Performance of SPL cavities at CERN

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on behalf of
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Introduction: CERN SRF activities and SPL

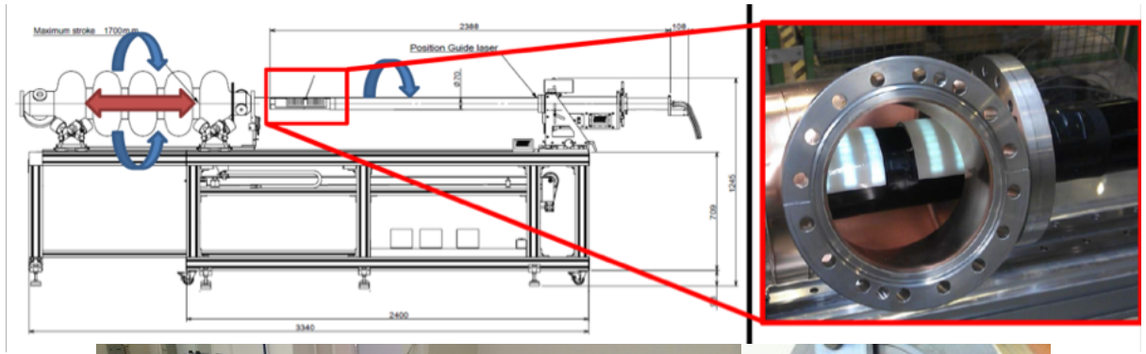
- **Objective:**
  - Characterise SPL Nb 5-cell cavities at warm
  - Setup and test SPL Nb 5-cell cavities in SM18 vertical cryostat
  - Ensure diagnostics + analysis tools in place for full evaluation of test data

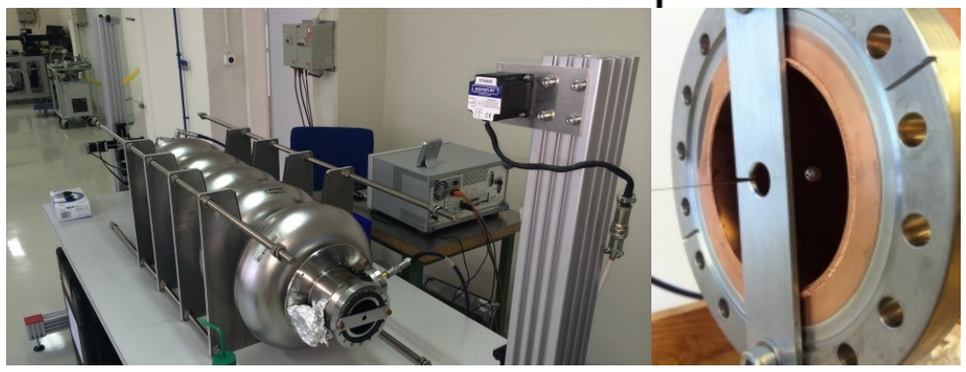
- **Objective**
  - Ensure infrastructure for production level testing
  - Development of personnel, procedures and techniques

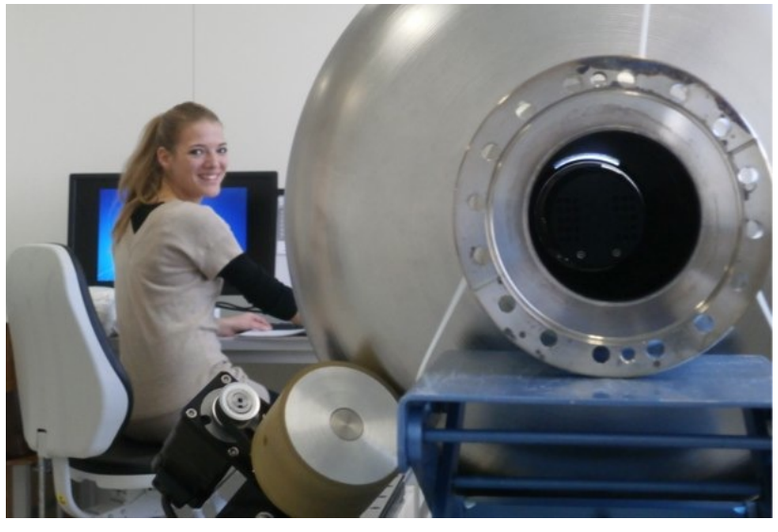
- **Plan**
  - Use SPL Nb Monocell and SPL Copper 5-cell cavities to meet development objectives
- **Plan**
  - Be ready to launch SPL Nb 5-cell cold test at SM18 by mid 2014.

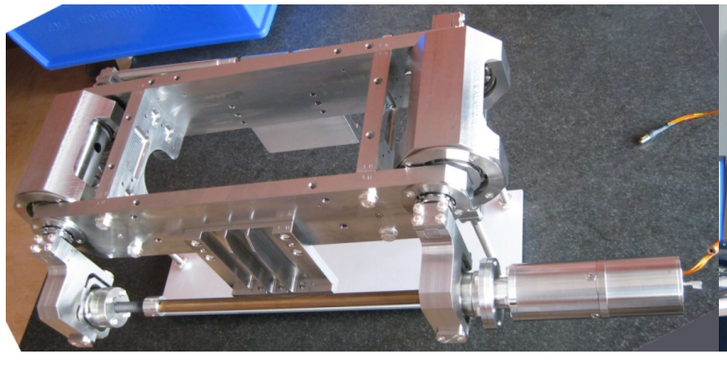
Cavity Reception and Warm testing lab

- **Set up for reception and testing of Cavities: HIE-Isolde, Crab, SPL, + …**
  - Cavity reception and leak testing
  - Optical Inspection
  - Bead Pull Measurements
  - SPL Tuning Bench
  - SPL Tuner Test
  - RF Measurements



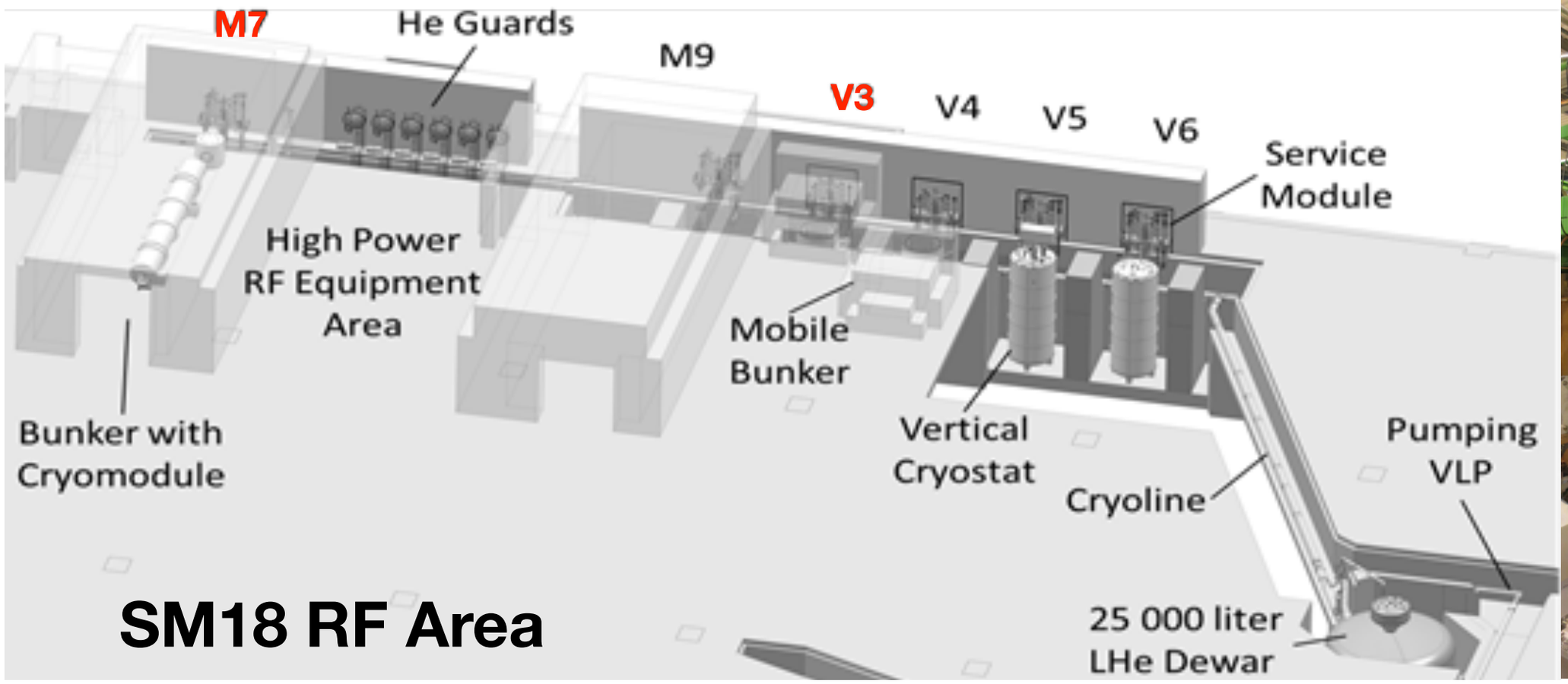






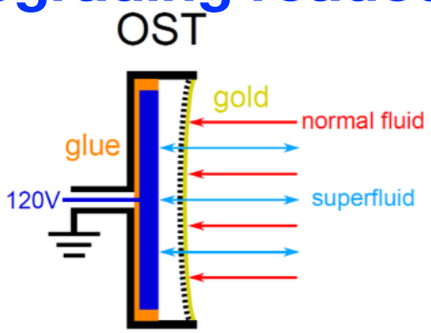
SPL: RF Cold Testing

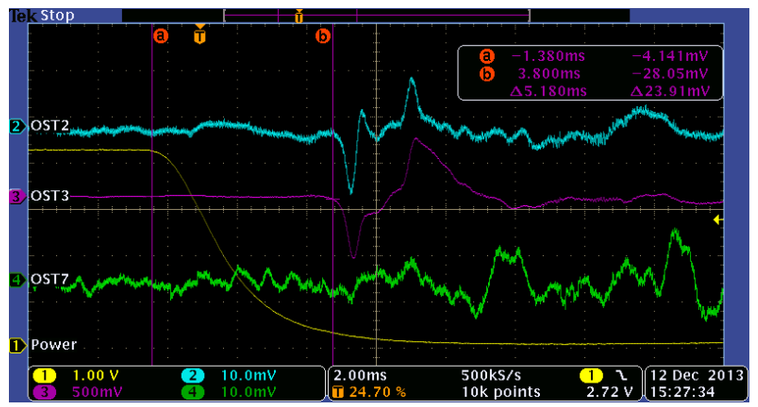
- **SPL RF Cold testing: SM18 RF Facility**
  - **Vertical Tests**: SM18 V3 Cryostat
    - ~3300 litre Cryostat: 1.8K operating temperature
  - **V3 Control Software**: Finishing full code review process
  - **Horizontal Tests**: M7 Bunker
    - Refurbishment of cryogenics distribution ongoing



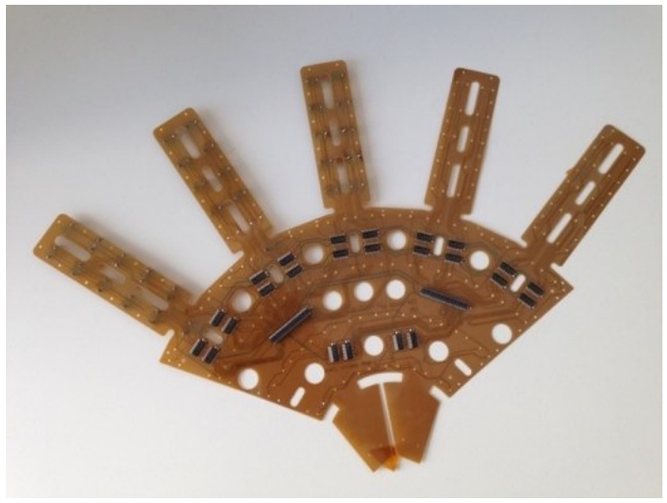
Cold Test Diagnostics

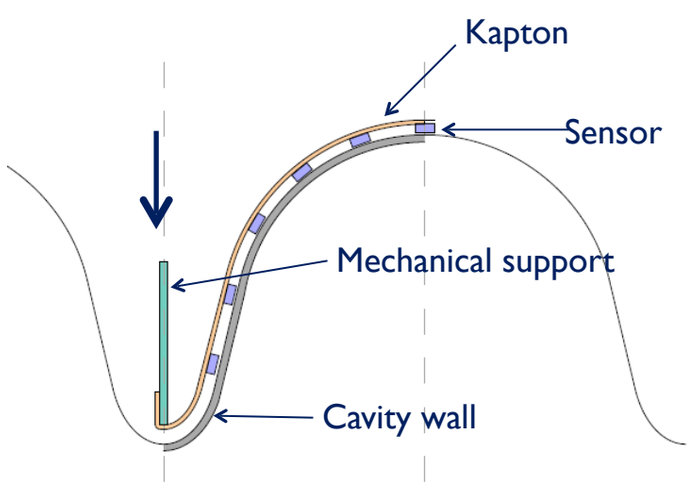
- **Quench Detection: OSTs and second sound**
  - OSTs were successfully deployed for SACLAY SPL & UK 4-Rod Crab tests
  - **Now upgrading readout system for SPL 5-cell tests**

