Plasma Processing R&D for SNS SRF cavities

Presented at the

Accelerator Advisory Committee Review

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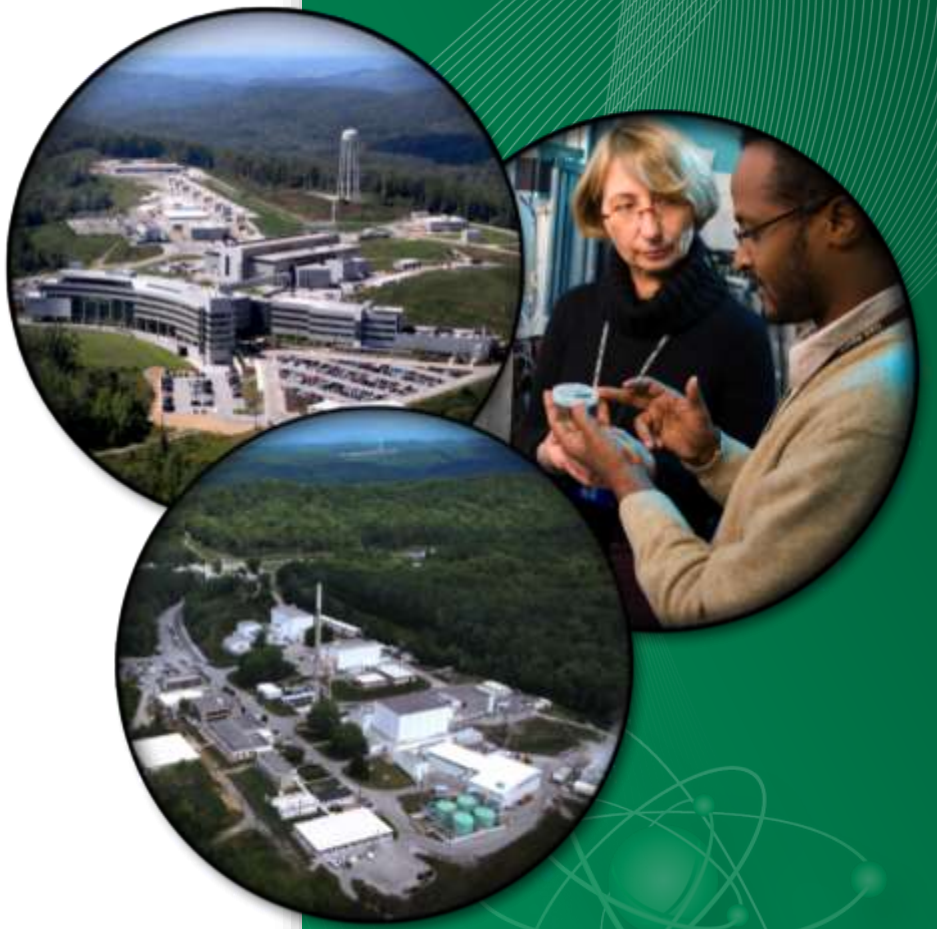
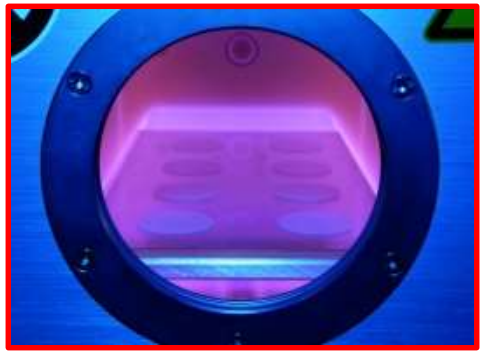


Outline

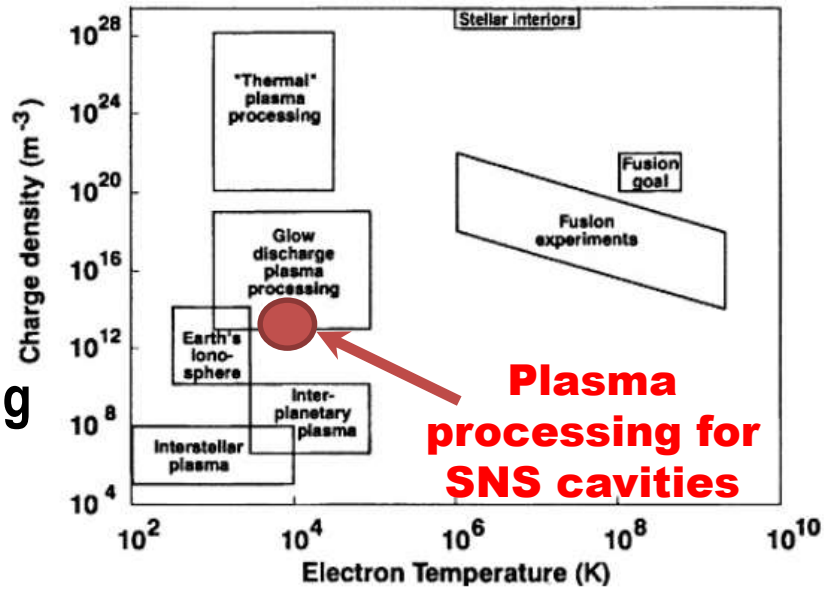
- Introduction on plasma processing and its use at the SNS
- Strategy for developing plasma processing
- Report on on-going R&D

