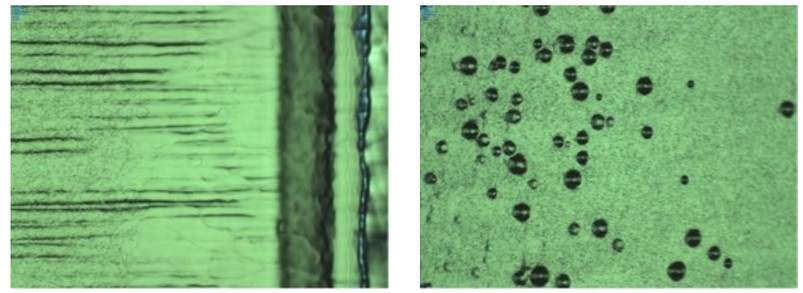


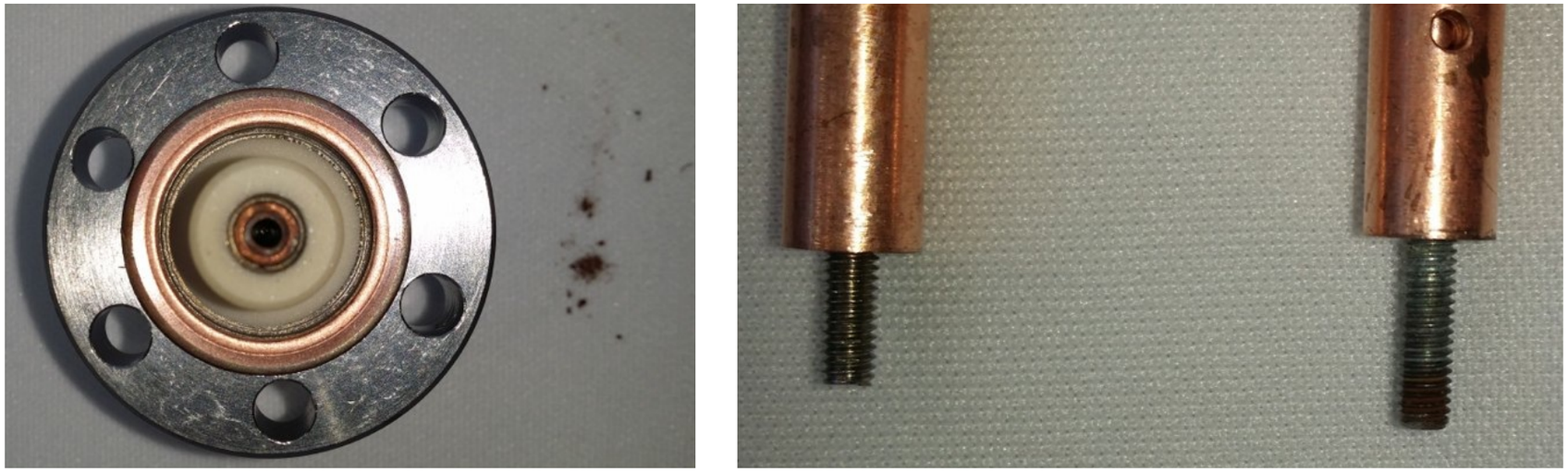
Cold test not completed due to breakdown of cable in cold section

Both Cold Tests: Problems and Issues

- **1st SPL Cold Test**
  - Surface issues due to Electro-polishing with non-optimal cathode
  - **HPR duration too short (2 hrs)**
  - Contamination from bellows of vacuum valve
- **2nd SPL Cold Test**
  - Surface issues due to Electro-polishing with non-optimal cathode
  - Non Optimised HPR (6hrs 45 min duration)
  - **Contamination from antenna feed through**
  - **Breakdown of power cable in during Helium Processing**



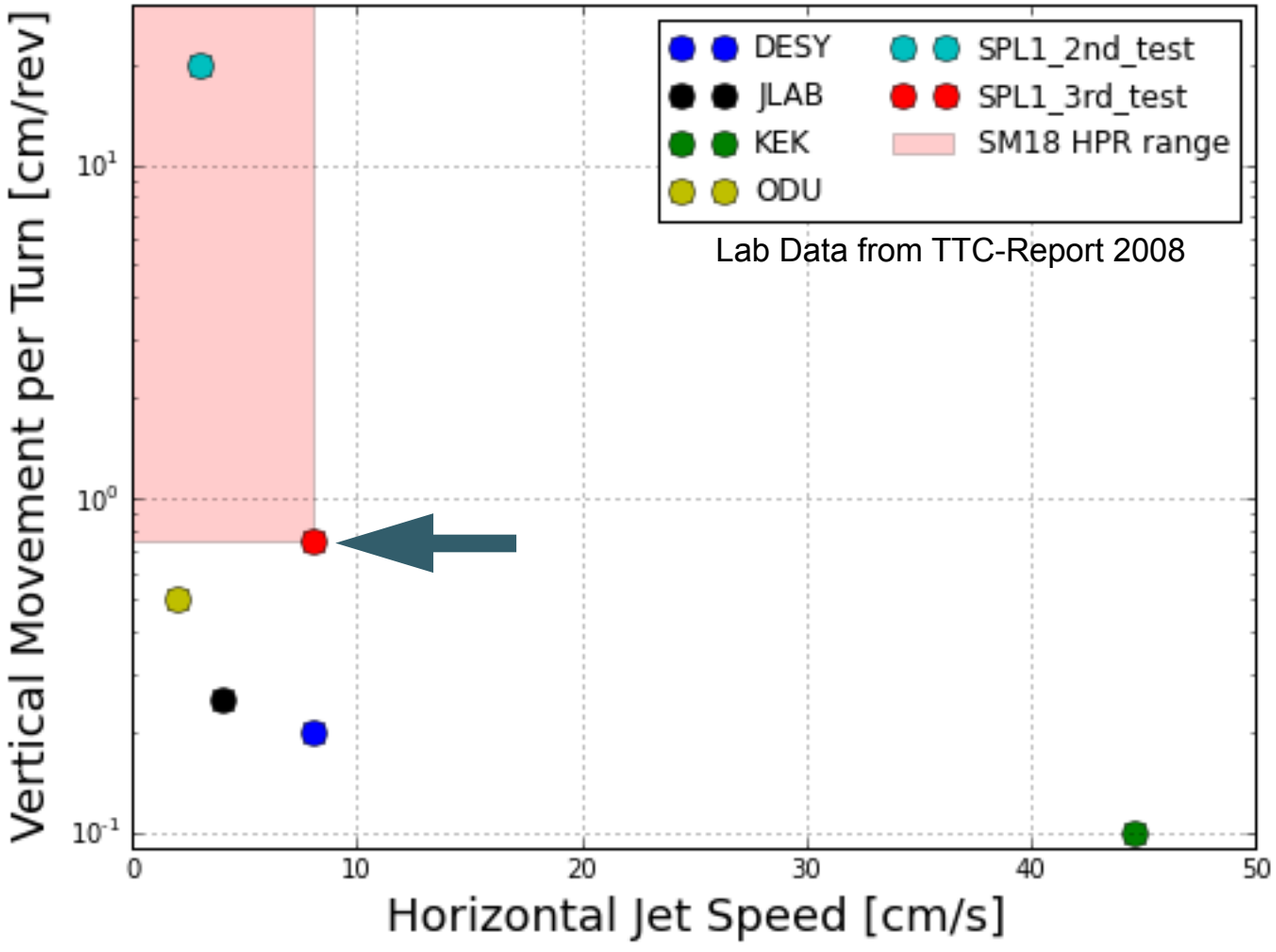
Surface effects



Contamination from power antenna connection to feedthrough

The Art of High Pressure Rinsing

- **Typical HPR -> not yet fully optimised**
  - Duration: ~6 hrs, Pressure: 100 bar Consumption: ~800 litres
- **Drying:**
  - 15 min purge with room temperature N2 + 45 min drying with 100° C N2
  - 12 hr dry in laminar air flow in ISO-4 clean room