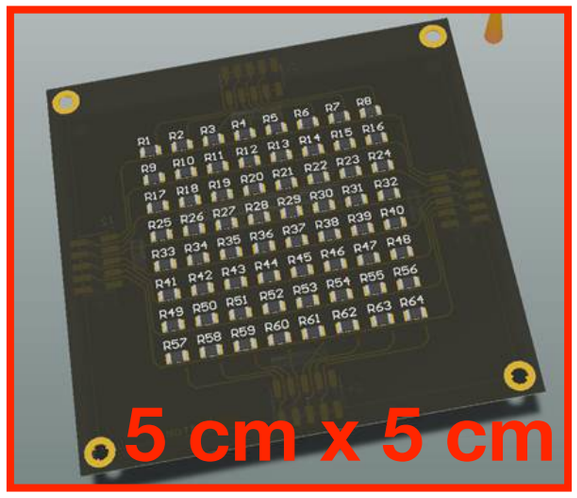




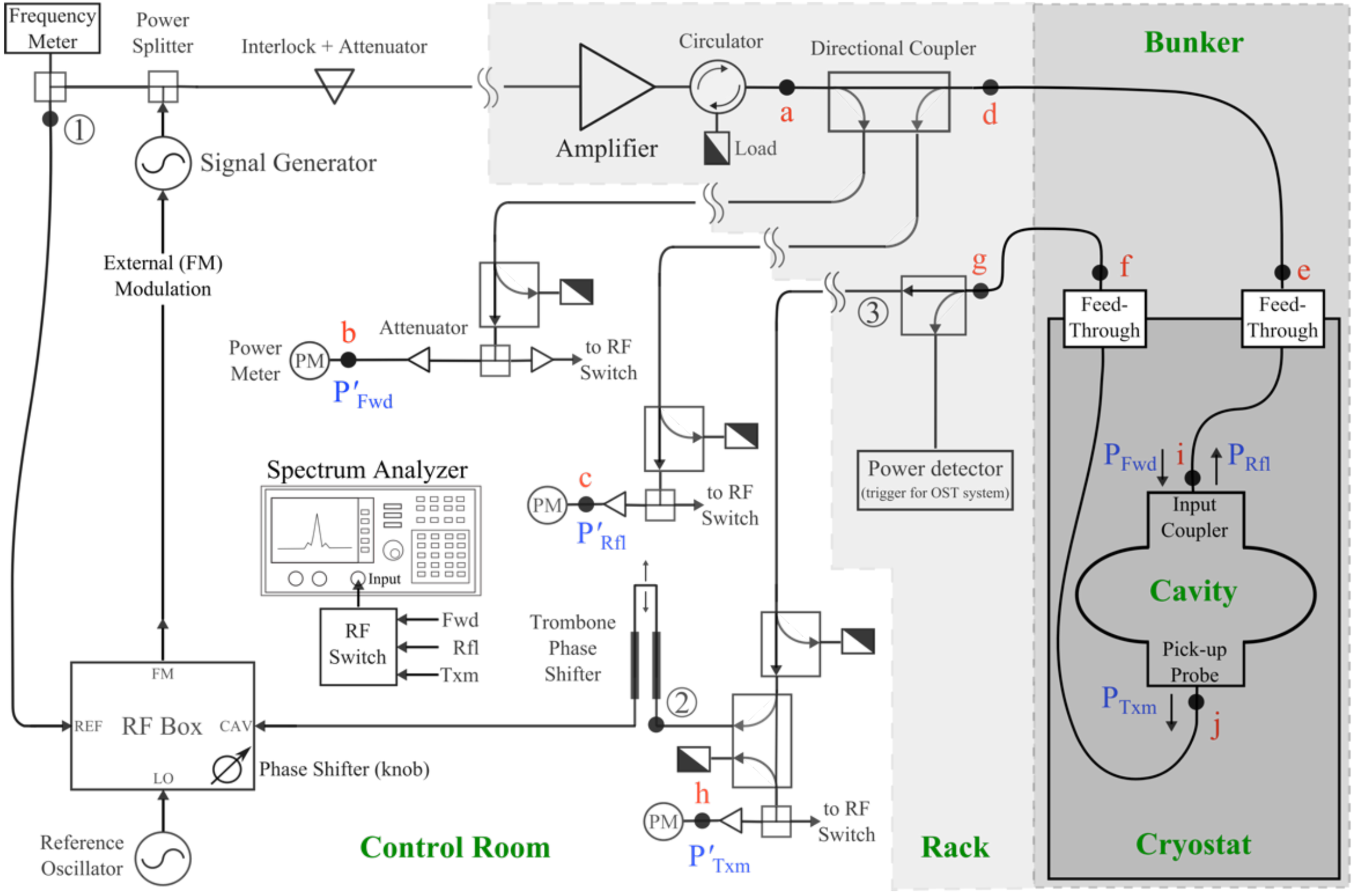
- **Temperature Monitoring**
  - Calibrated Allen Bradley resistors with LHC-based PLC acquisition
  - **Upgrading to Ruthenium Oxide sensors**: SMD sensors on pogo-sticks
- **Temperature Mapping**
  - Prototype test: Developing flexible sensor grid to with RuO_2 sensors



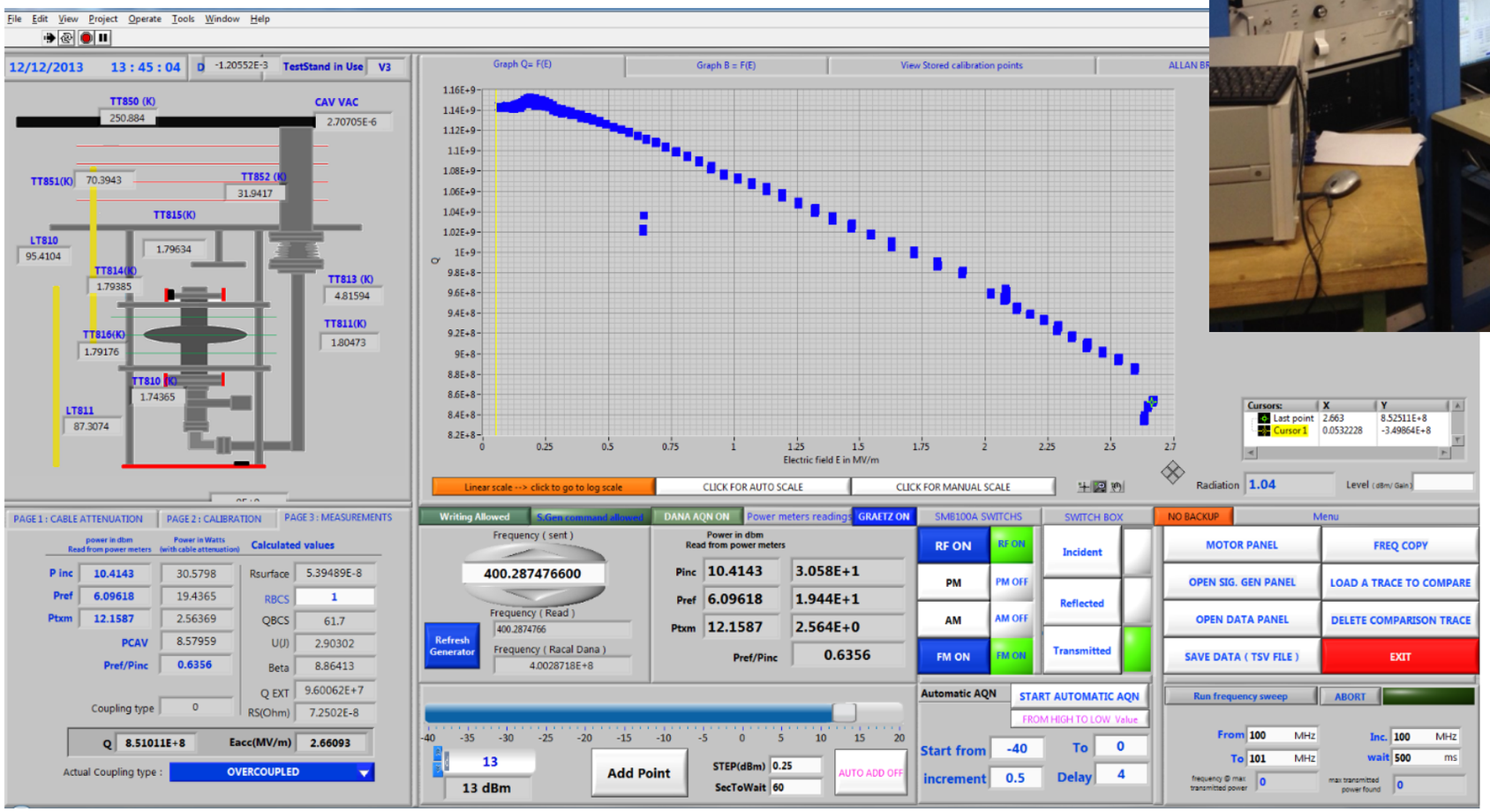




SM18 1.8K Teststand: V3 Vertical Teststand



SM18 1.8K Teststand: V3 Vertical Teststand Reality



SPL β=1 Nb Monocell: Cold Test

- **SPL Nb Monocell: A “Test” cavity. Validation of assemby & procedures**
  - Tested at SM18 Vertical cryostat: Measured at 4.5K, 2.4K and 1.8K
  - Q0 = 1.7 10^{10} at 1.8K G=270 => R_Residual =14.5nOhms

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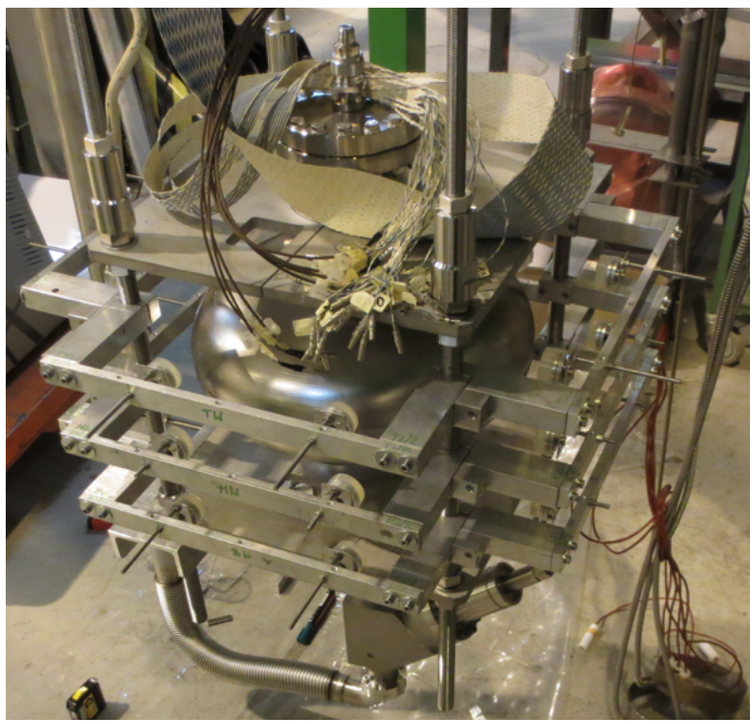
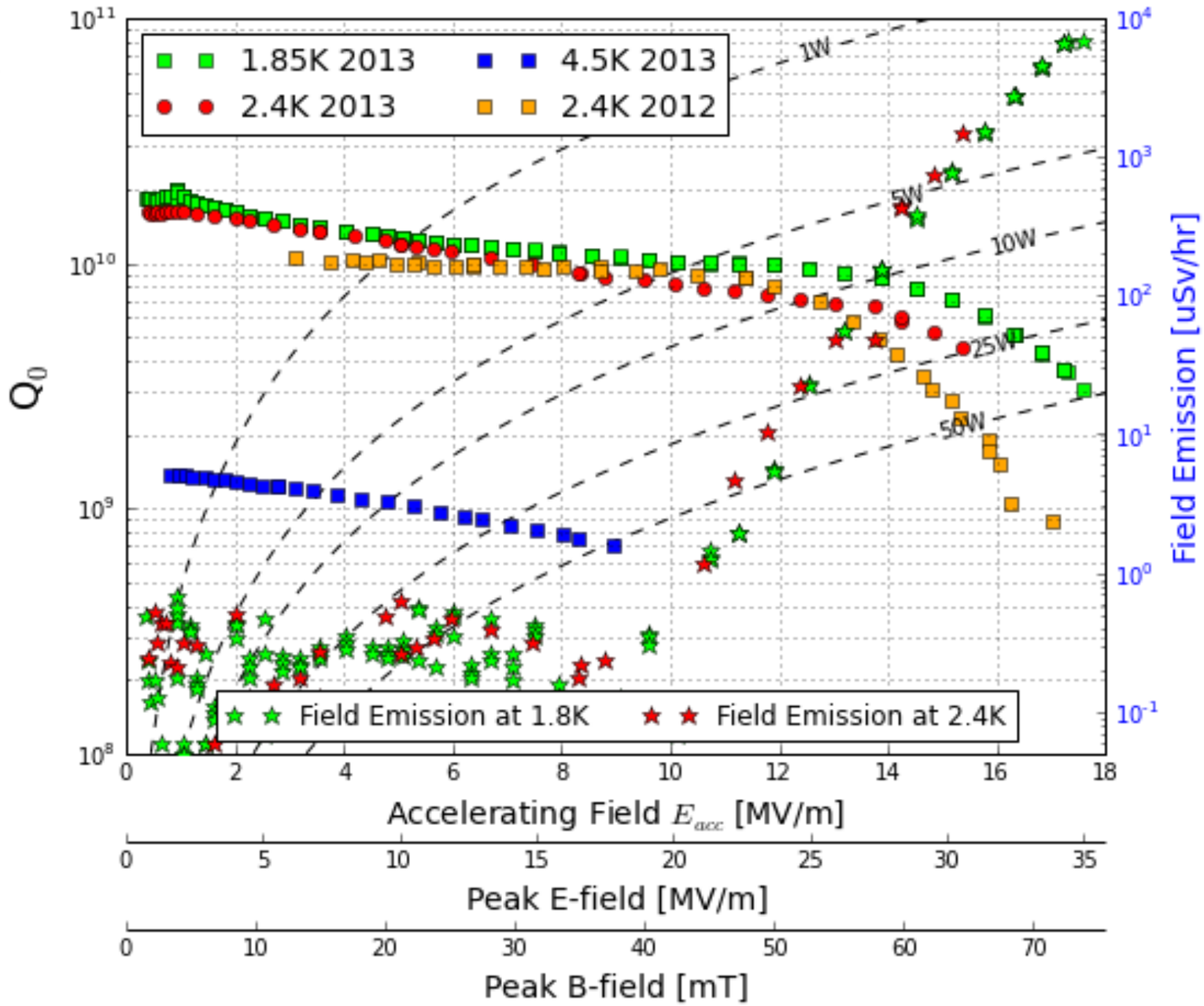
  - Q0 = 1.7 10^{10} at 1.8K G=270 => R_Residual =14.5nOhms
- **E_{acc}~15MV/m at Q0=1x10^{10}**
  - No thermal treatment
- **Limitation in performance dictated by field emission**
- **No evidence of quenching**