Plasma processing and its use at SNS

- Plasma-based processes are used by many industries
  - Electronics, aerospace, automotive, biomedical….



- Plasma-surface interaction includes
  - Cleaning, deposition, activation, etching, cross-linking…
- Plasma processing at SNS
  - Develop a an in-situ plasma processing technique for SRF cryomodules



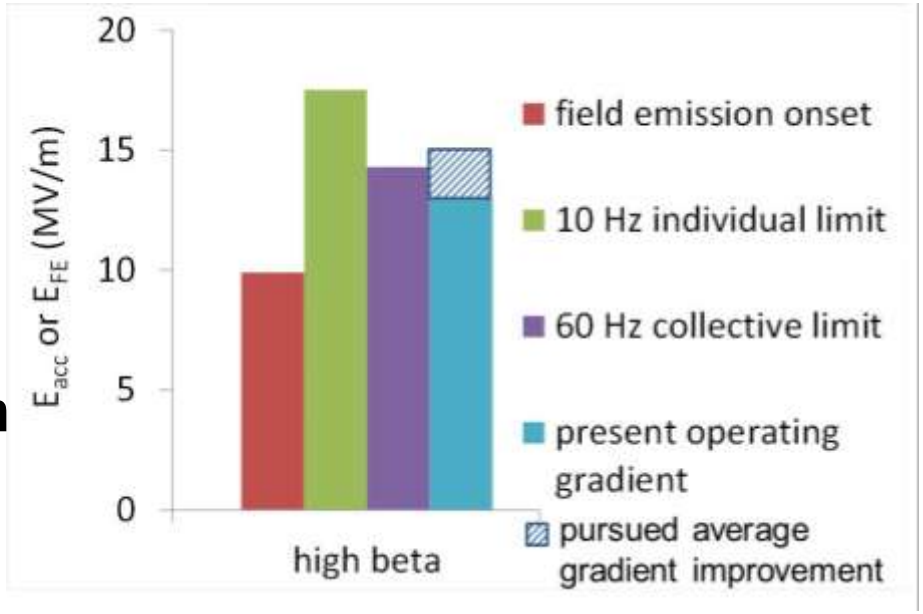
Plasma processing to reach 1 GeV

- SNS Accelerator 1.4 MW Plan *
  - Pulse length extension
  - Beam current increase
  - Beam energy increase
    - (repair damaged cryomodules, on-going effort)
    - Plasma processing R&D
    - In-situ processing of SCL RF cavities

* G. Dodson AAC 2013 for details

Pursuing a 15% increase of HB gradients

- Accelerating gradients in SNS SRF cavities mainly limited by
  - Field emission
  - Thermal Instability in end-groups
- S-h. Kim proposed in-situ plasma processing to reduce FE
  - Mild attempt of plasma processing in a cryomodule in 2009 showed promising results*



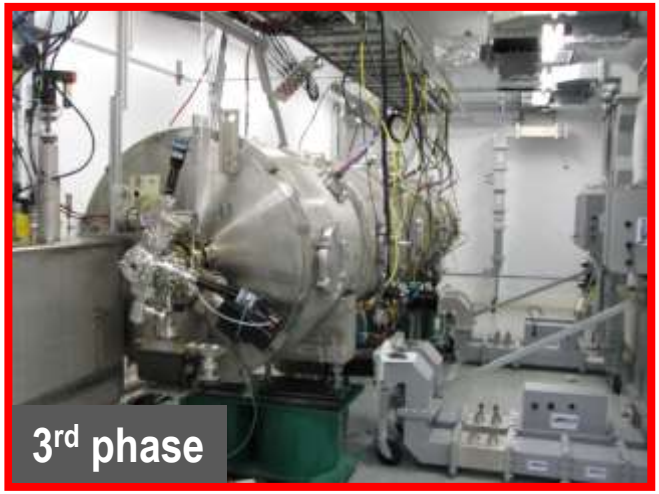
- R&D started in 2012 to develop a reliable technique for in-situ plasma processing at SNS