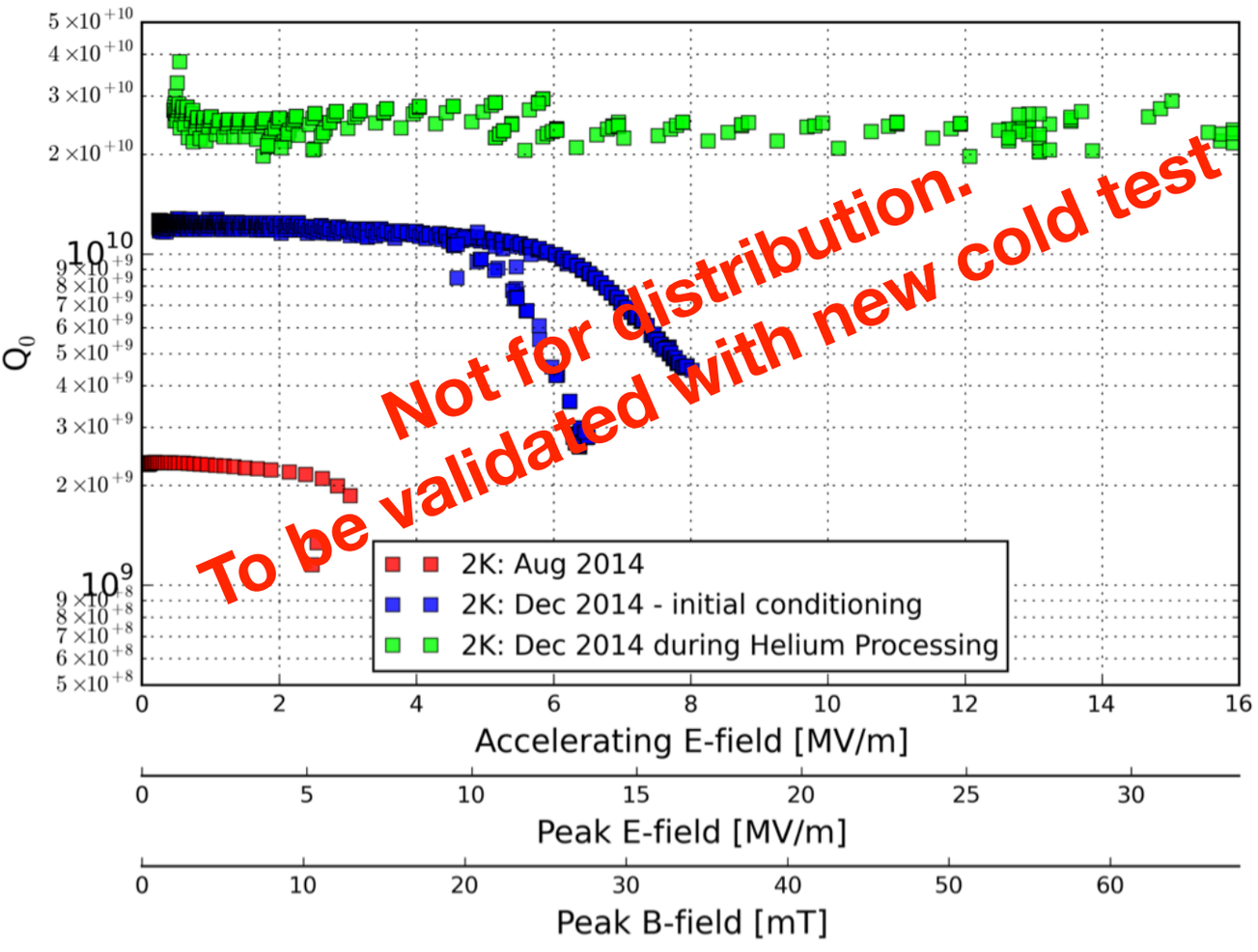
1st SPL Cold Test:
HPR Duration= 2 hrs
2nd SPL Cold Test:
HPR Duration= 6.75 hrs

3rd SPL Cold Test (March 2015):
HPR Duration= 7 hrs

HPR Optimisation Tests in March-April 2015

What I shouldn't show you

- **2nd Cold test: Measurement after short helium processing**
  - Input power cable failing and difficult to calibrate …
- **Comparison with Crab Cavity Cold Test in same cryostat**



SPL_1: After Helium Processing but with cable break down

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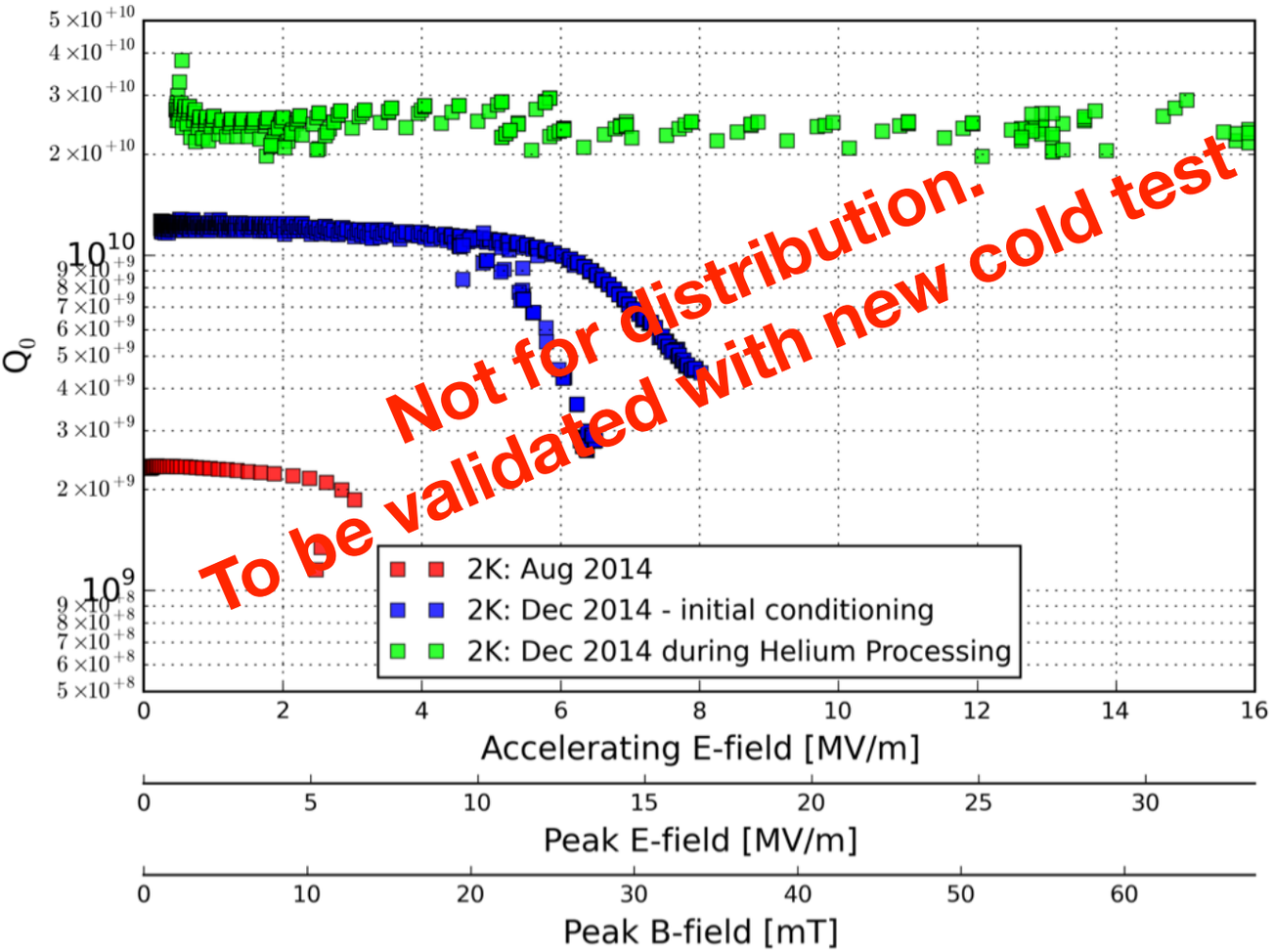