SPL β=1 Monocell: Post Cold Test Inspection

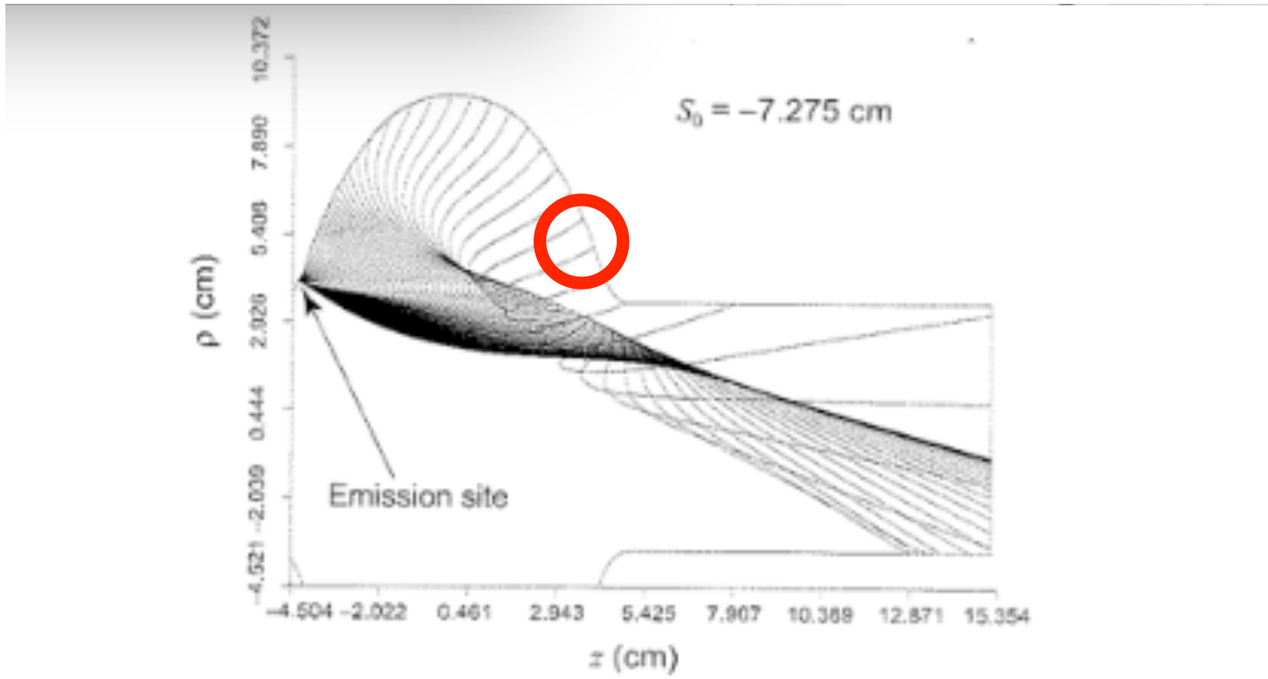
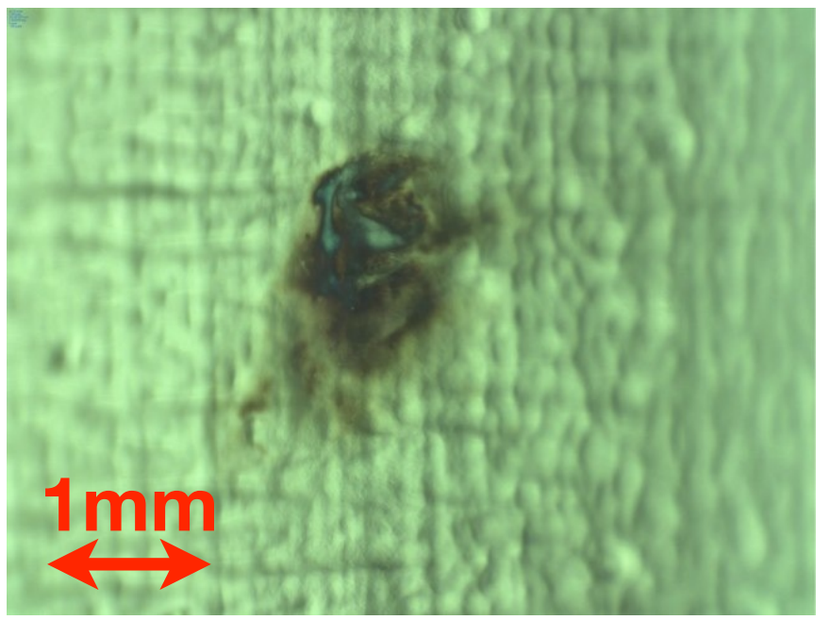
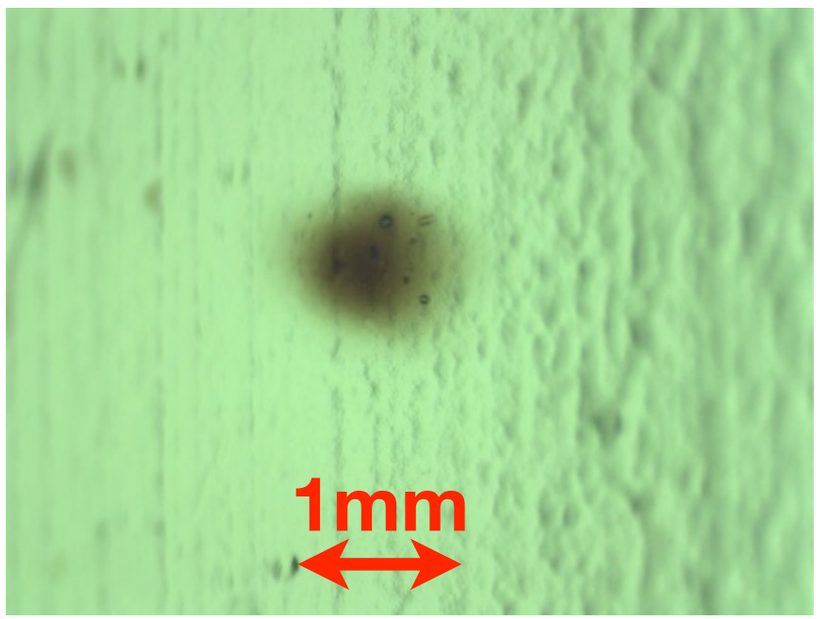
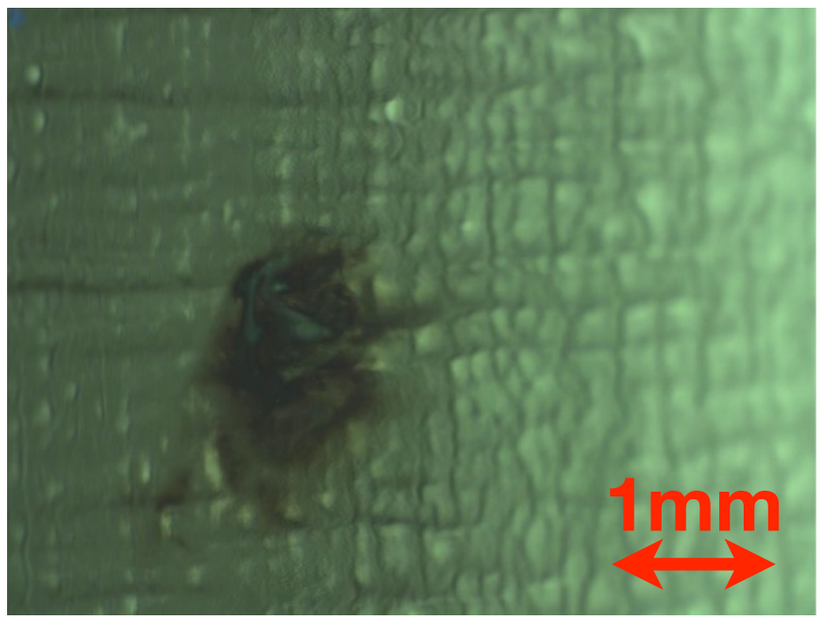


Figure 12.46: Electron trajectories in a 1.5-GHz single-cell cavity, emitted at intervals of 1/200th of the rf cycle. The trajectories lie in the ρ–z plane of the emitter. $E_{pk} = 17.38$ MV/m and the emission energy is 0 eV.

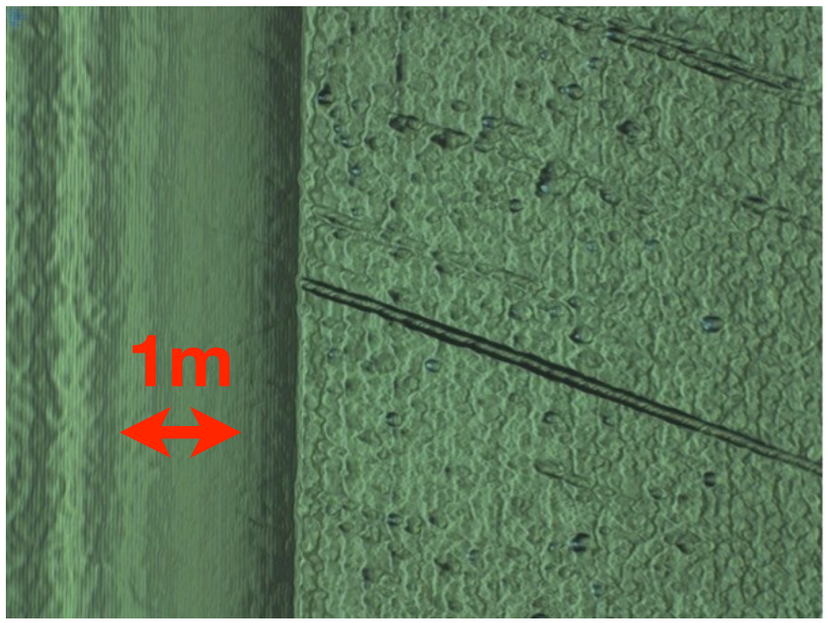






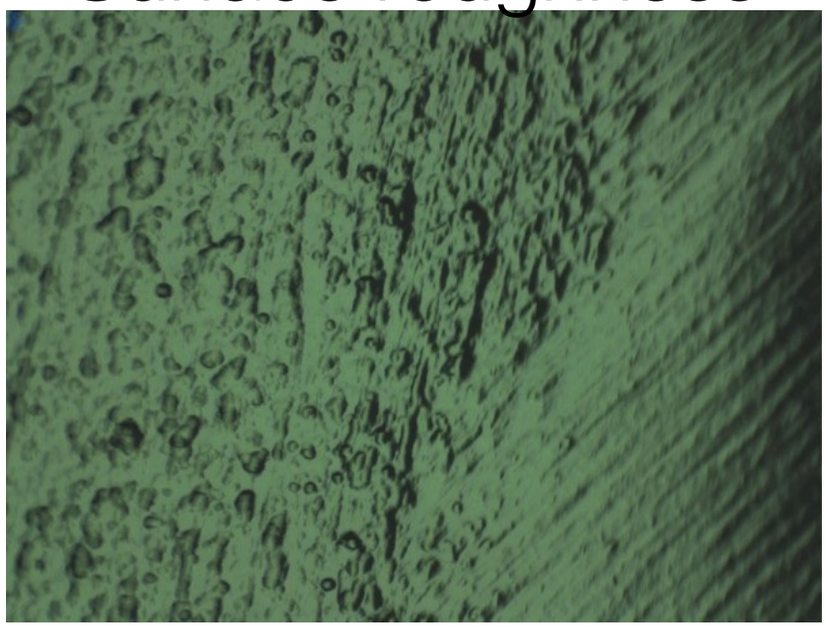
SPL β=1 Monocell: Post Cold Test Inspection

Scratches



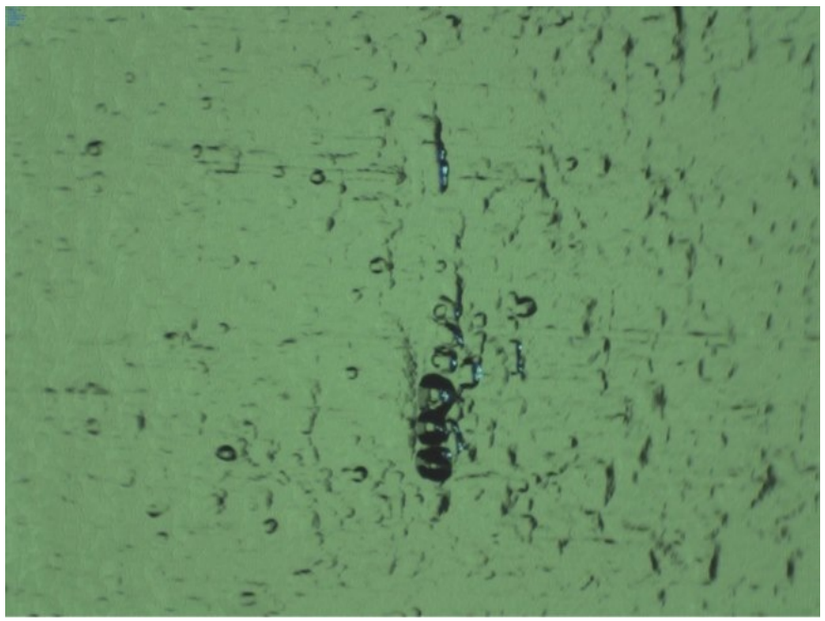
- **Scratches at Equator:**
  - **Pre-date EB welding. Direction varies**

Surface roughness



- **Regions of different surface roughness and scouring direction**

Pinholes

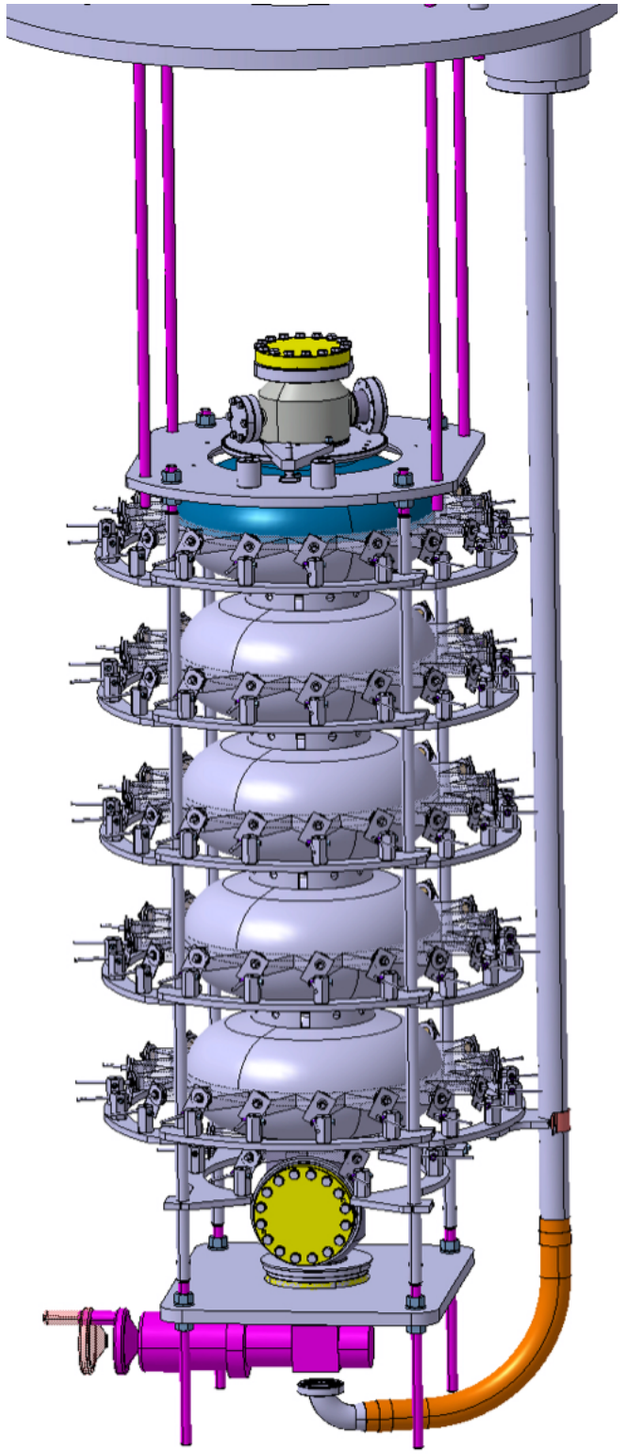


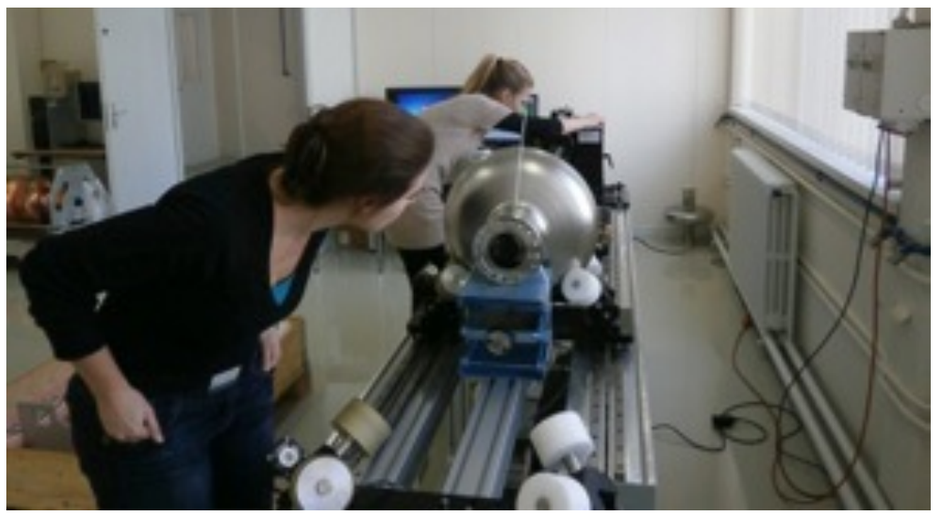
- **Pinholes Observed near the equator.**