* S-h Kim AAC 2010

R&D to in-situ processing in 4 phases

R&D with 3-cell and 6-cell cavities

Processing of 6-cell cavity in HTA*



Processing of cryomodule in test cave

In-situ processing in linac tunnel

* Horizontal Test Apparatus

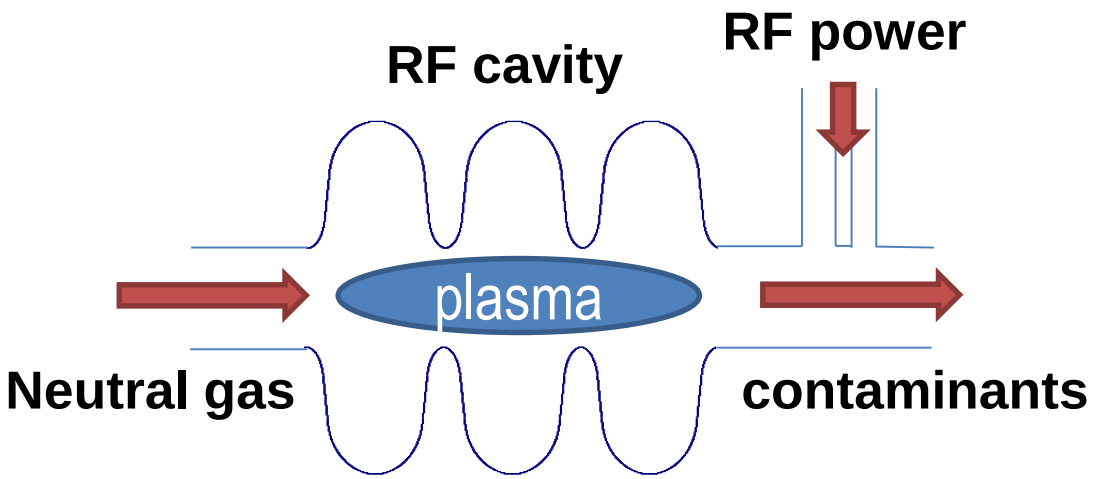
4 phases from FY12 to FY17

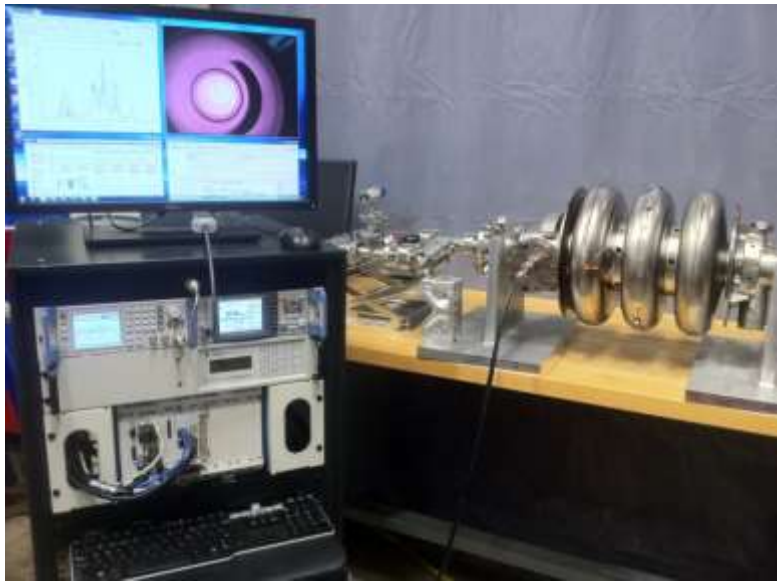
- **Progressively move from plasma processing in R&D system to in-situ processing in operating cryomodules**
  - **Leverage existing and new SRF facility***
  - **Test cave, HTA etc…**

	FY12	FY13	FY14	FY15	FY16	FY17
Plasma R&D station set-up	X					
R&D with 3-cell & 6-cell		X				
HTA set-up		X				
R&D with HTA			X			
Cryomodule set-up			X			
R&D with cryomodule				X		
in-situ processing set-up				X		
In-situ processing					X	X