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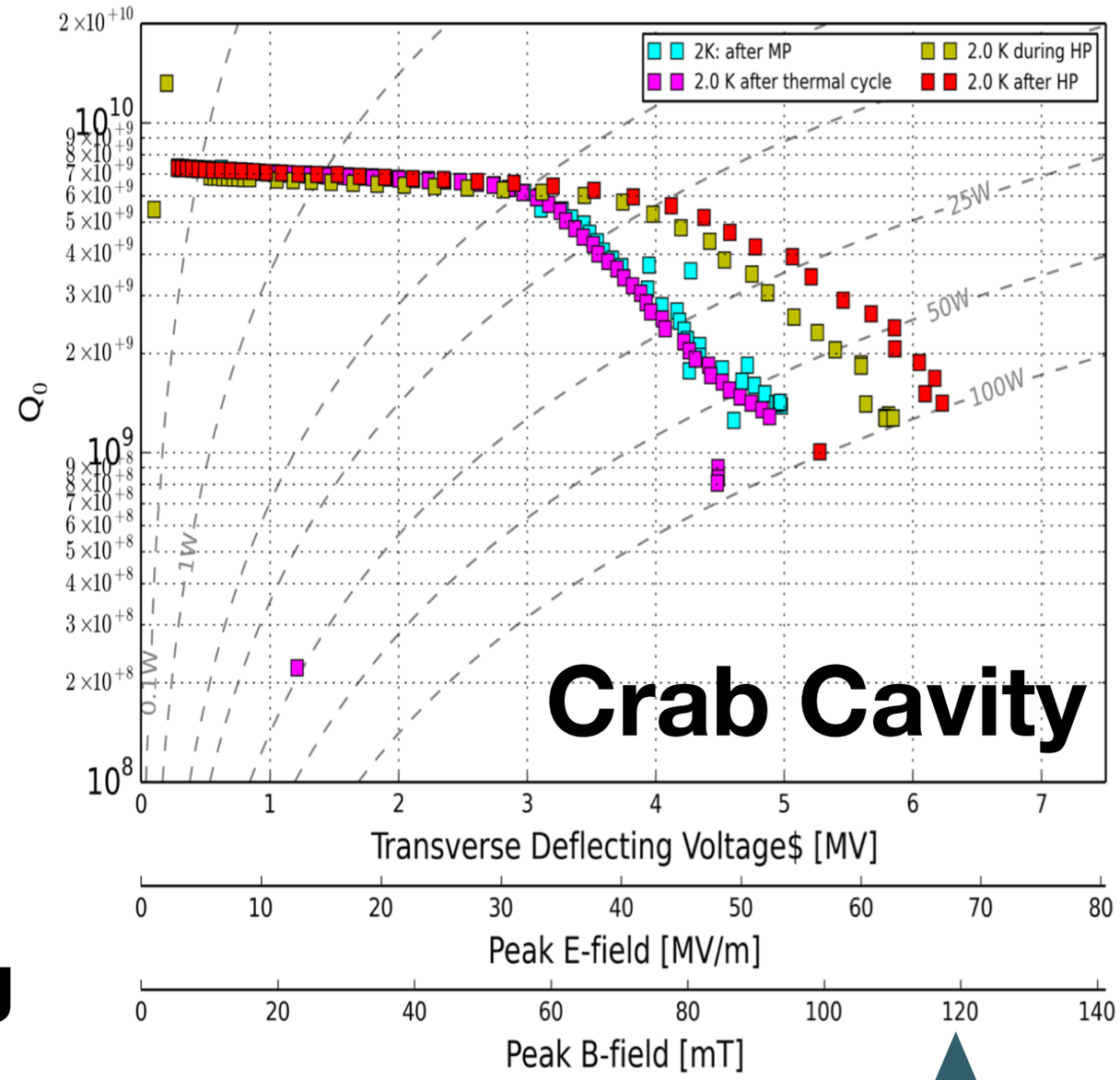
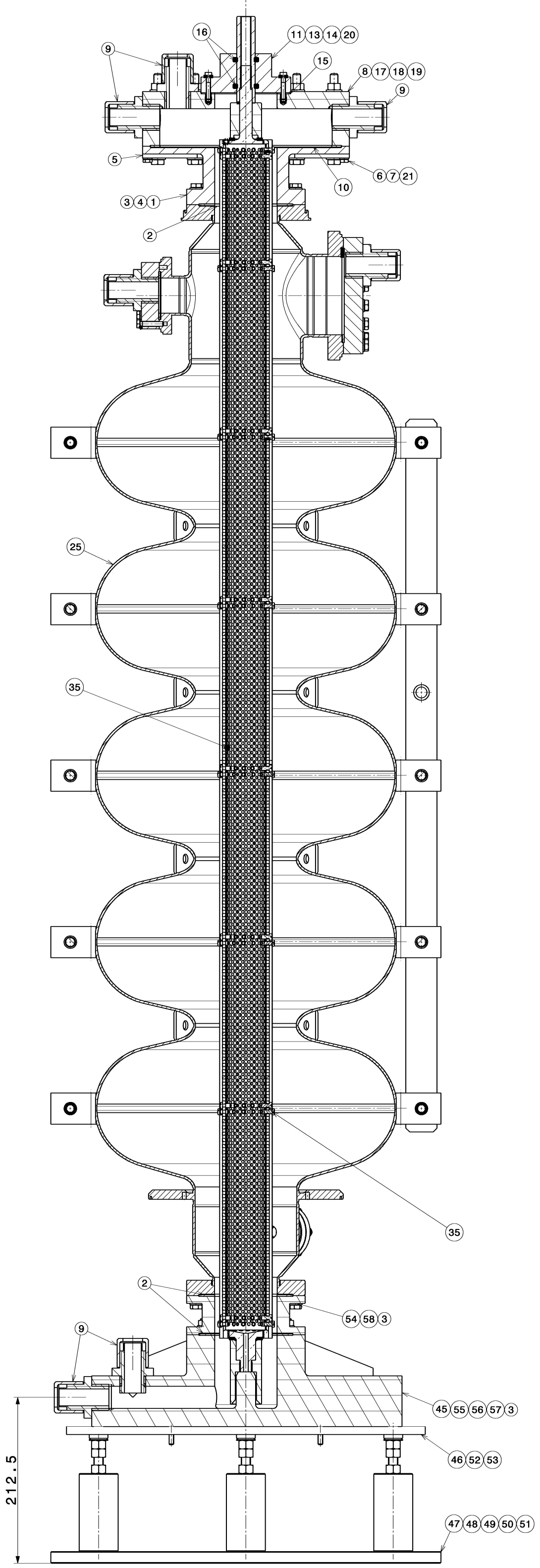
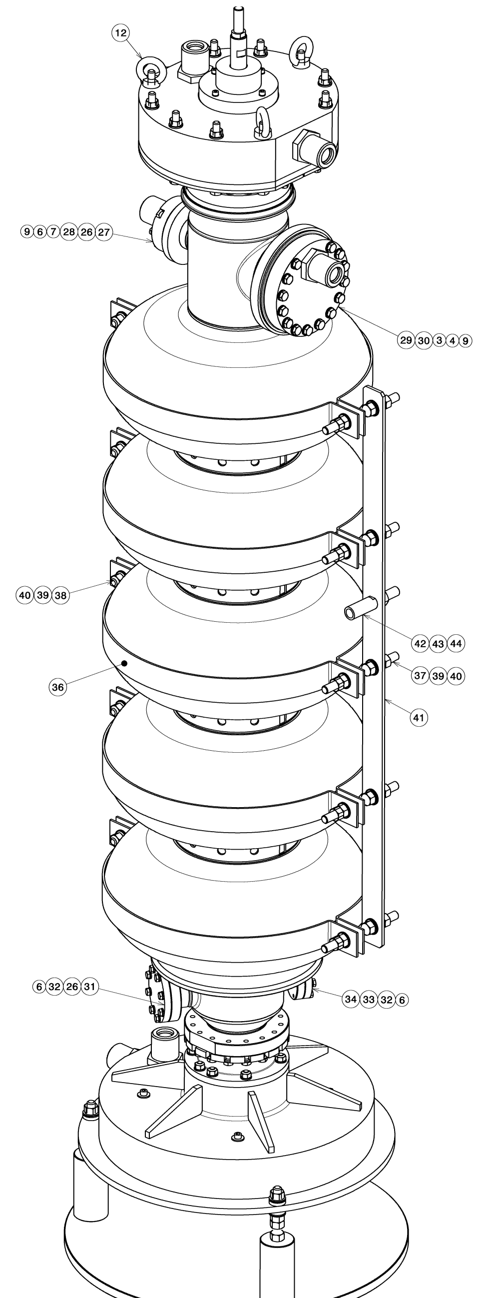


Schedule, Plans and Improvements

Chemistry:New Electro-Polishing Cathode





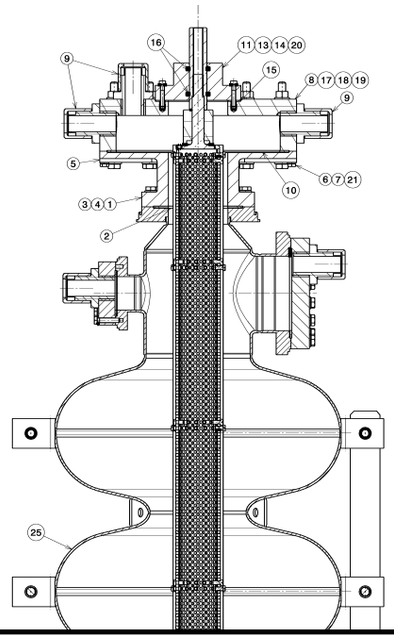
ASSEMBLY CATHODE SEQUENCE
SEE **SPLACST_0297**

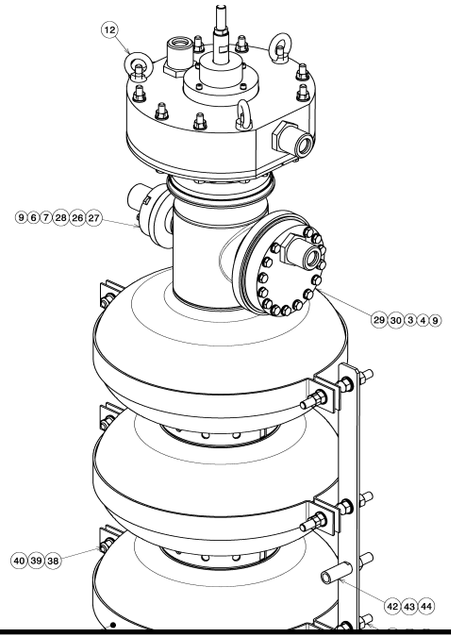
PLANT GUIDE CATHODE + FLANGES REF. FOR
CAVITY RETURNED, SEE **SPLACST_0298**

NOTA:
SILVER INOX THREAD RODS & SCREWS

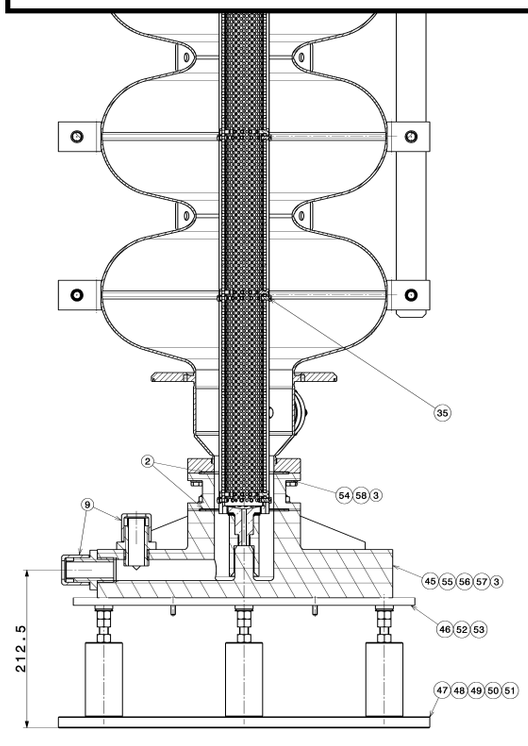
6	HEX HD SCREW GRADE A M6X35 VIS H GRADE A M6X35	64	St. Steel A4	ISO 4017_M6x35-A4	47.62.8 262.6
1	FLANGE PICK UP BRIDE PICK UP	63	Polyvinylidene fluoride PVDF	SPLACST_0243 ST0441248	
1	UPPER FLANGE CAVITY RETURNED BRIDE SUPERIEUR CAVITE RETOURNEE	62	Polyvinylidene fluoride PVDF	SPLACST_0242 ST0441096	
1	FLANGE HOM BRIDE HOM	61	Polyvinylidene fluoride PVDF	SPLACST_0241 ST0441011	
1	FLANGE COUPLING BRIDE COUPLEUR	60	Polyvinylidene fluoride PVDF	SPLACST_0240 ST0441009	
1	GUIDE PVDF CATHODE RETURNED GUIDE PVDF CATHODE RETOURNEE	59	DELRIN ® (POM)	SPLACST_0296 ST0477530	
8	HEX HD screw grade A M8x20	58	St. Steel A4	ISO 4017_M8x20-A4	