Cavity Preparation for SM18 Cold Test

Cavity Preparation for SM18 Cold Test

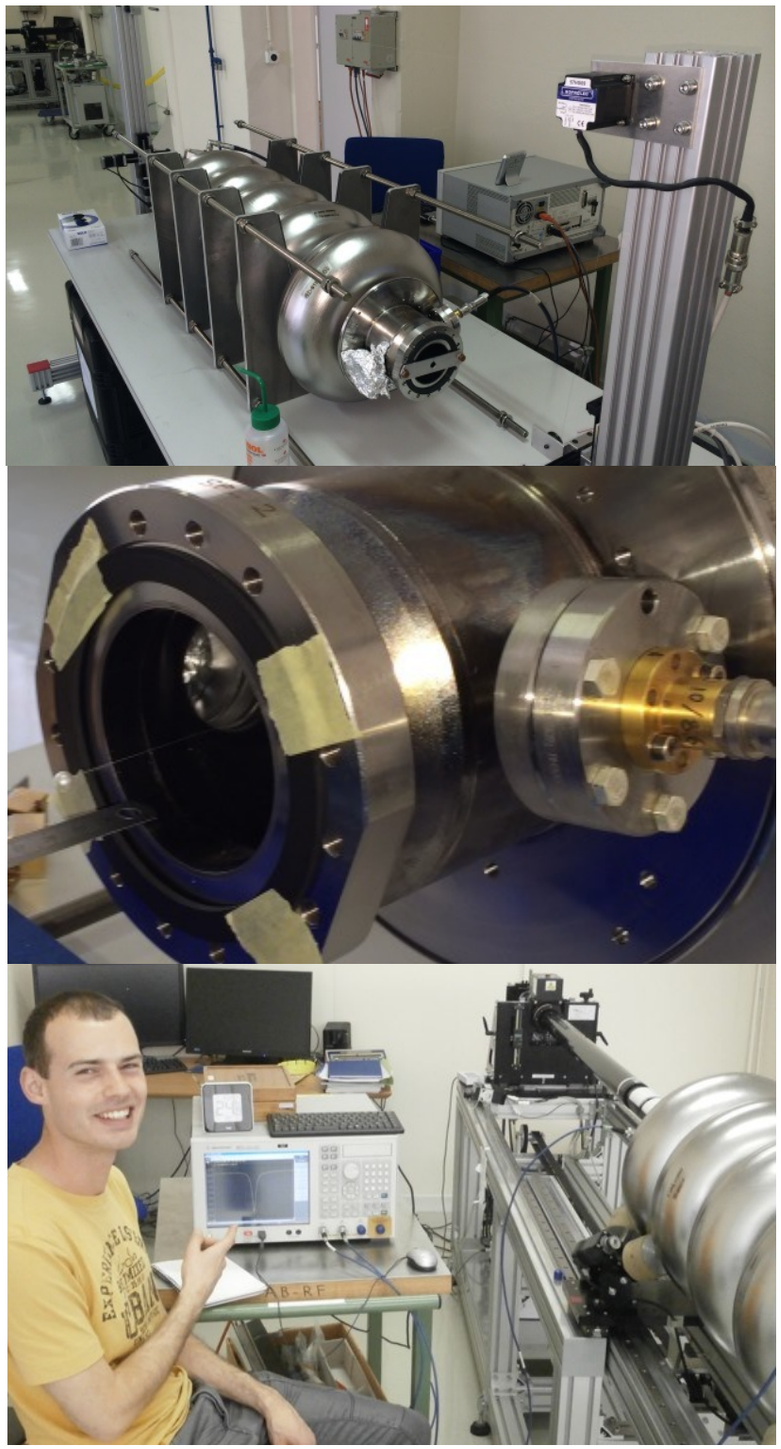
- **Cold test of 1st SPL Nb 5-cell: Expected in June 2014**
- **Preparations ongoing**
  - **Measurement of Cavity at 300K**
    - RF measurements, Field Flatness etc
  - **Preparation of cavity surface**
    - Electro polishing, thermal treatment, 120º C bake
  - **Preparation of cryostat insert**
    - OSTs + temperature & environmental monitoring.
  - **Upgrade of diagnostics and test stand software**
    - Both CW and Pulse mode operation
- **Training of Cavity Testing Team well advanced**
  - Teams for both warm and cold measurements





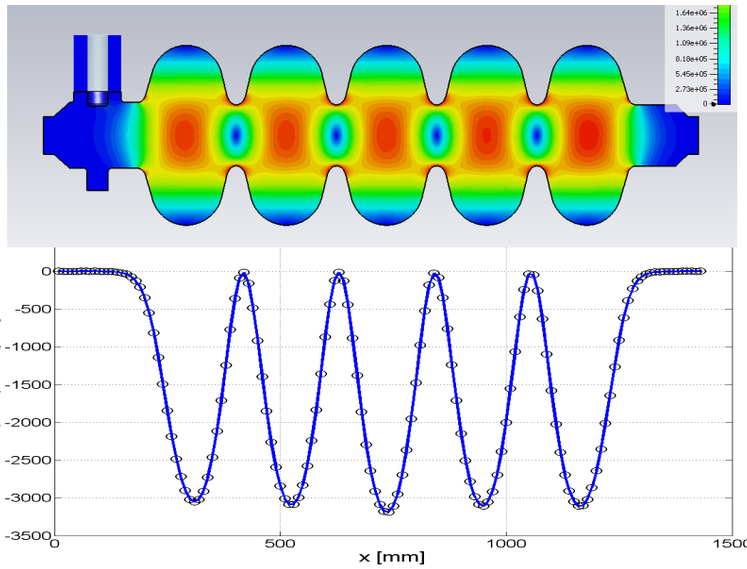
RF Measurements - Field Distribution

- **Bead-pull measurements in comparison with simulations to identify modes and their field distribution at the center axis**

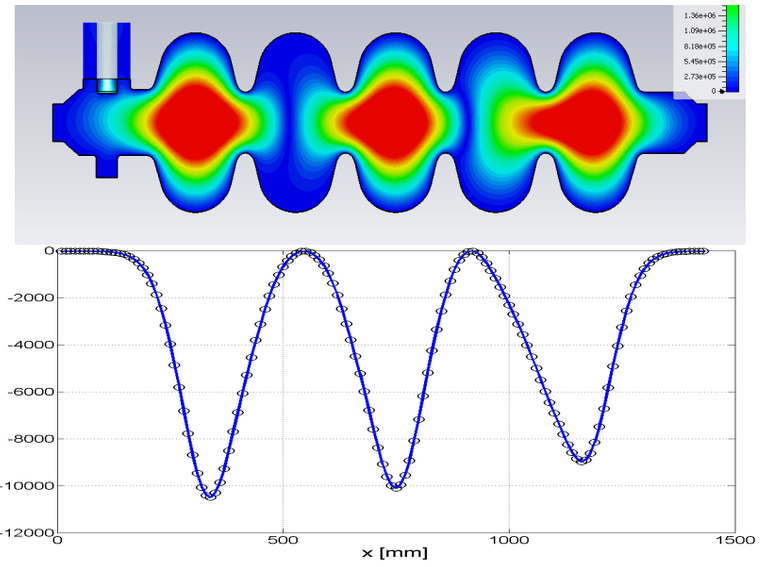


Magnitude of E-field vs. Frequency shift due to bead

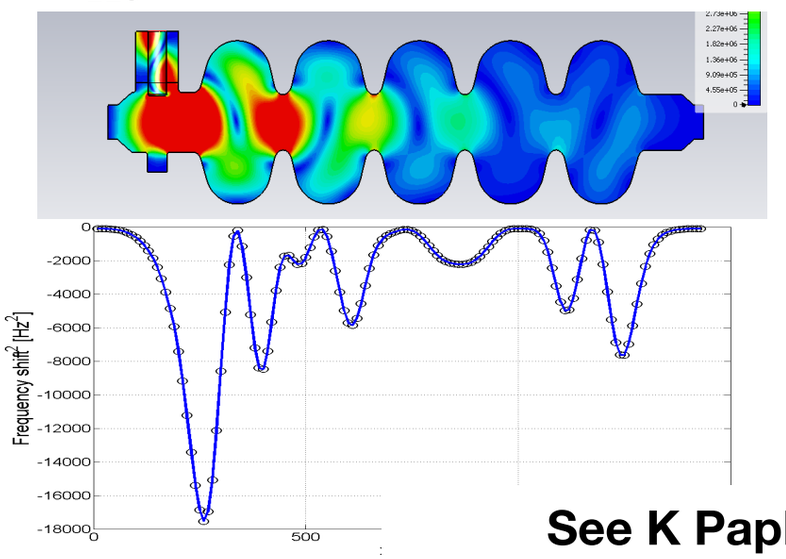
TM_{010} π – Mode (704 MHz)



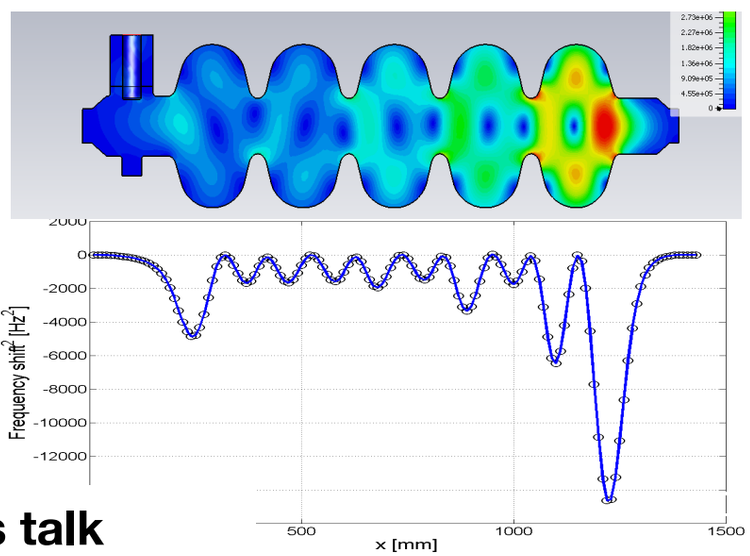
TE_{111} 3/5 π– Mode (920 MHz)



TM_{110} 4/5π – Mode (1330 MHz)



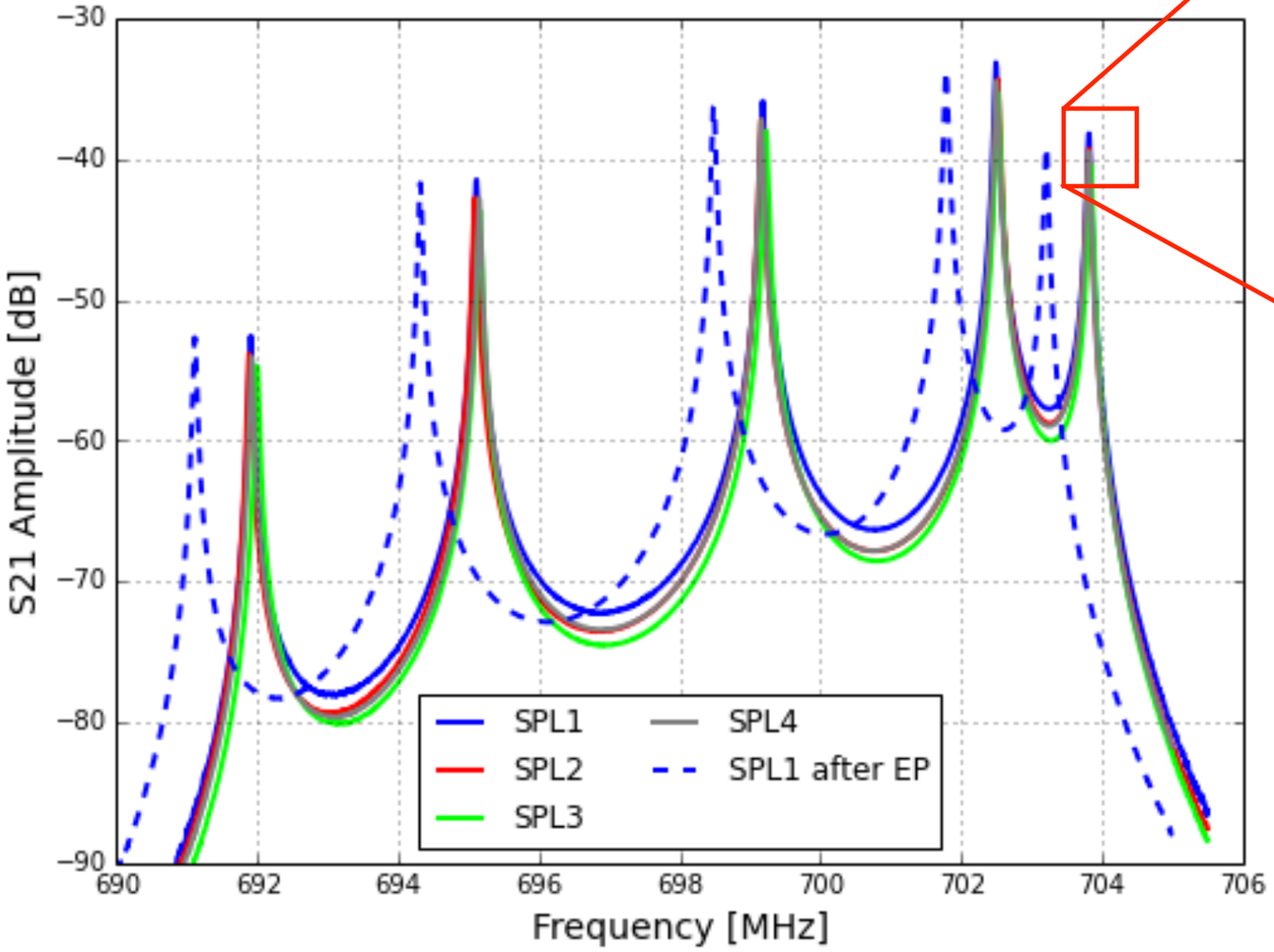
TM_{110} π – Mode (1333 MHz)

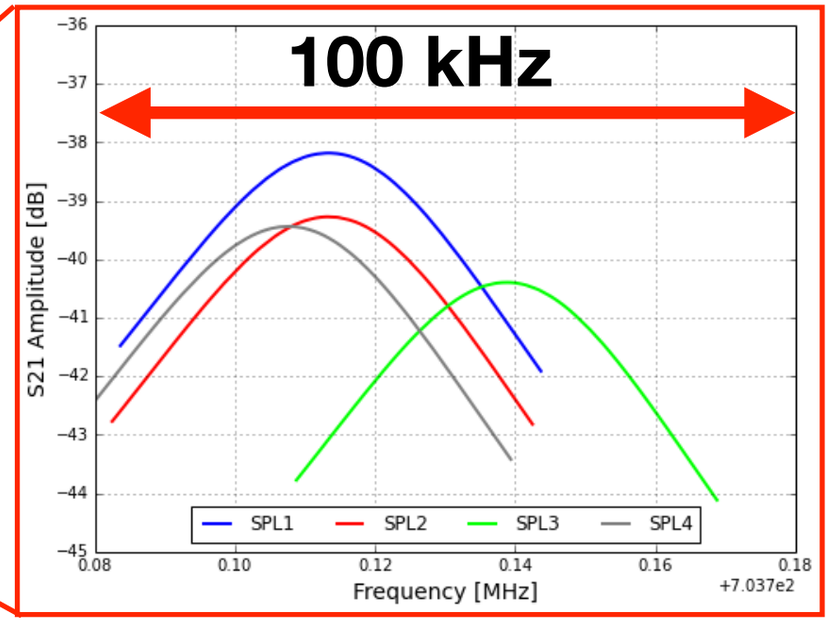


See K Papke's talk
SPL HOM coupler development

π-Mode Frequency Validation of SPL Nb 5-Cell

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



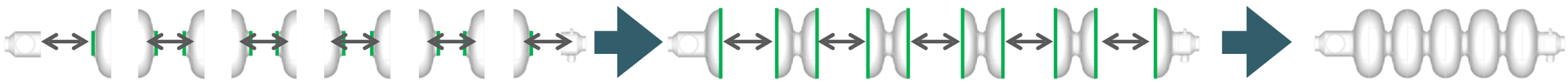


Coupler port Pick-up port

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

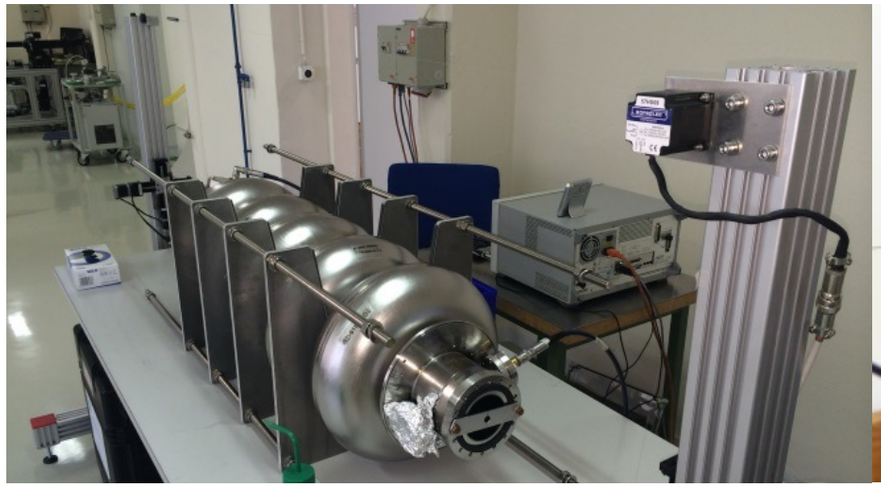
π-Mode Frequency Validation: Assembled cavities

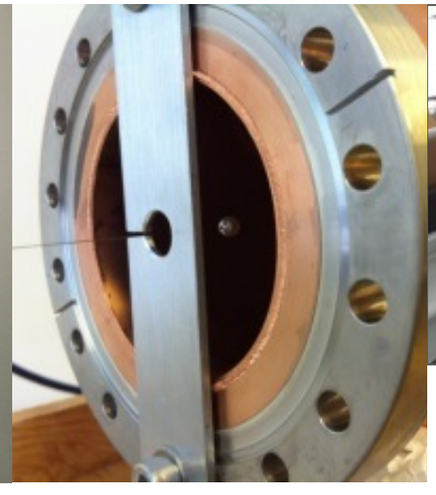
- **Assembly Process**
  - Dumb-bells trimmed so that final cavity assembly had correct length
  - Assembled cavity required to π-mode frequency within specification
    - **Tuning performed at manufacturer after assembly.**

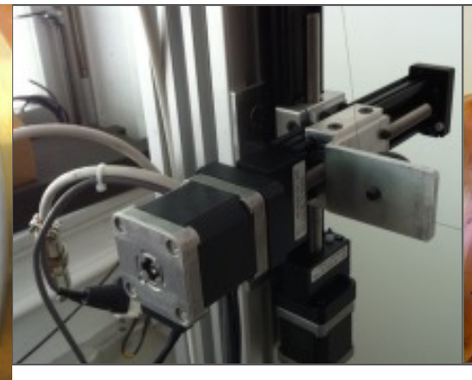


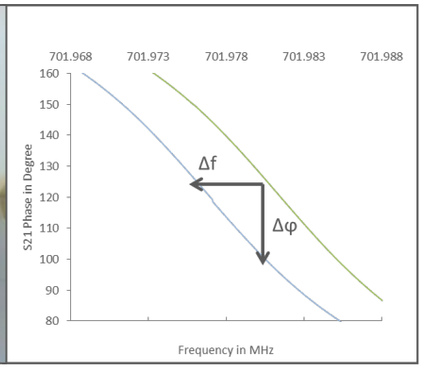
π-mode frequency and deviation specificationvalue of 704.043 ± 0.07 MHz. Values corrected to an evacuated cavity at 22 °C								
	SPL1		**SPL2**		**SPL3**		**SPL4**	
Measurement phase	f	Δ	f	Δ	f	Δ	f	Δ
At RI before tuning	703.608	-0.435	703.823	-0.220	703.775	-0.268	703.768	-0.275
At RI after tuning	704.024	-0.019	704.045	0.002	704.044	0.001	704.041	-0.002
At CERN at arrival	704.044	0.001	704.032	-0.011	704.045	0.002	704.046	0.003
Cavity length in mm	L	ΔL	L	ΔL	L	ΔL	L	ΔL
Spec.: 1397.3 mm ± 3	1395.886	1.414	1393.831	**3.469**	1395.592	1.708	1395.229	2.071

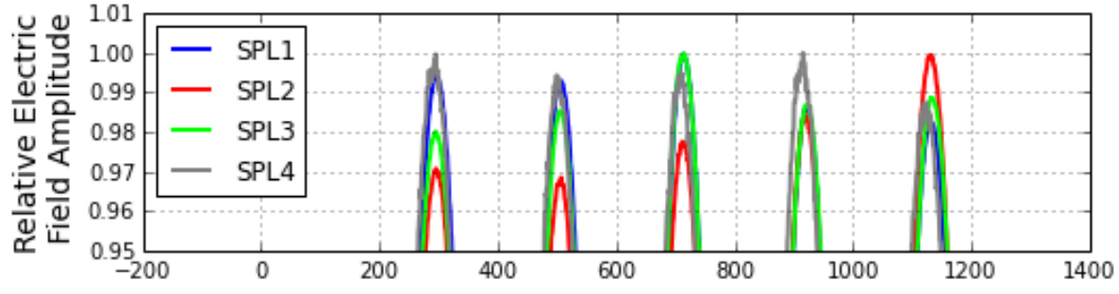
5-cell: Field Flatness







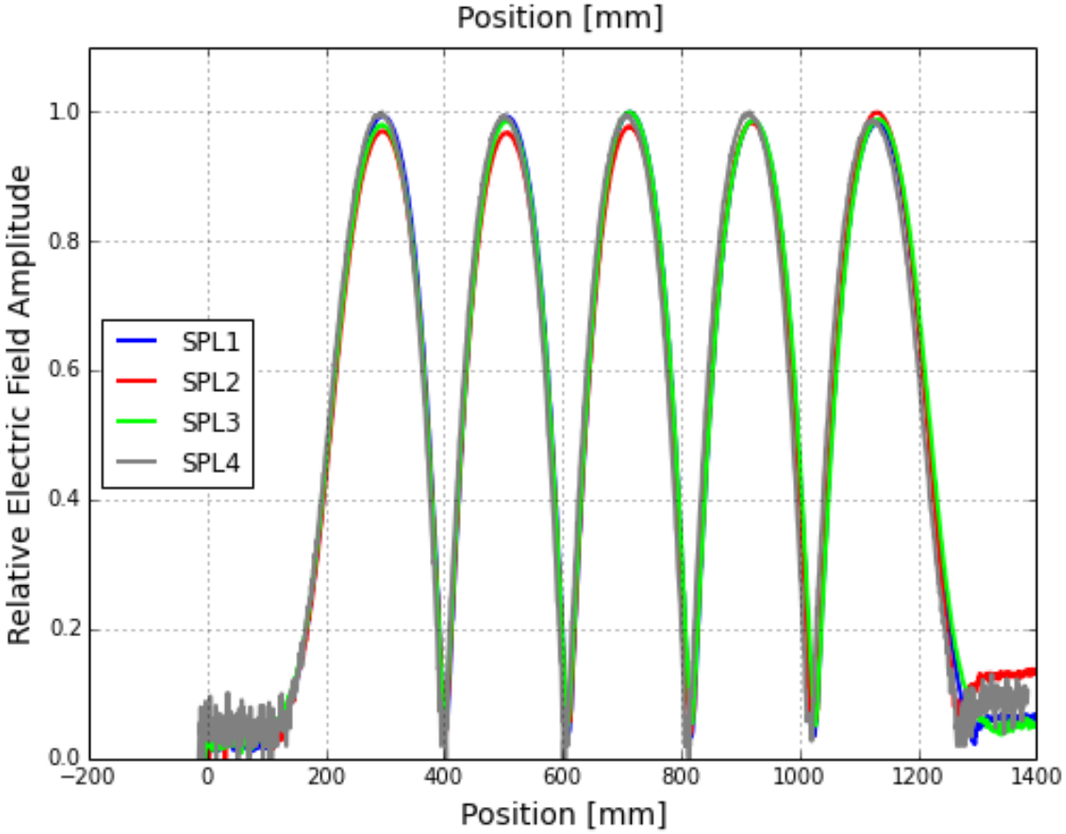




- **Field Flatness Measurement**
  - Phase method (transmission)
  - 28 s sweep time (100 Hz IFBW)
  - Bead: Dielectric, 5mm diameter
  - Position Resolution: 0.8 mm

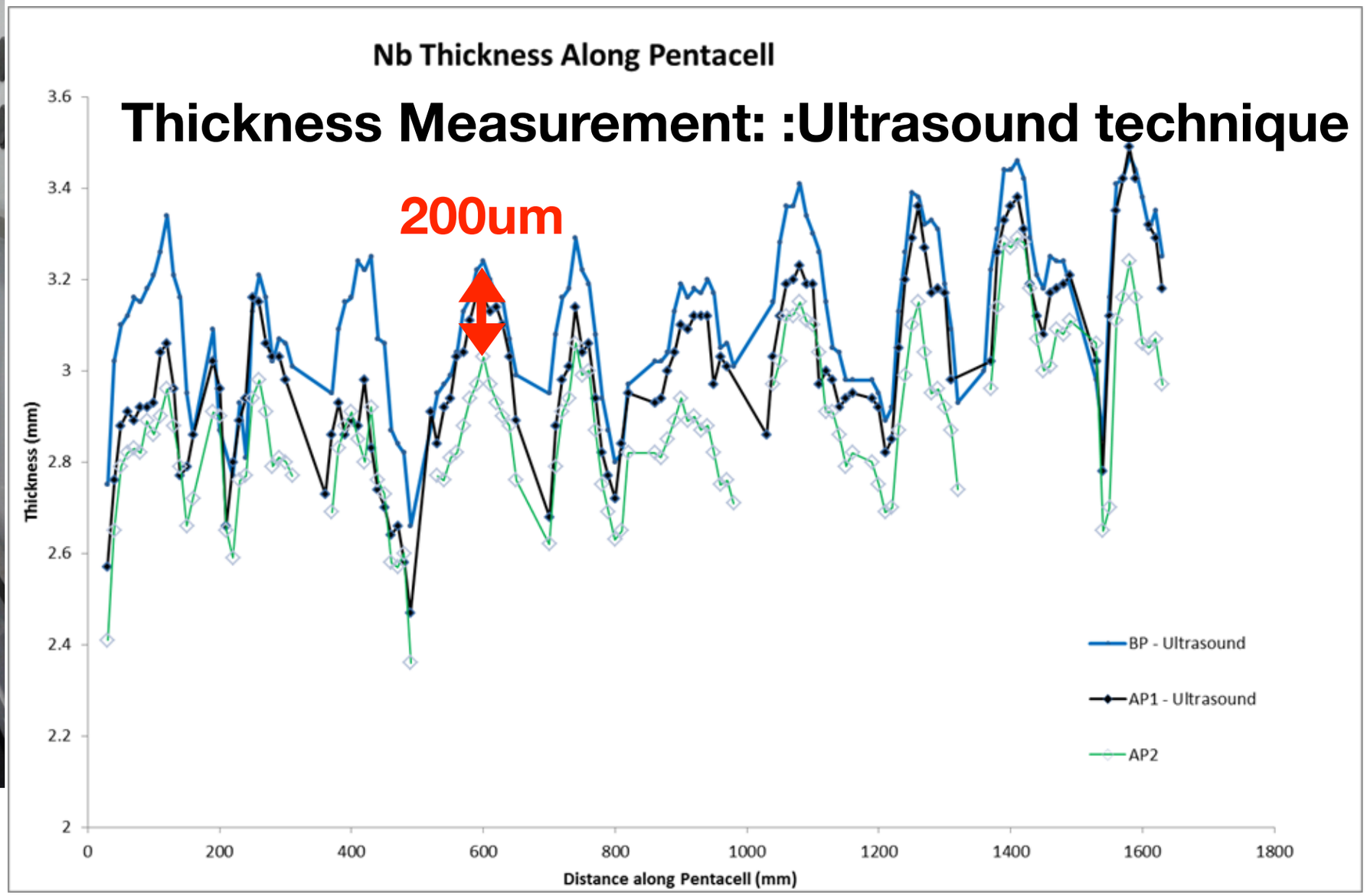
Measured field flatness in %				
	SPL1	**SPL2**	**SPL3**	**SPL4**
RI: Before tuning	14.98	50.6	15.97	51.14
RI: After tuning	1.92	0.70	1.72	1.10
Required tuning steps	10	8	5	6
CERN: after delivery	1.70	**3.26**	1.99	1.25
δ(CERN:after delivery)	0.03	**0.18**	0.07	0.39
At CERN after EP	7.98			

Field Flatness Specification < 2.5%



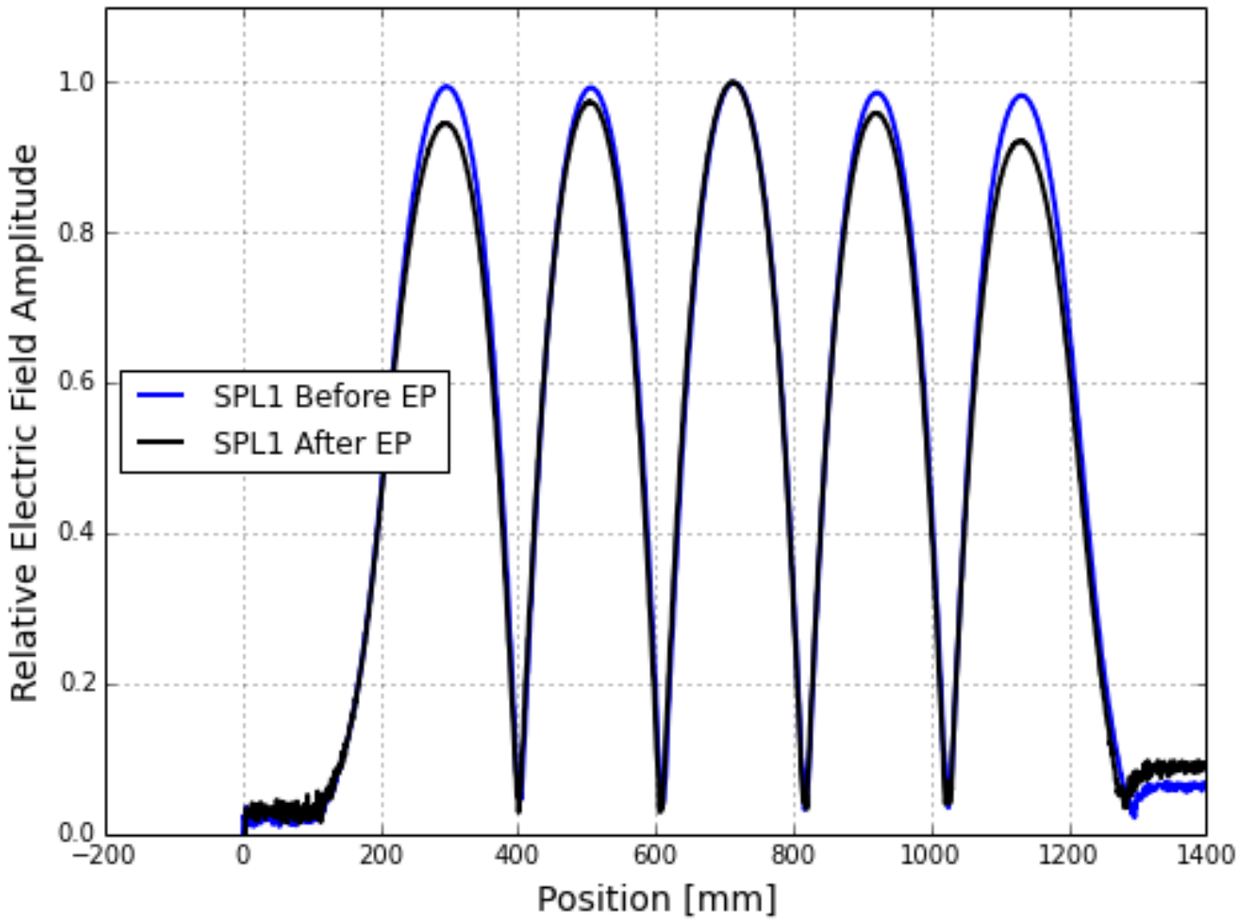
Nb 5-cell: Electropolishing

- **Electro-polishing: vertical orientation**
  - ~200 um removed
  - 2 step process: 180o after ~100um removal
  - Bath: 90% Sulphuric: 10% Hydrofluoric acid