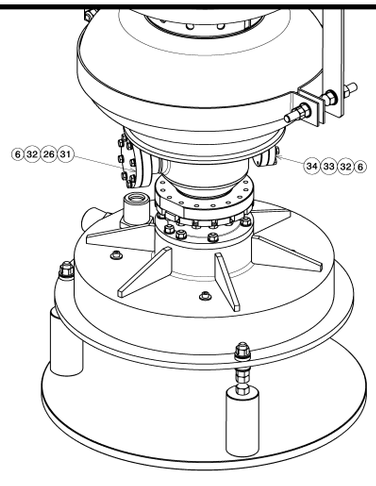
Chemistry:New Electro-Polishing Cathode





Being Validated on SPL_2





ASSEMBLY CATHODE SEQUENCE
SEE **SPLACST_0297**

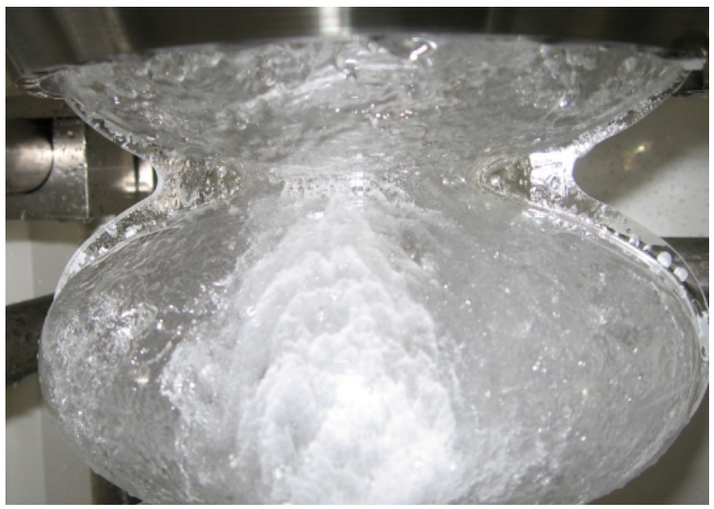
PLANT GUIDE CATHODE + FLANGES REF. FOR
CAVITY RETURNED, SEE **SPLACST_0298**

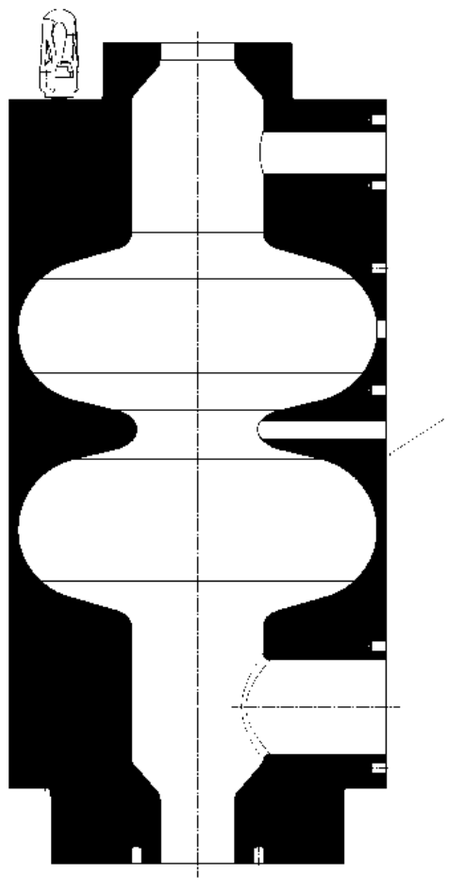
6	HEX HD SCREW GRADE A M6X35 VIS H GRADE A M6X35	64	St. Steel A4	ISO 4017_M5x35-A4	47.62.6 262.6
1	FLANGE PICK UP BRIDE PICK UP	63	Nylon/Libre Farde PVDF	SPLACST_0243 ST0441248	
1	UPPER FLANGE CAVITY RETURNED BRIDE SUPERIEUR CAVITE RETOURNEE	62	Nylon/Libre Farde PVDF	SPLACST_0242 ST0441096	
1	FLANGE HOM BRIDE HOM	61	Nylon/Libre Farde PVDF	SPLACST_0241 ST0441011	
1	FLANGE COUPLING BRIDE COUPLEUR	60	Nylon/Libre Farde PVDF	SPLACST_0240 ST0441009	
1	GUIDE PVDF CATHODE RETURNED GUIDE PVDF CATHODE RETOURNEE	59	DELRIN ® (POM)	SPLACST_0296 ST0477530	
8	HEX HD screw grade A M8x20	58	St. Steel A4	ISO 4017_M8x20-A4	

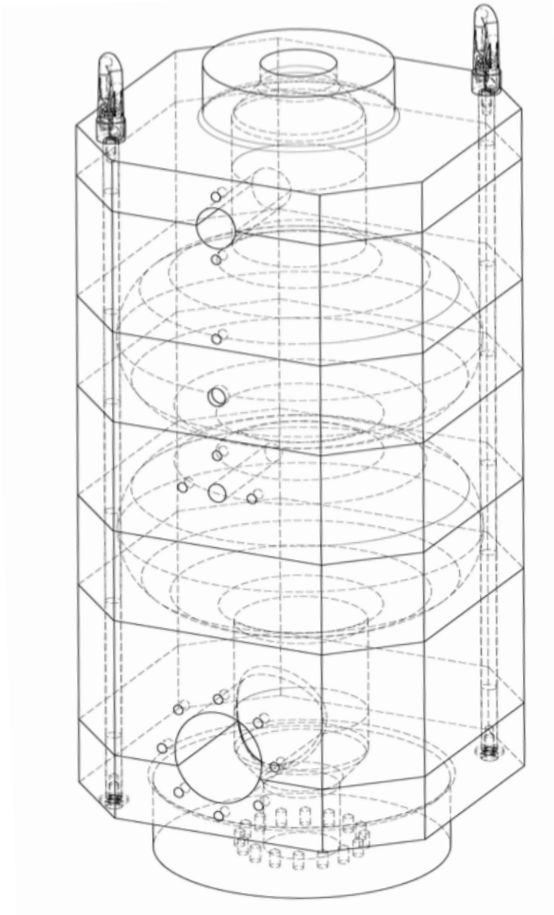
NOTA:
SILVER INOX THREAD RODS & SCREWS

SM18 HPR Optimisation

- **Cavity geometry dictates optimal HPR water pressure and flow rate**
  - Transparent cavity under construction for HPR Optimization
- **HPR nozzle parameters to be optimised for reduction of field emission**
  - Nozzle speed and RPM settings to be optimised for SPL
- **HPR and drying process under under review**
  - Nitrogen atmosphere for HPR to avoid carbonates and hydrides



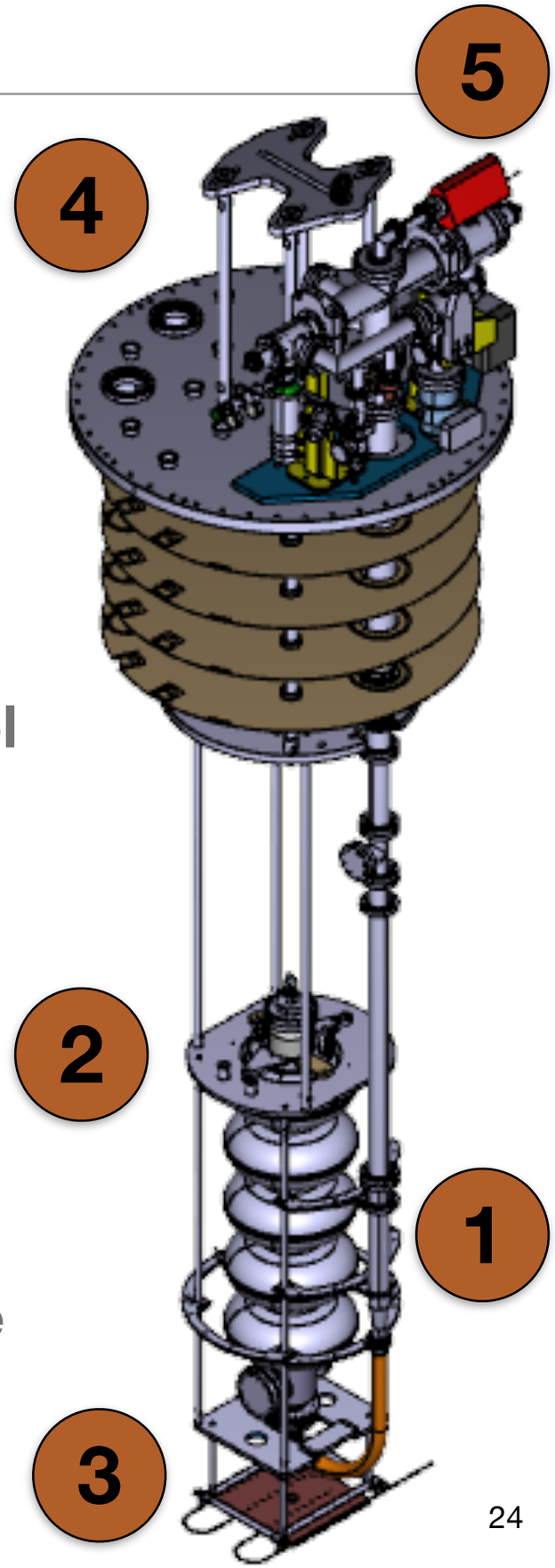




Designed and out for Manufacture

Upgrade of cryostat insert

1. **Improvement of connection of cavity pumping line**
   - Controlled laminar flow. Controlled installation zone
2. **Standard SPL mounting frame with possibility to electrically isolate cavity cavity from cryostat**
   - Isolating inserts to monitor thermal-electric currents
3. **Improved environmental monitoring and heating control**
   - Temperature monitoring: CERNOX, RuO2, Allen Bradley
   - 0-50 mbar bath pressure sensor
   - Ambient Magnetic field compensation: below 10 nT
4. **Completely new insert and power cables setup**
   - Insert rated unto 500W CW
5. **Integrated Residual Gas analyser on cavity vacuum line**