Nb 5-cell: Field flatness and wall thickness after EP

- **Field Flatness measured after EP**
  - Symmetric drop in Electric field at outer cells
  - E_field profile consistent with increased material removal at centre cell
    - Suggests increased inter-cell coupling at iris of centre cell



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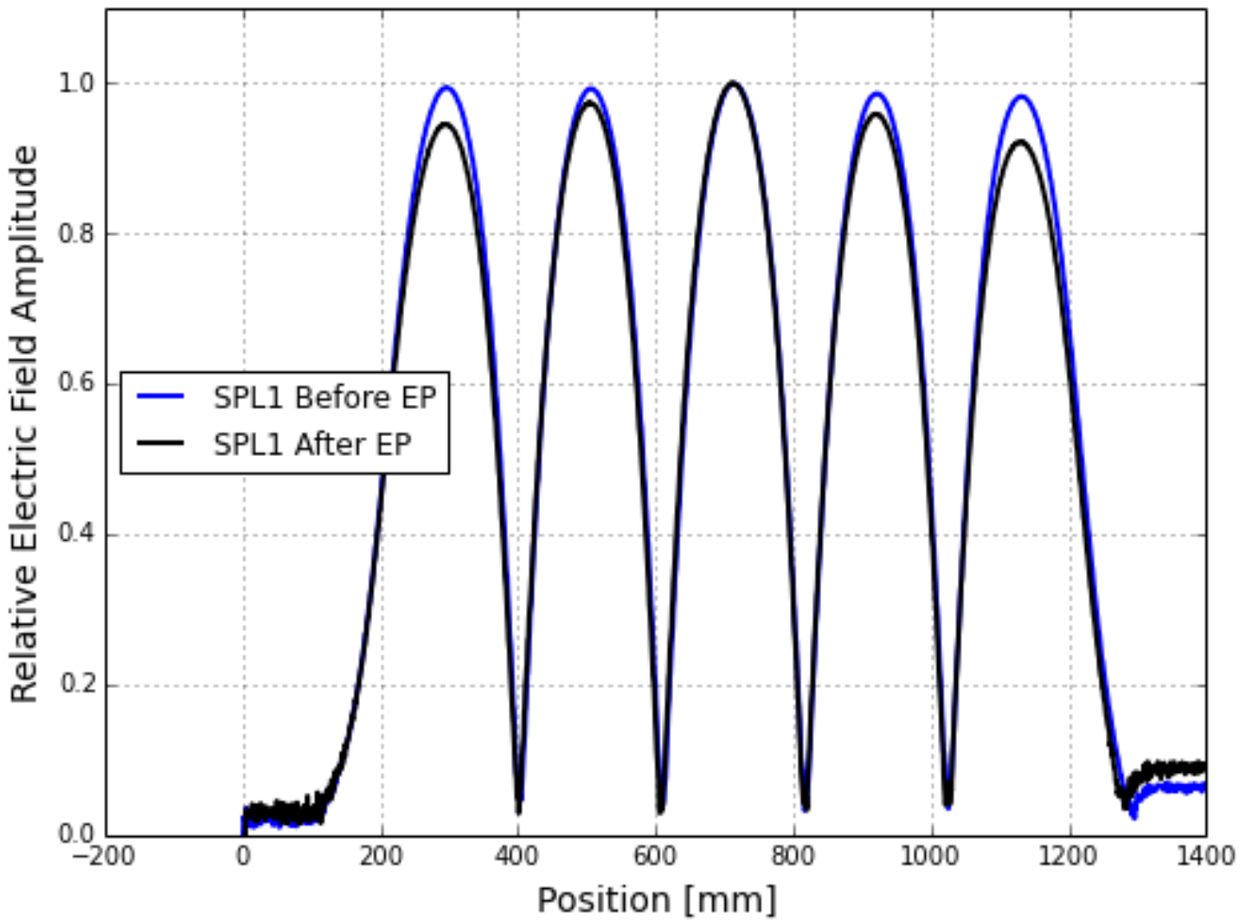
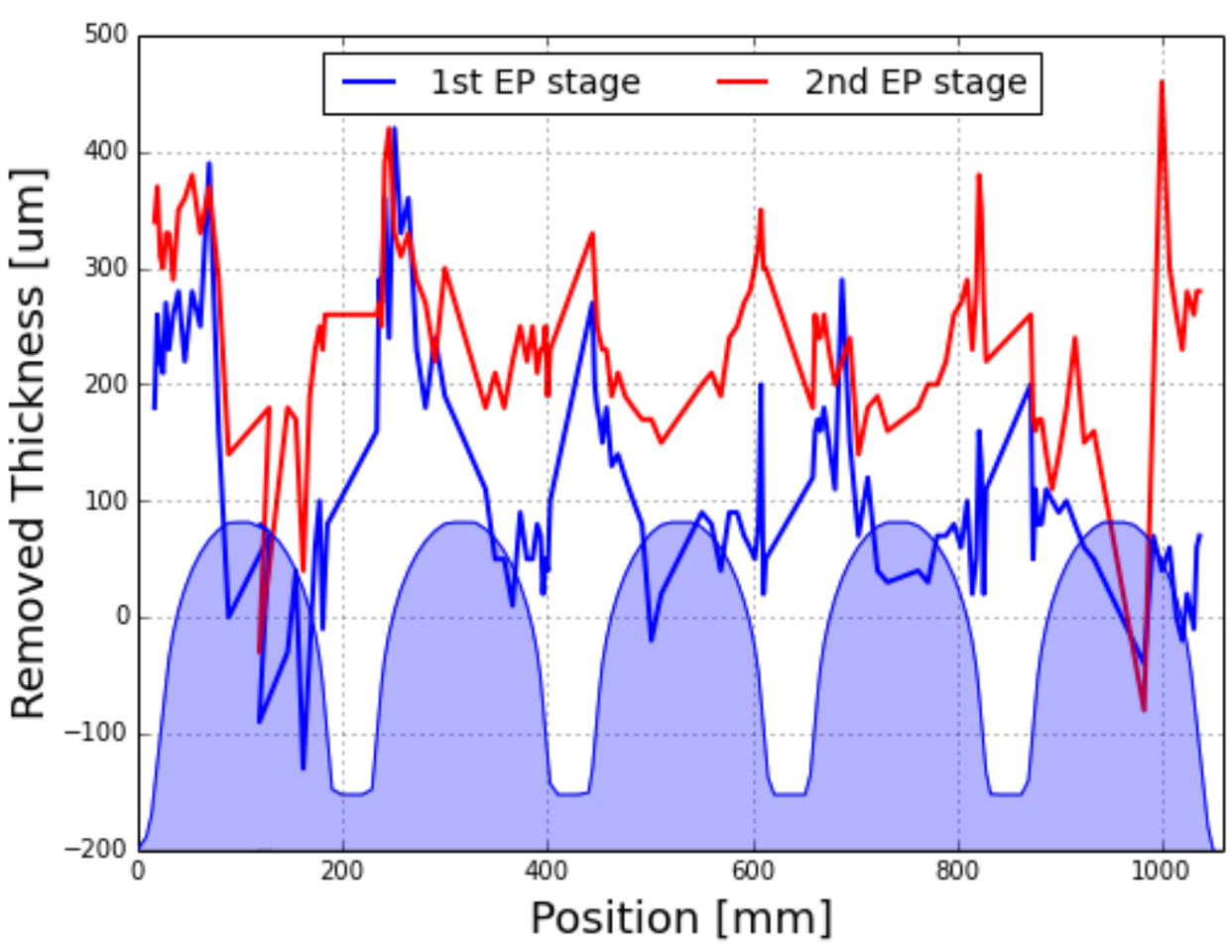


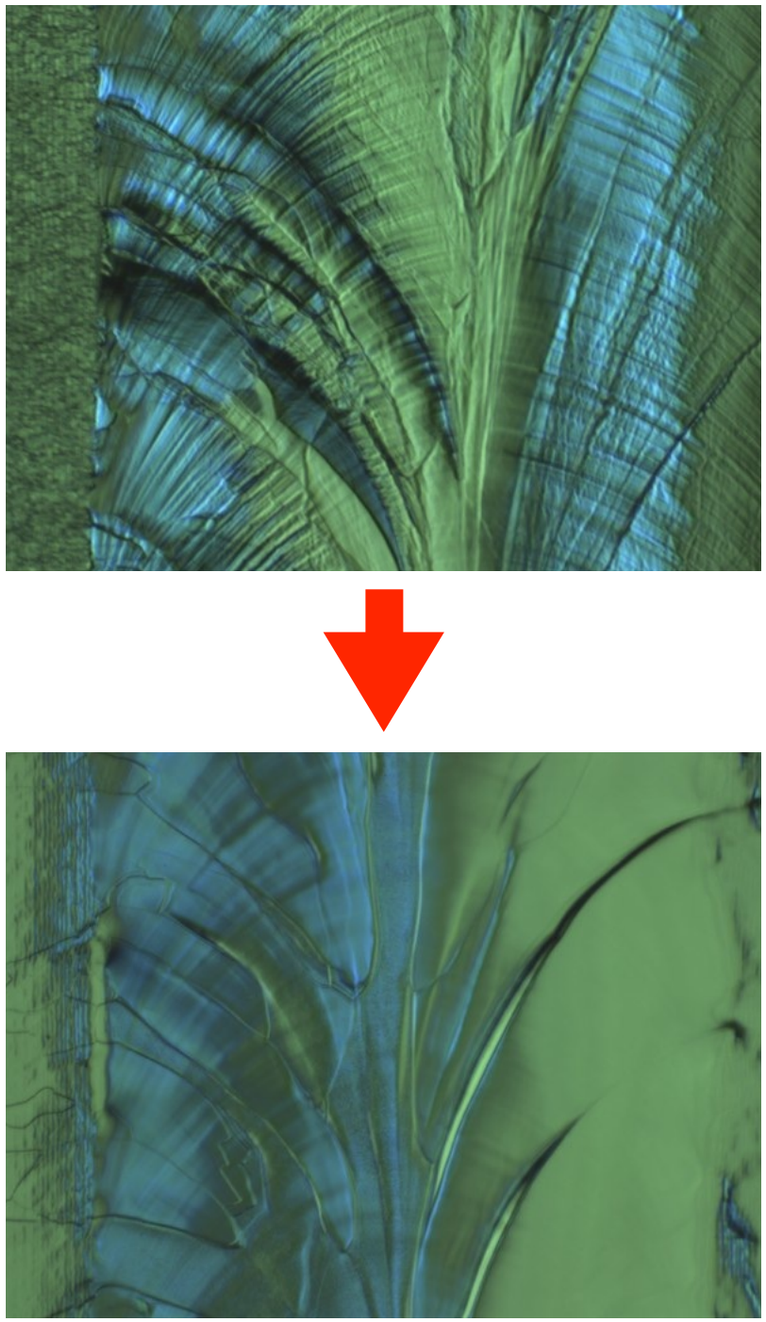


- **Ultra-sound Thickness cross check**
  - Cavity thickness measured by ultrasound technique
  - Measured before EP, after 100um EP, and after cavity rotated and another 100um removed

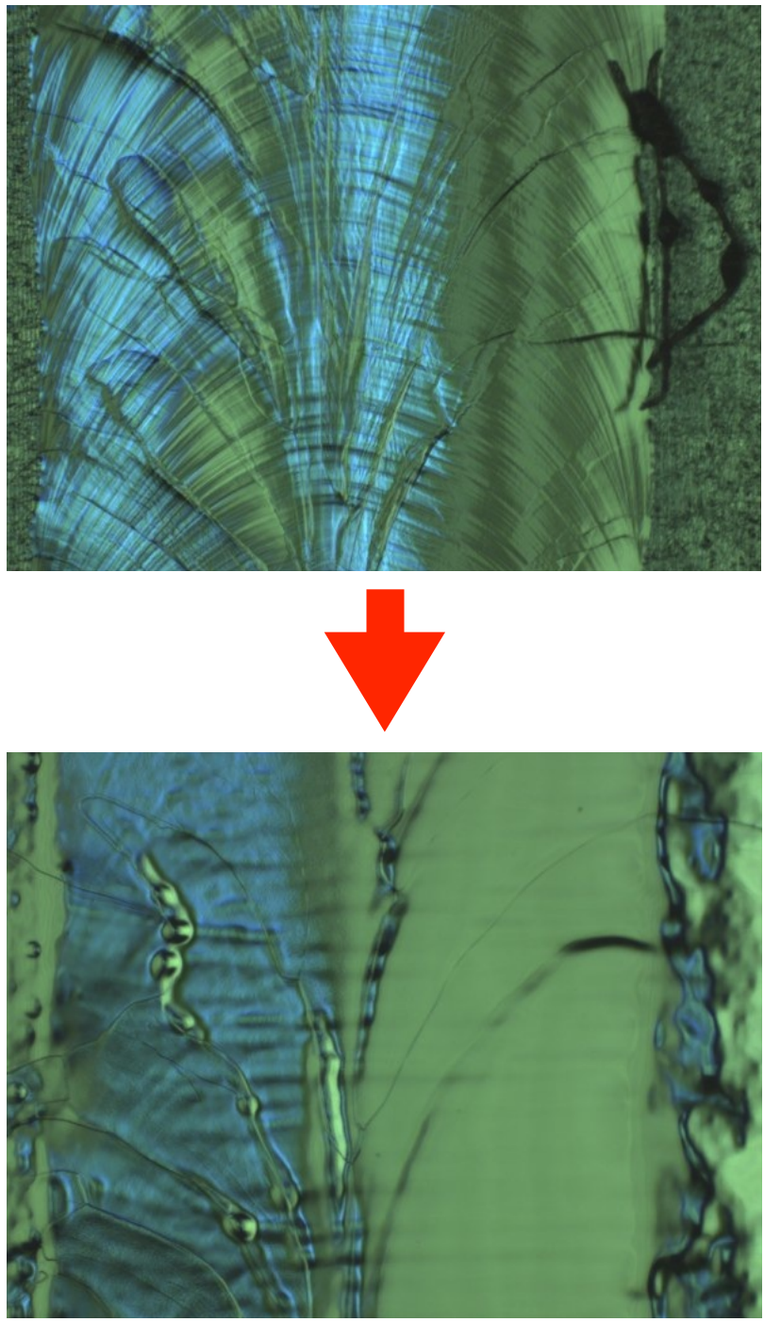
SPL Nb 5-cell: Optical Inspection

- **Inspection before and after electro-polishing: ~200um removed**

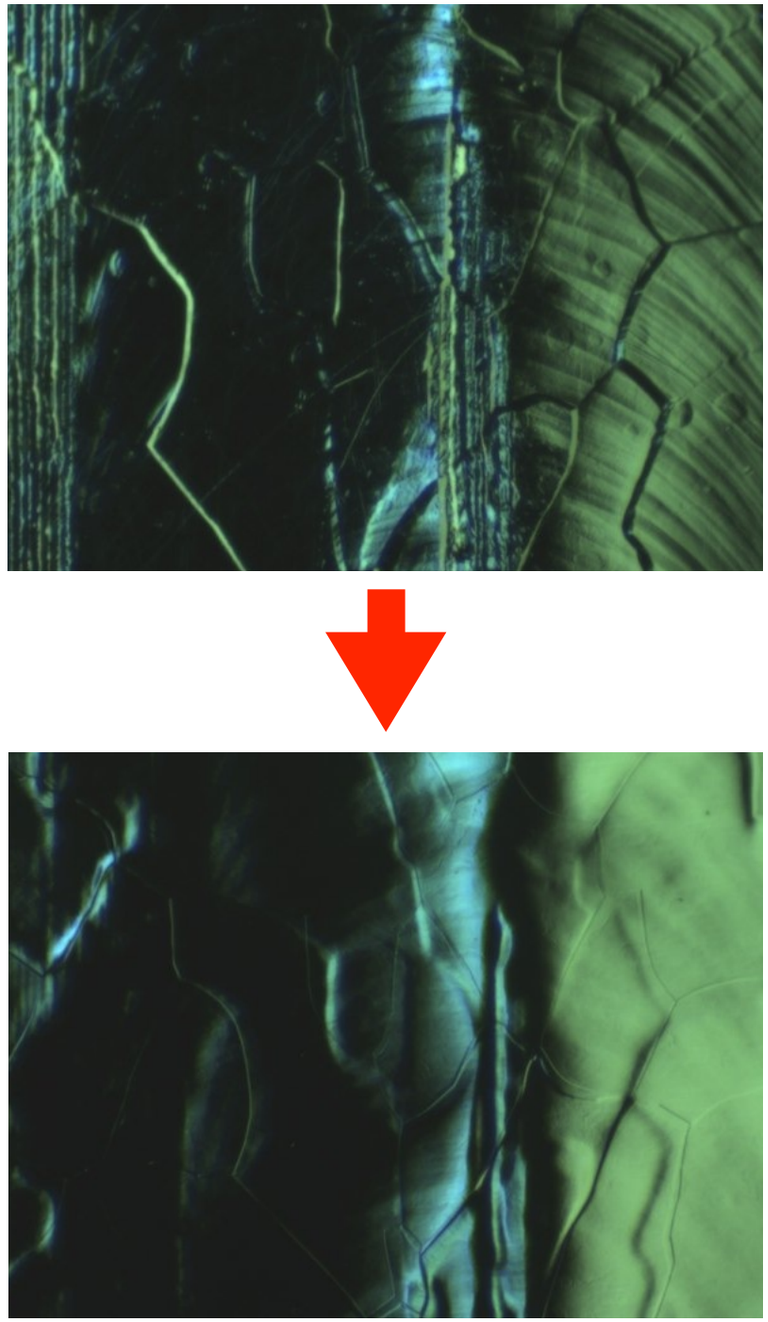
Equator weld features



Surface Objects

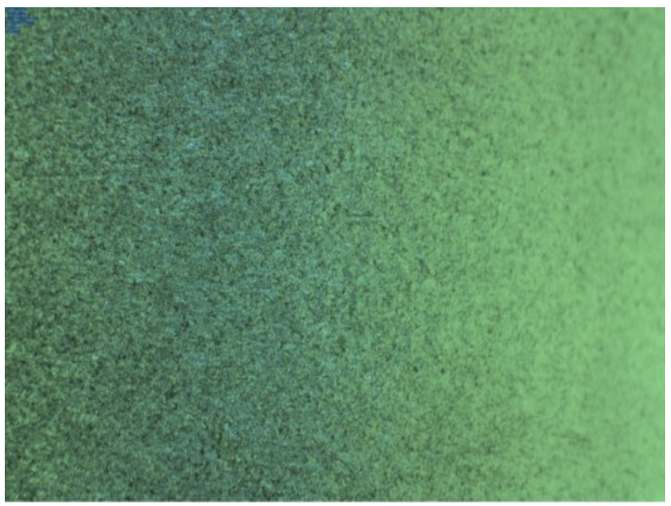


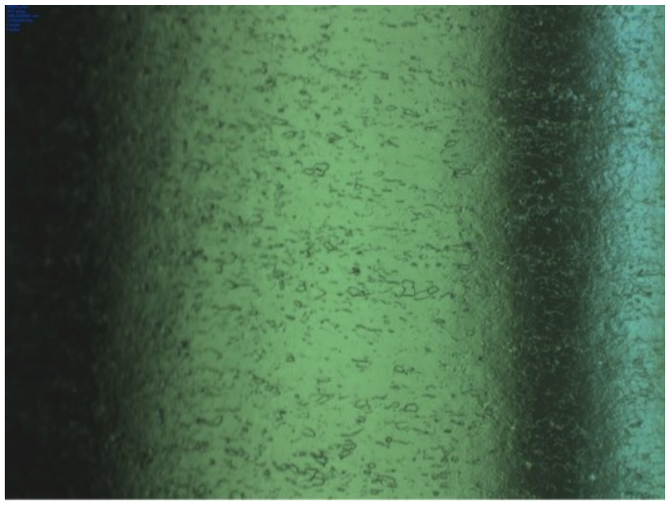
Scratch on Iris



SPL Nb 5-cell: Optical Inspection

General Surface





SPL Nb 5-cell: Optical Inspection

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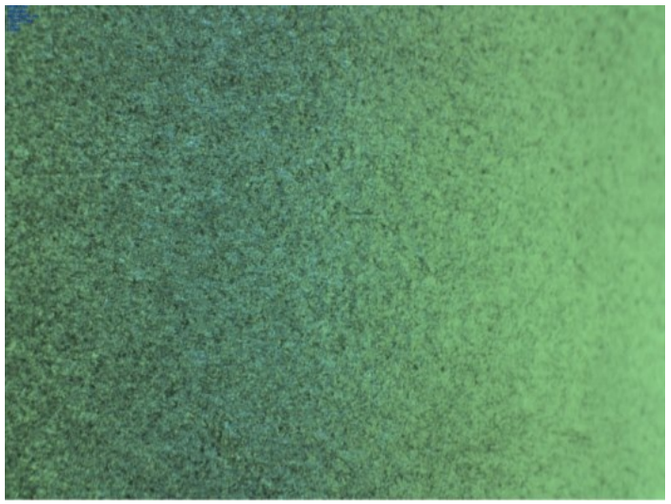
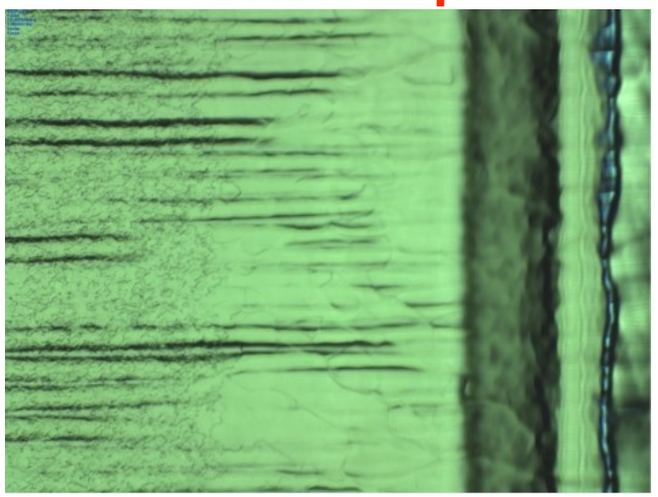
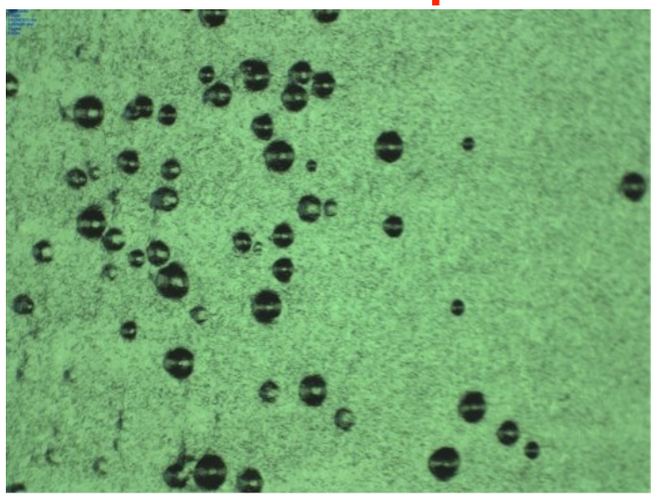


New features after electro-polishing

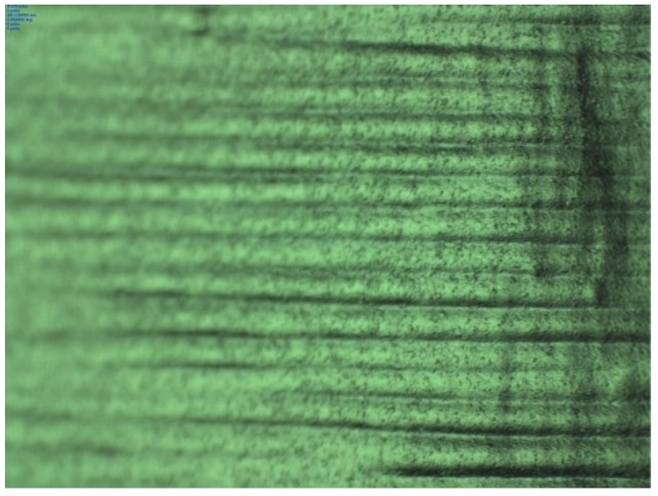
Cell 1: Near Equator



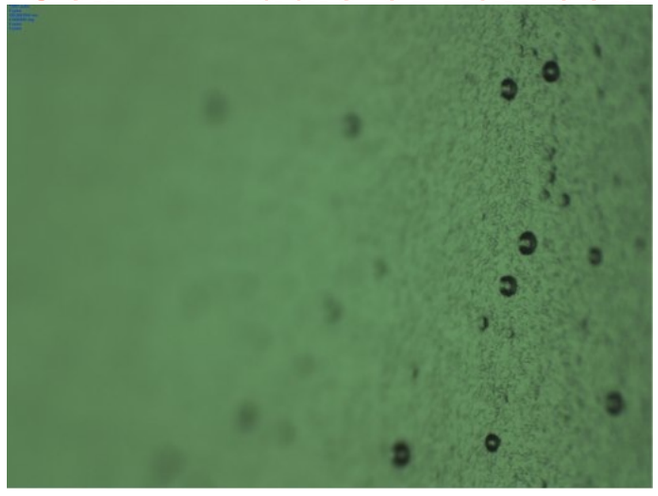
Cell 1: Near Equator



Cell 4: Near Iris

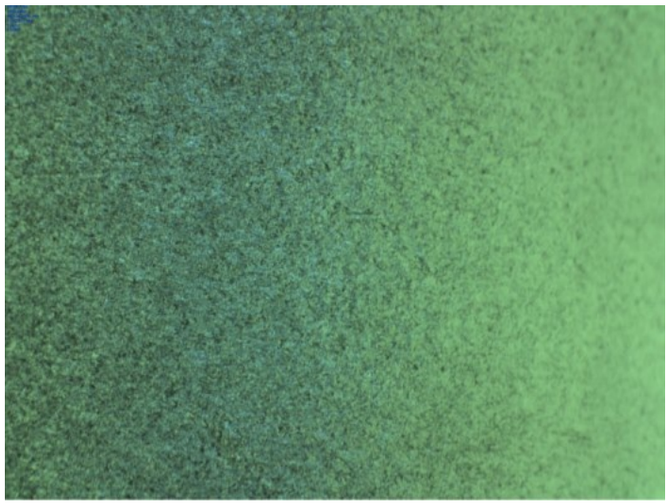


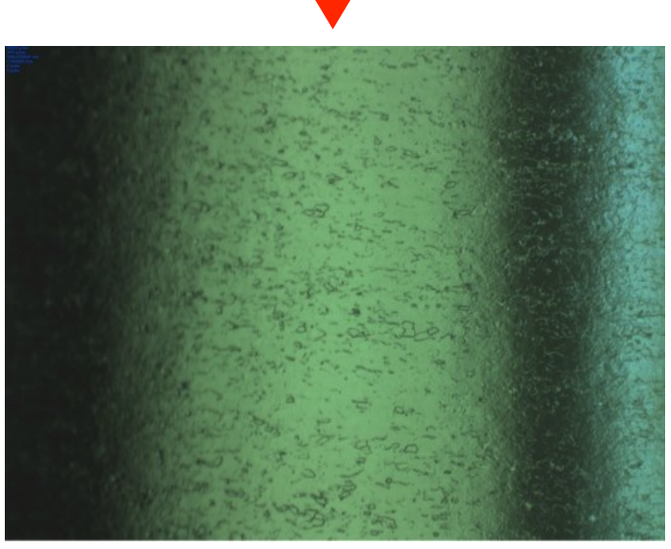
Cell 2: Middle of half cell



SPL Nb 5-cell: Optical Inspection

General Surface





New features after electro-polishing

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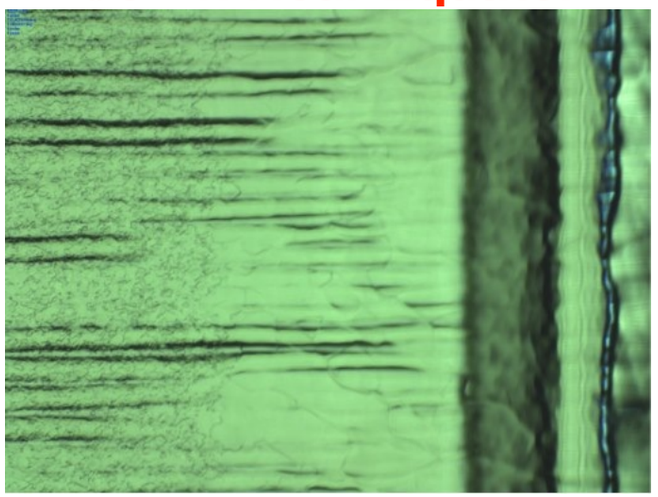
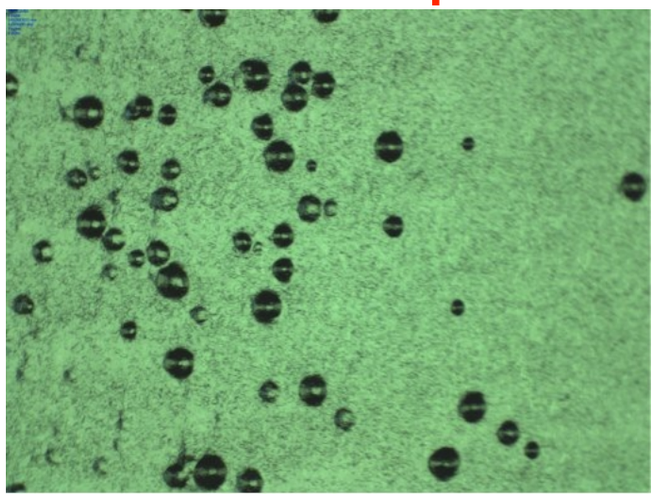
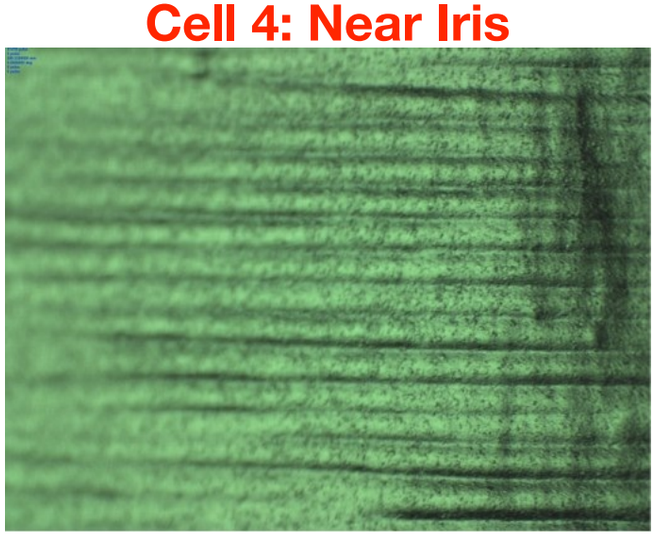