Schedule & plans

- **Cold Test Objectives for 2015 :**
  - **Cold Test 4 SPL cavities in SM18** after treatment with new EP cathode
    - Successful cold test => 25 MV/m with a low field Q0>1010
  - SPL cold test activities must interleave with Crab cavity test program
- **Implications to schedule**
  - Cryo returns to SM18 test facility on 23rd March
  - **SPL_1: Retested as is** => test to validate HPR + preparation steps
    - Test Duration: 6 weeks After: back to Chemistry for EP& retest
  - **SPL_2: Chemistry + Optical inspection finished by end of April**
    - Available for Testing by May Test slot: 1 month Duration
- **Other cavities to follow**
  - SPL_3 assigned to tuner tests SPL_4 assigned to tuning bench
- **In parallel:**
  - **SPL_5 Construction:** Trimming of dumb-bells finished in March.
  - Helium tanks at CERN and we start with Mechanical checks ….
  - **Preparation of the SM18 Horizontal bunker** -> main issue is cryo distribution line

Summary remarks

- **Trimming and Tuning activities**
  - Construction and measurement program advancing well
  - Development of a broad base of expertise and skills

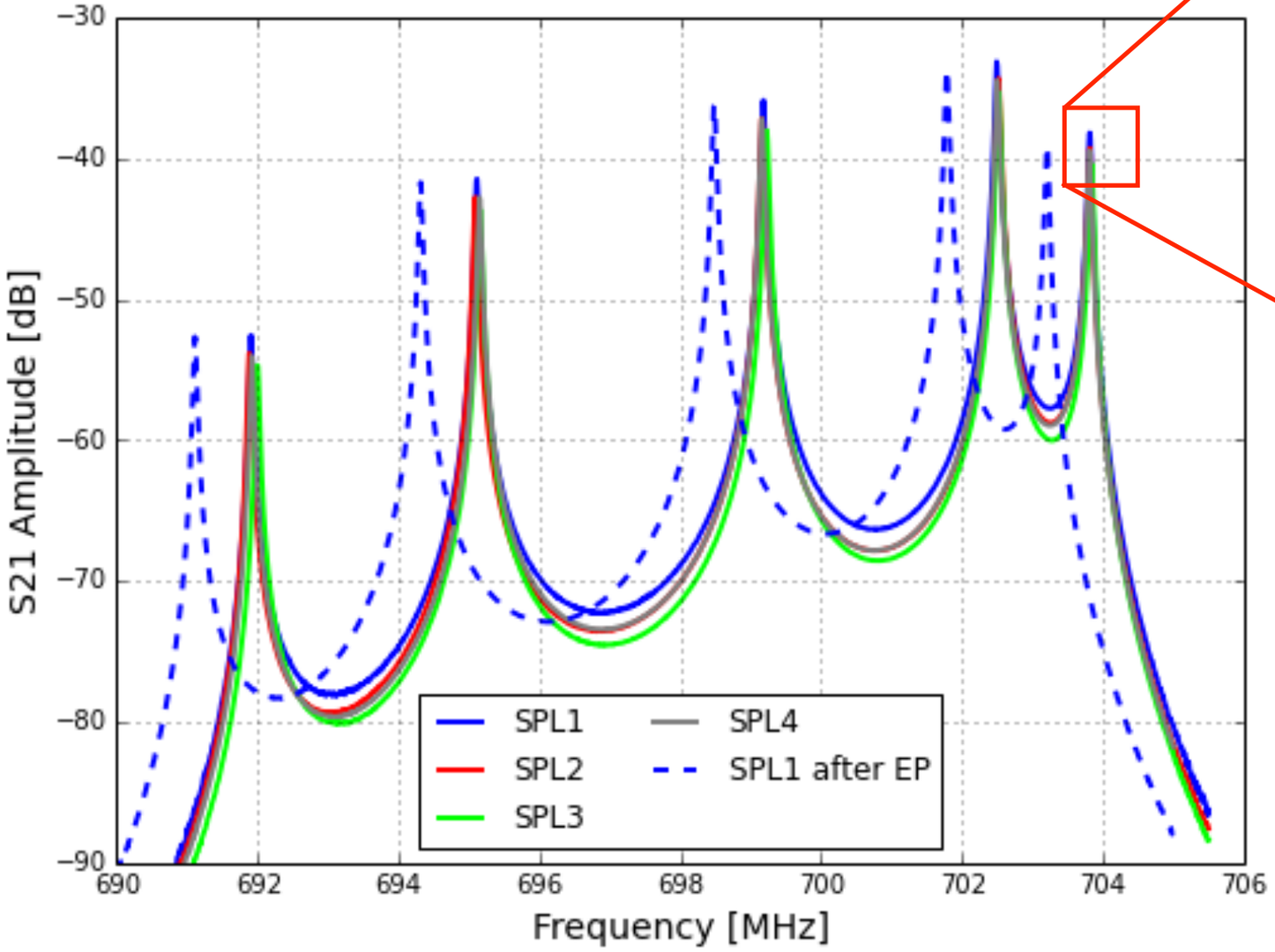
- **Cold Test results**
  - 1st & 2nd cold tests of SPL_1 hampered by surface contamination issues
  - Preparing for a 3rd Test to verify preparation & installation sequence
    - There is cause for optimism with the upcoming cold test
  - SPL_2 Is expected to be tested by mid year after EP with new cathode

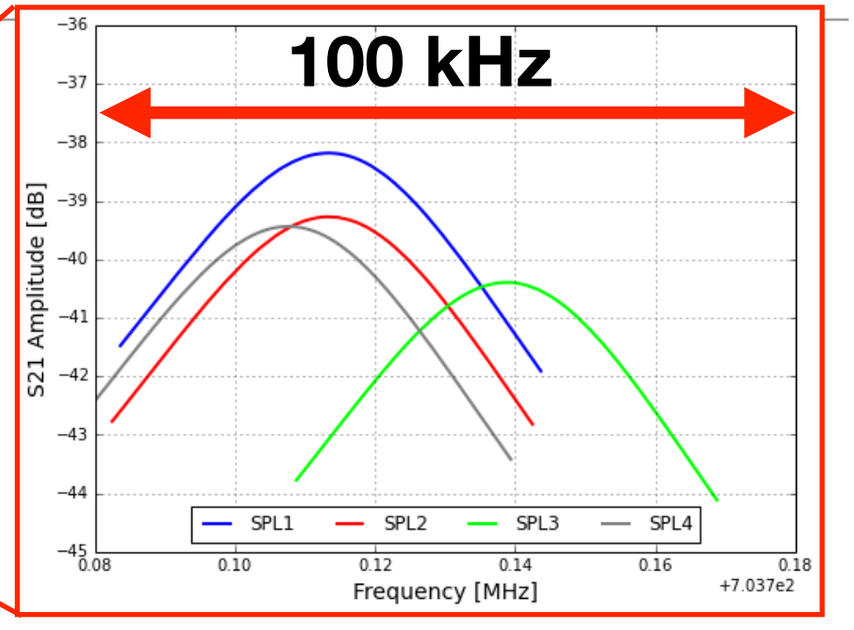
- **Schedule & upgrades**
  - Significant time and effort is being invested in upgrading and training
  - 2015: a full year of cavity preparation and testing CERN's SM18 facility