Cell 1: Near Equator



Cell 4: Near Iris

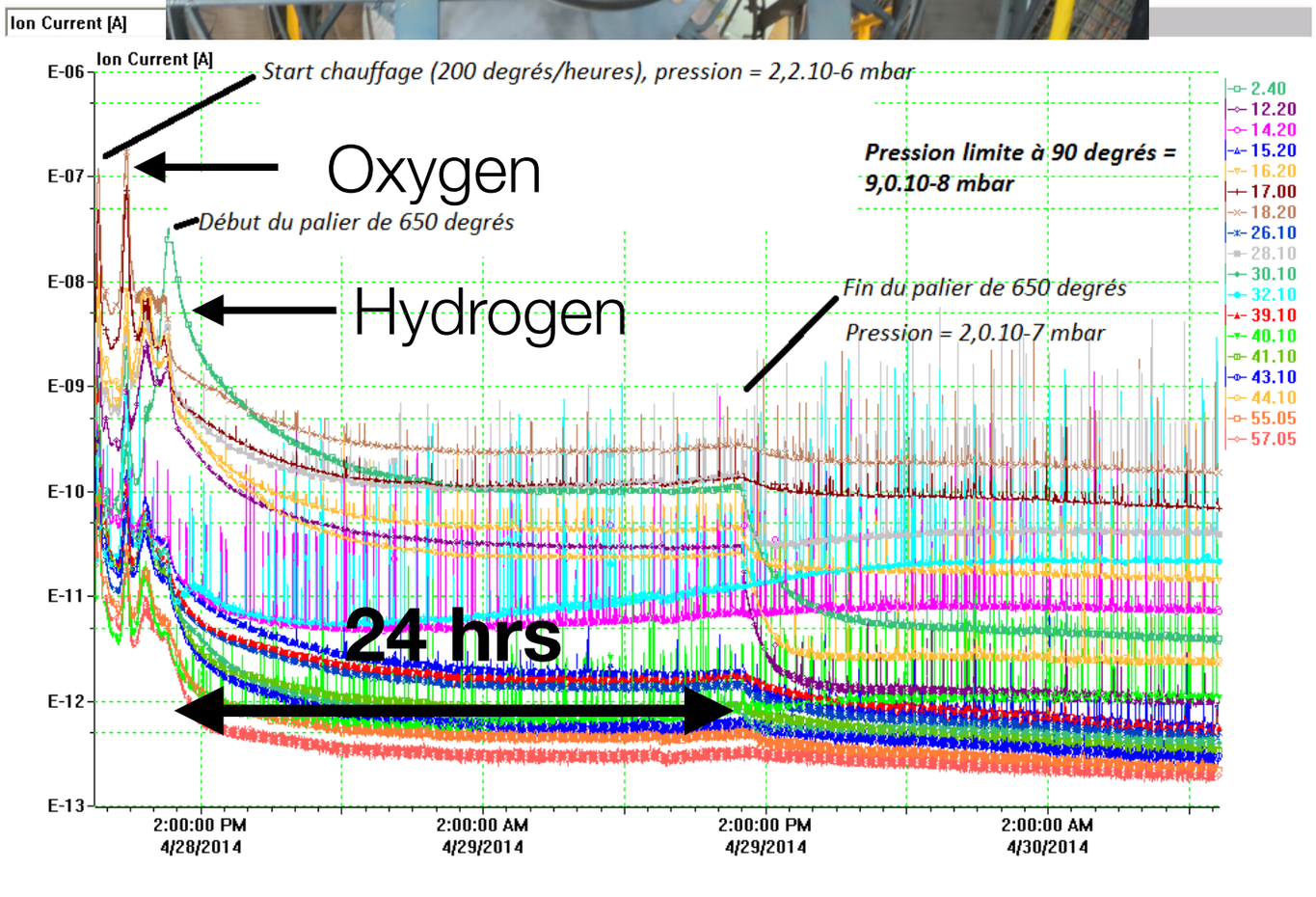


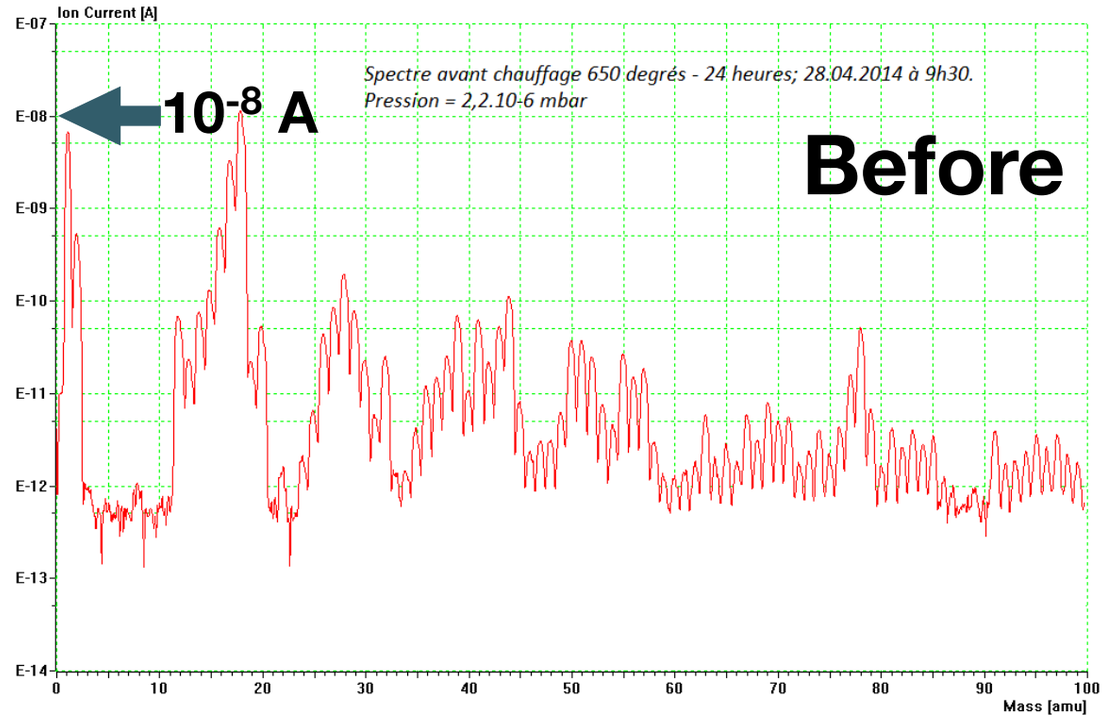
Cell 2: Middle of half cell

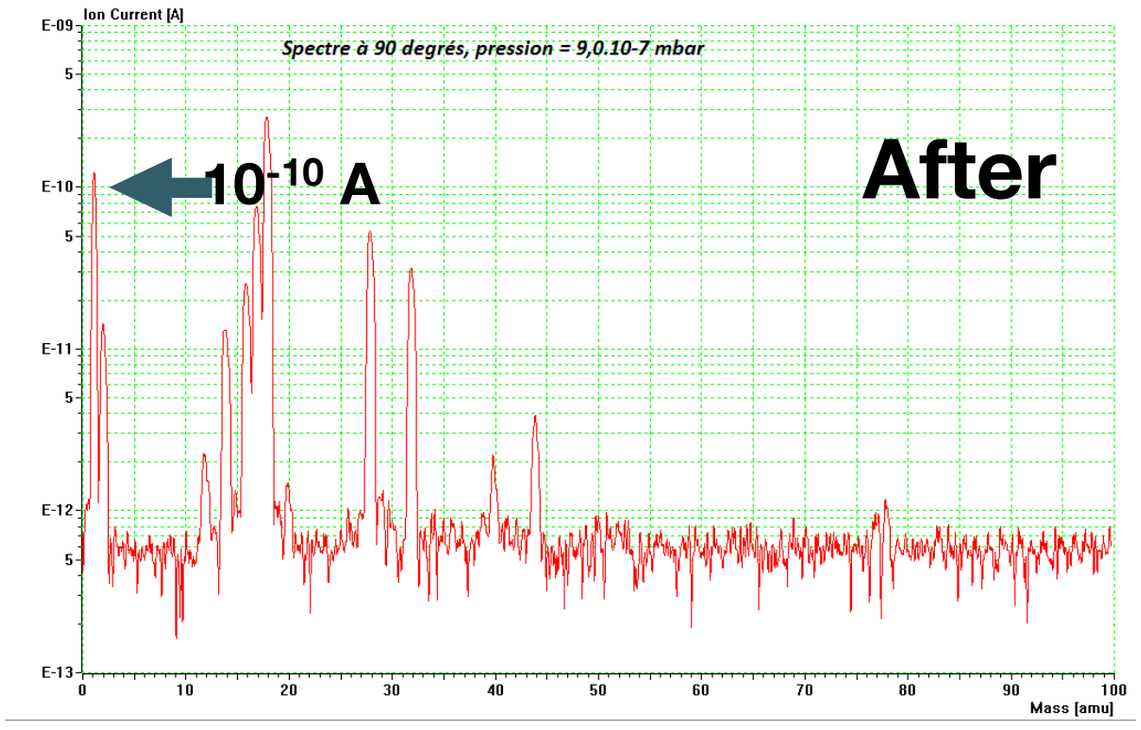
- **New features imply modification of EP program, in order to suppress them**
  - Suspicion: observed features related to vertical EP stand and size of cavity

SPL Nb 5-Cell: Thermal Treatment

- **Thermal Treatment: 650 ºC for 24hrs**







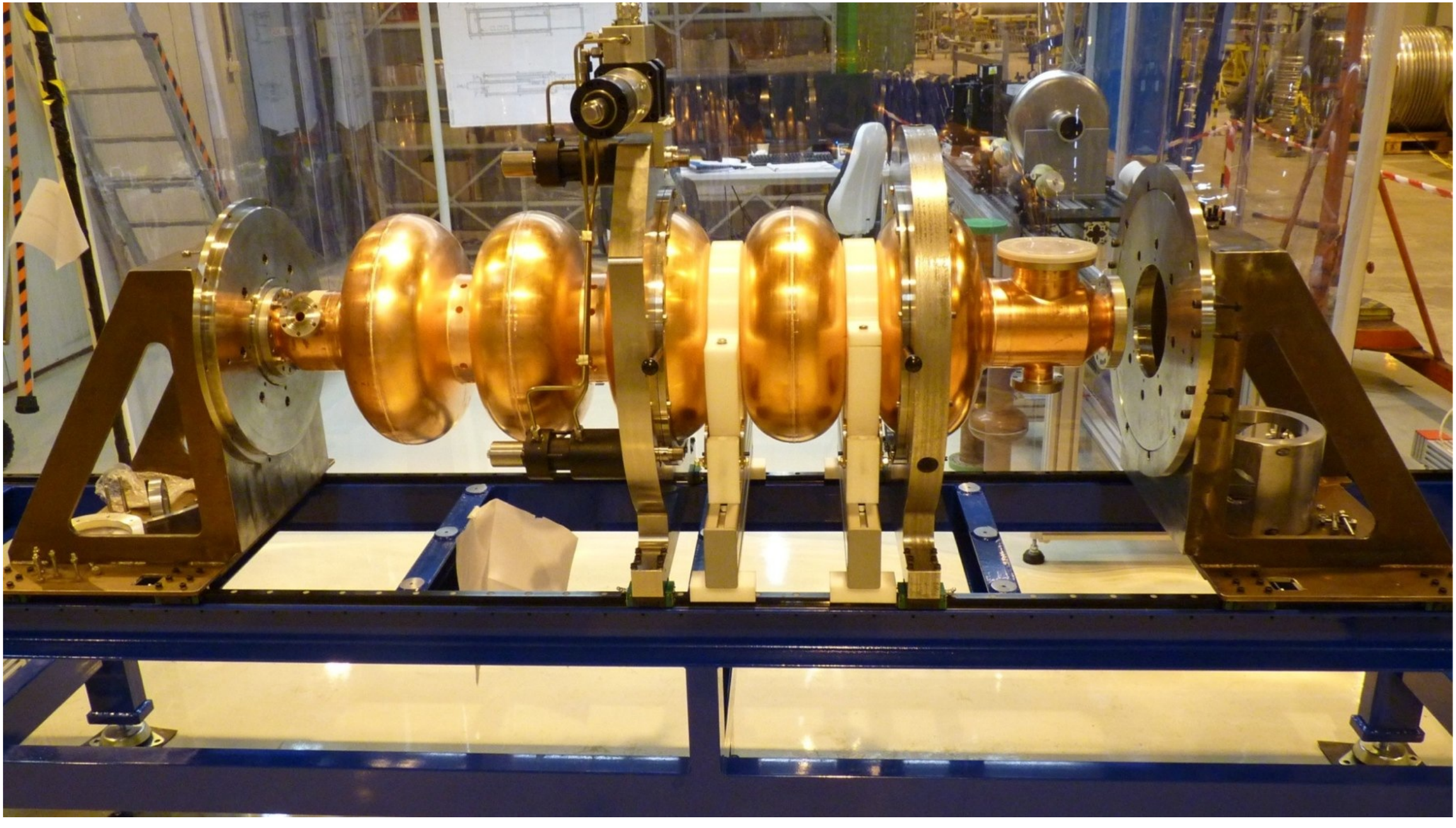
Same thermal treatment as SACLAY cavity

5-Cell Tuner Test Preparations

Tests of the Tuner starts next week

SPL Tuning Bench

- **Tuning Bench Status:**
  - Retooling required as bench could not deliver sufficient plastic deformation
  - Retooling is finishing: **Validation expected in June**



Summary Comments

- **Infrastructure for RF testing of SPL Nb 5-cell cavities is converging**
  - Realities of procedure for cavity preparation being worked out.
  - Test of SPL Nb 5-cell: **On target for cold test starting late June 2014.**

- **Technical training and technical expertise for SPL RF testing is in place**

- **SPL Monocell: An excellent test cavity**
  - Successfully used as prototype: not foreseen as a high performance cavity.
  - Cold test limited by field emission

- **SPL Nb 5-cell cavities (as received) are mostly within RF specification**

- **Electro-polishing process**
  - Attention needed regarding pinholes and “channel” features

- **Validation activities with SPL Nb cavities for tuning bench (plastic deformation) and tuner (elastic deformation) starting**