Spare Slides

π-Mode Frequency Validation of SPL Nb 5-Cell

- **π-mode measured on all 4 Nb 5-cell cavities**

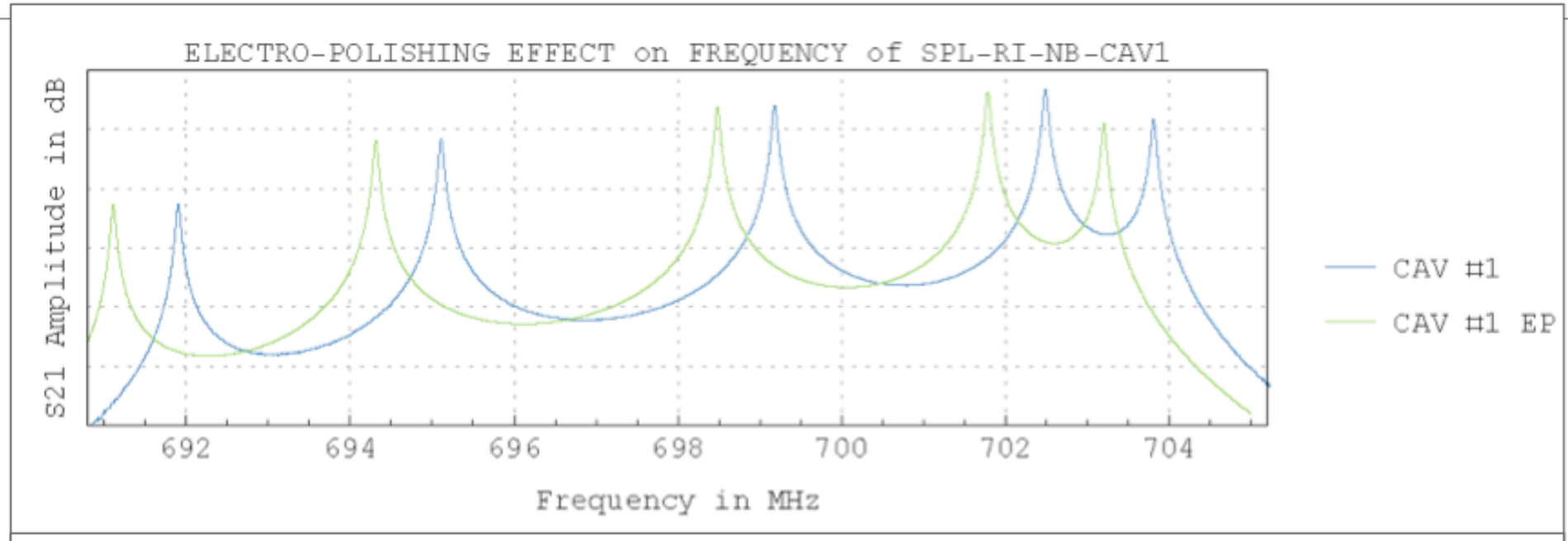


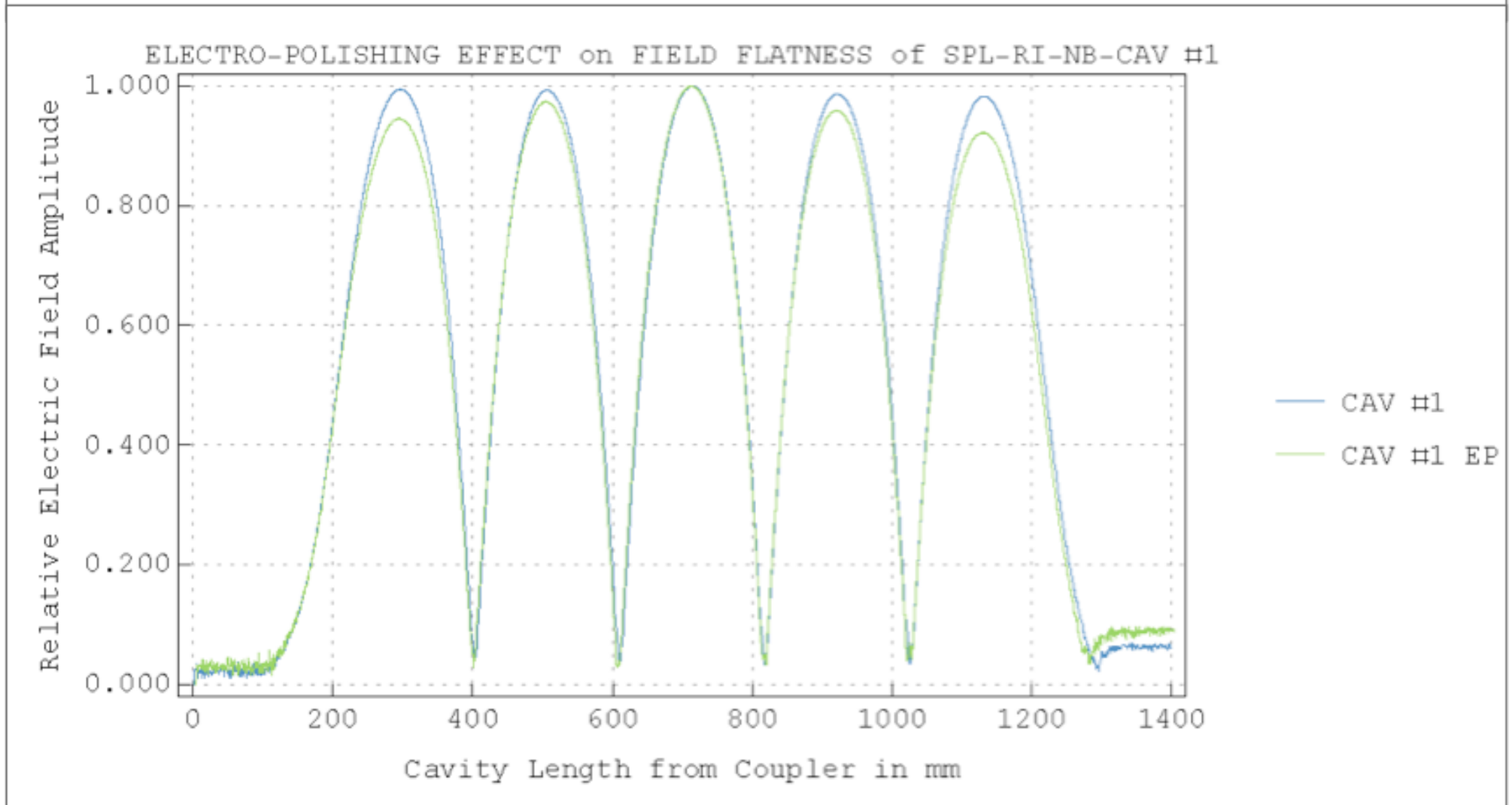


Coupler port Pick-up port

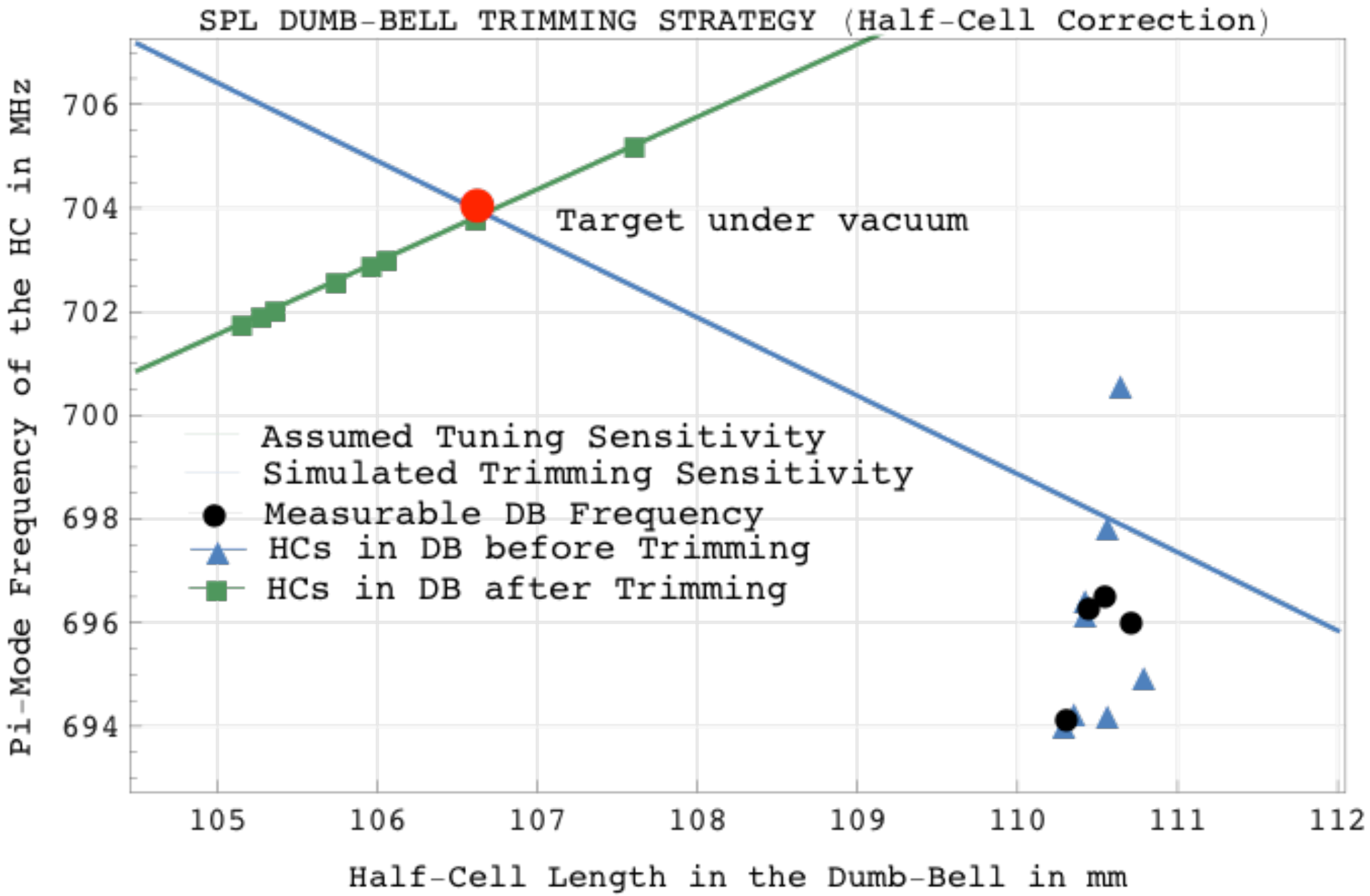
~600 kHz frequency shift due to hard electro-polishing.
agrees with expectation from simulation

Effect of Electropolishing



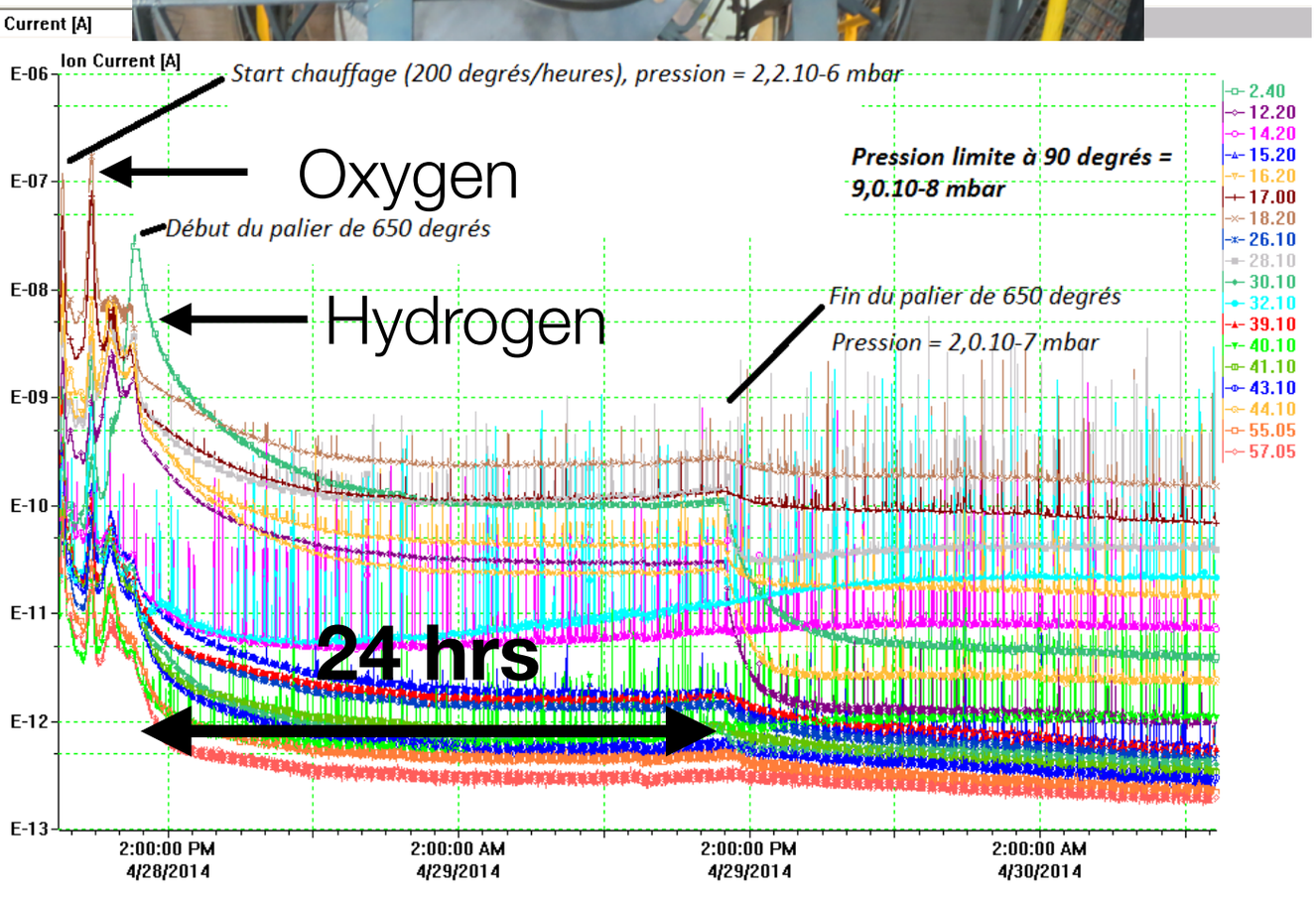


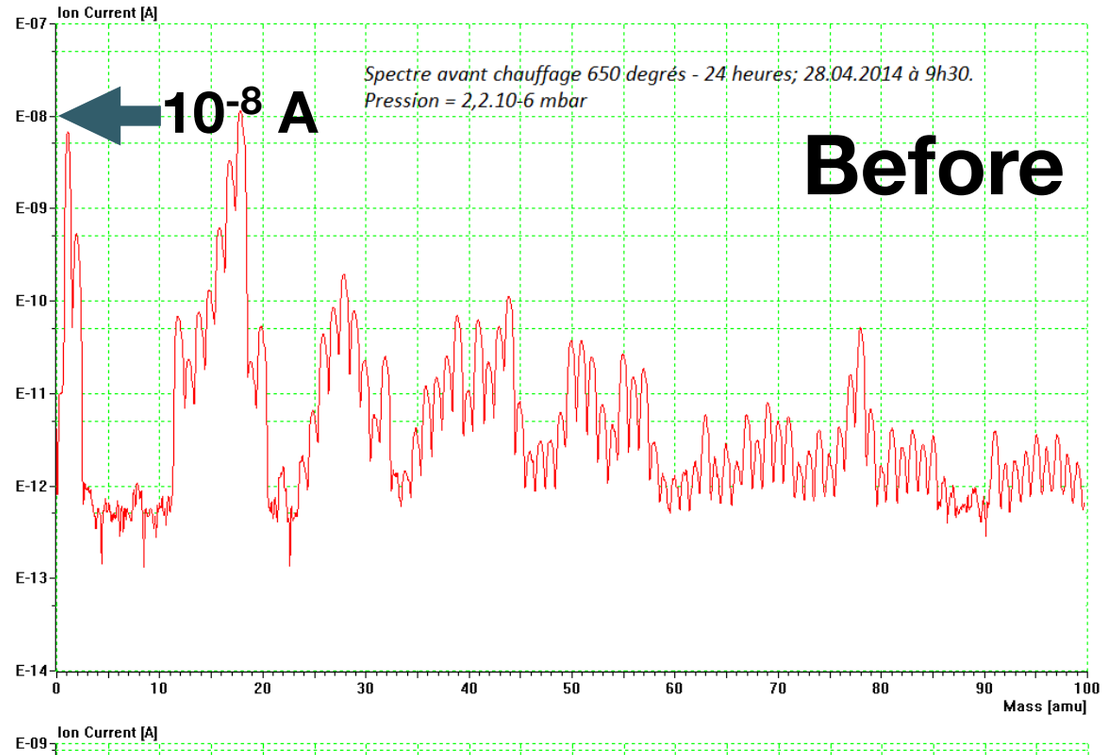
SPL Trimming and Tuning

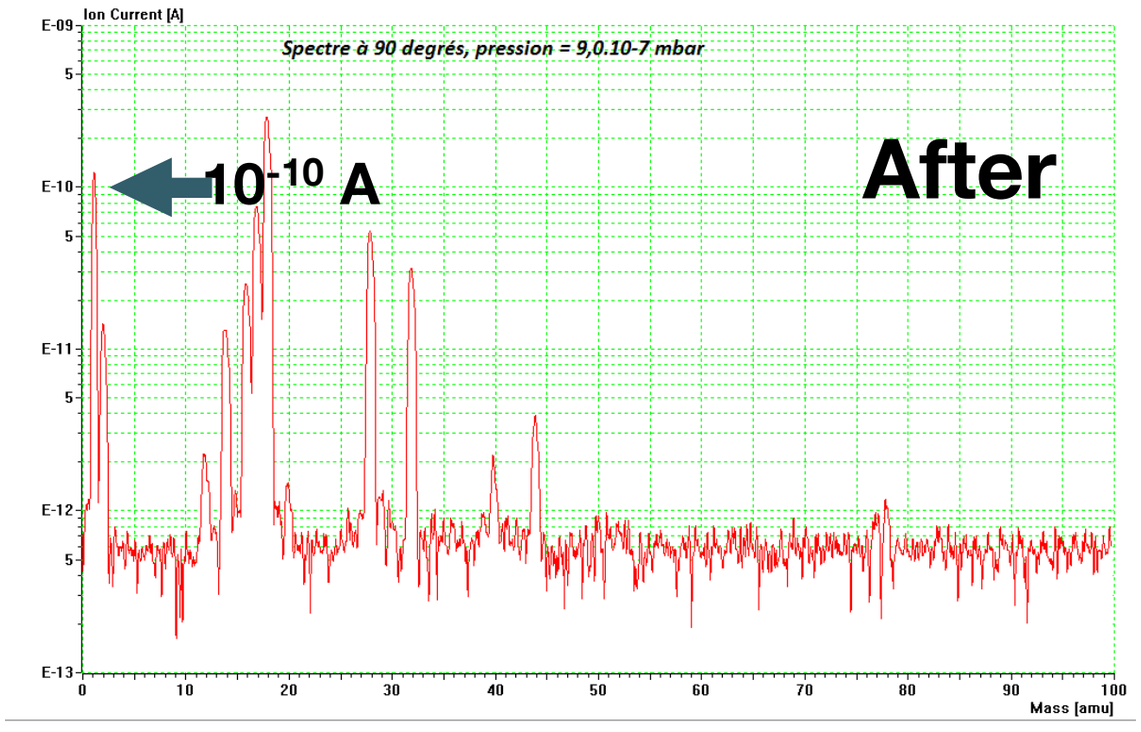


SPL Nb 5-Cell: Thermal Treatment

- **Thermal Treatment: 650 °C for 24hrs**



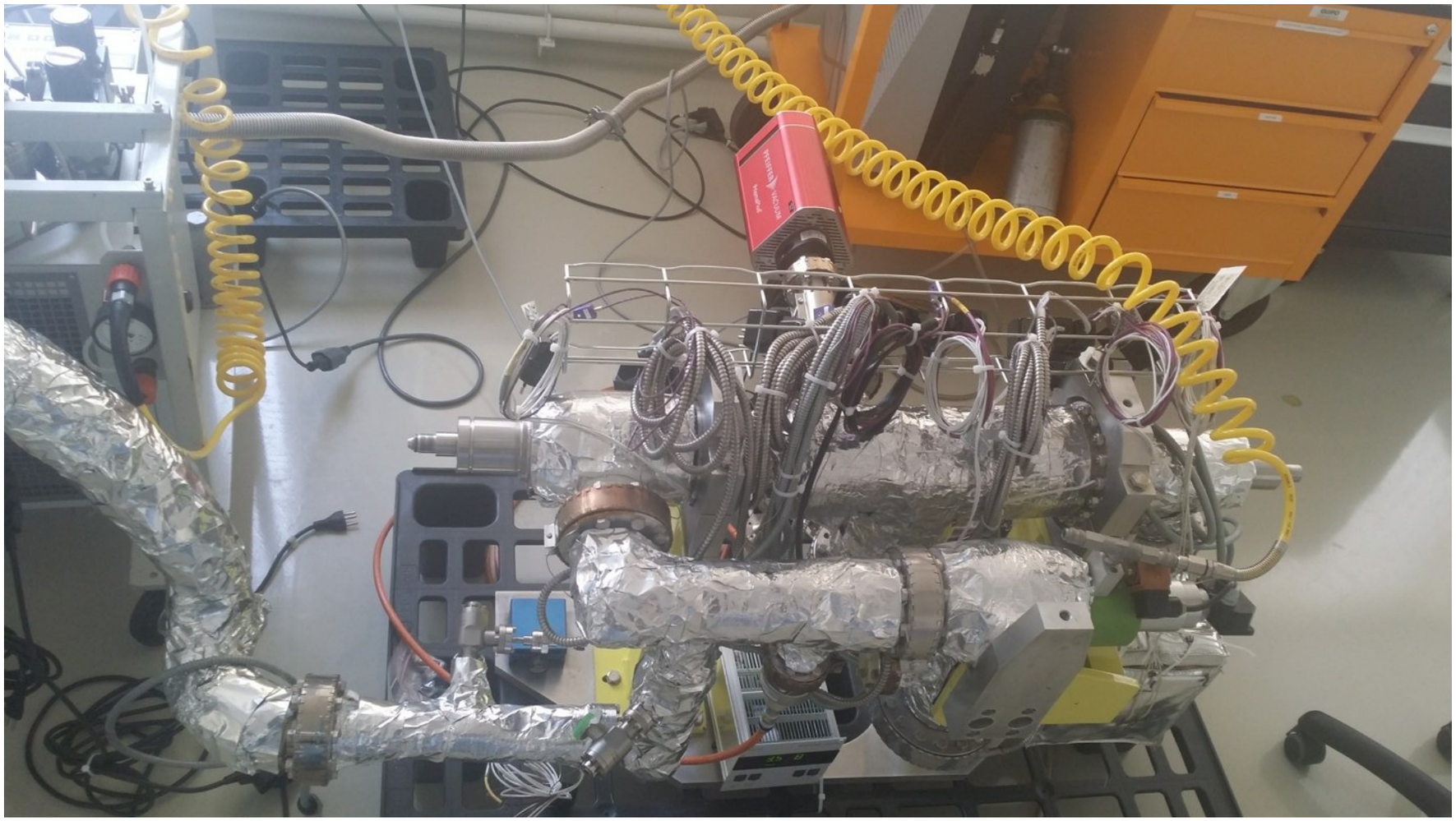


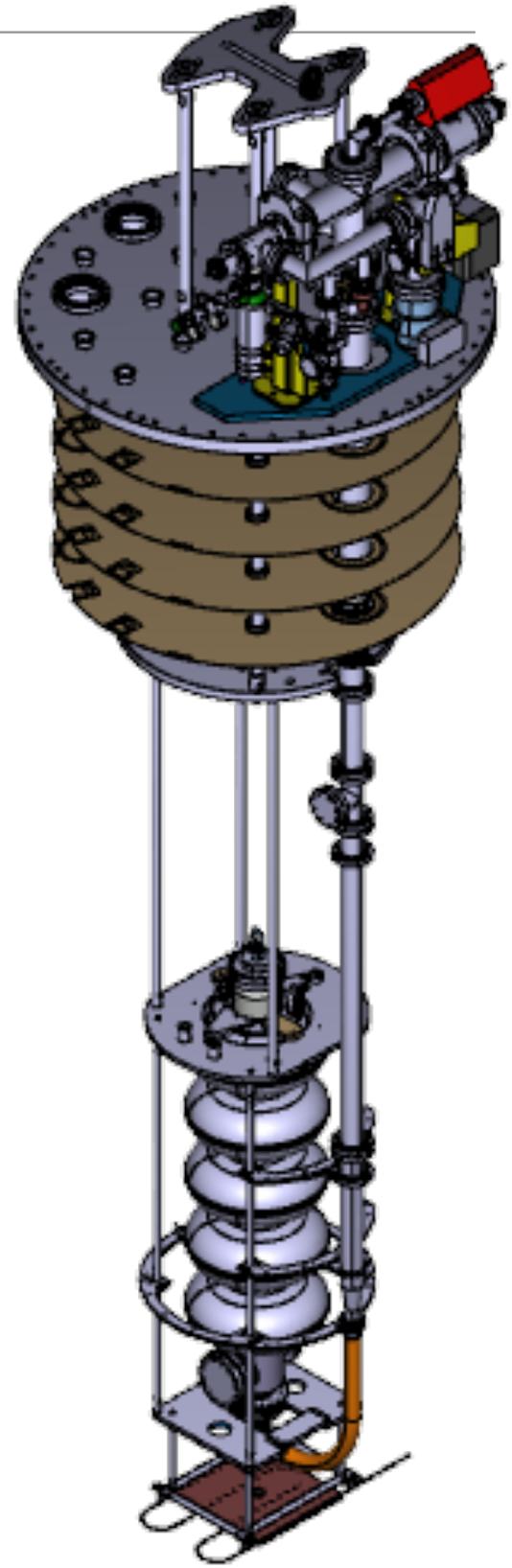


Same thermal treatment as SACLAY cavity

Insert Upgrade

- Validation of insert infrastructure
  - Pumping line
  - Helium injection into cavity vacuum
  - Residual gas analysis system

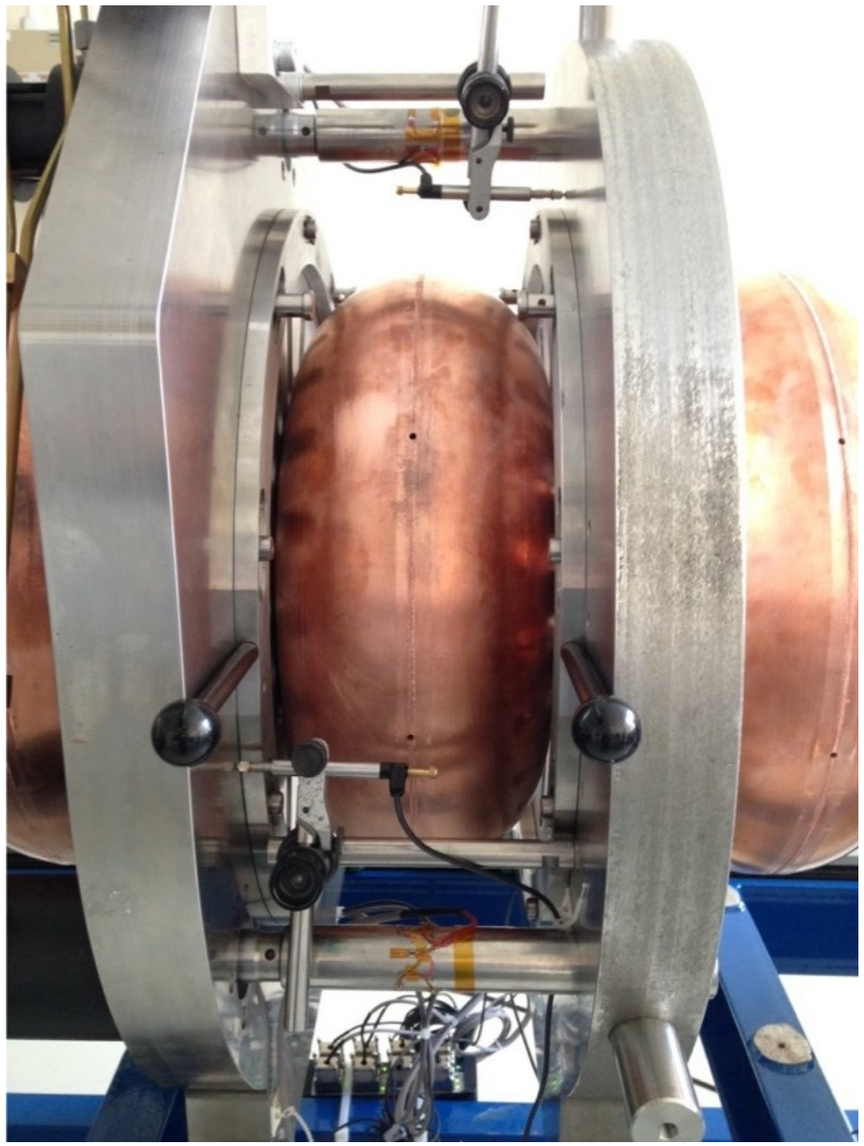




Helium Tanks

Upgraded Mechanical sensor system

Strain gauges



Displacement sensor