*** M. Howell AAC 2013**

RF Plasma generated in SNS cavities





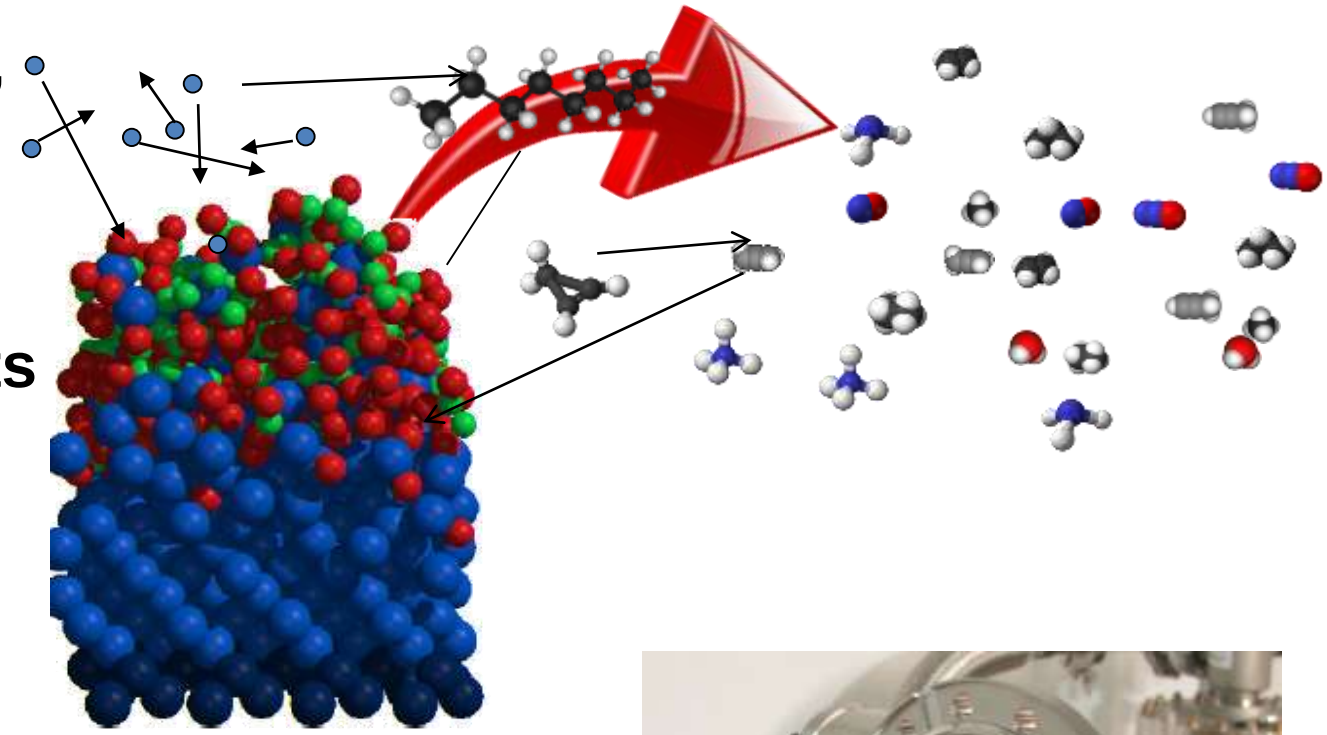
- Inject gas in cavity (~1-100 mTorr)
- Excite EM fields in cavity (~10-100s W)
  - Seed electrons reach gas ionization energy
  - Have enough ionization to sustain rf discharge
- Pump out contaminants released from cavity surface
  - e.g. residual hydrocarbons

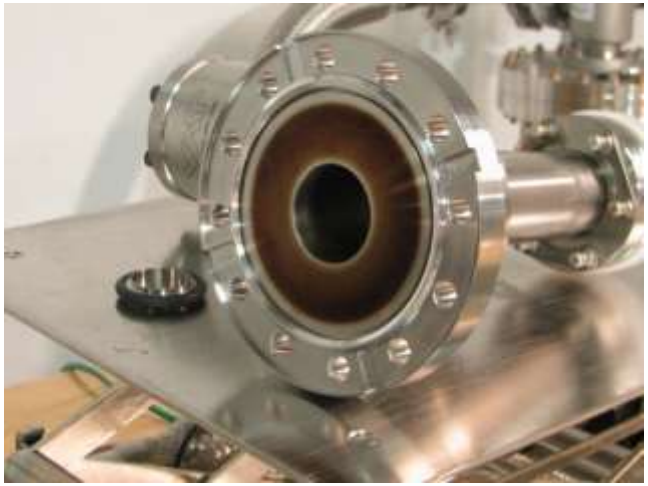
R&D to control plasma chemistry

Ions, electrons, molecules (radicals)

contaminants

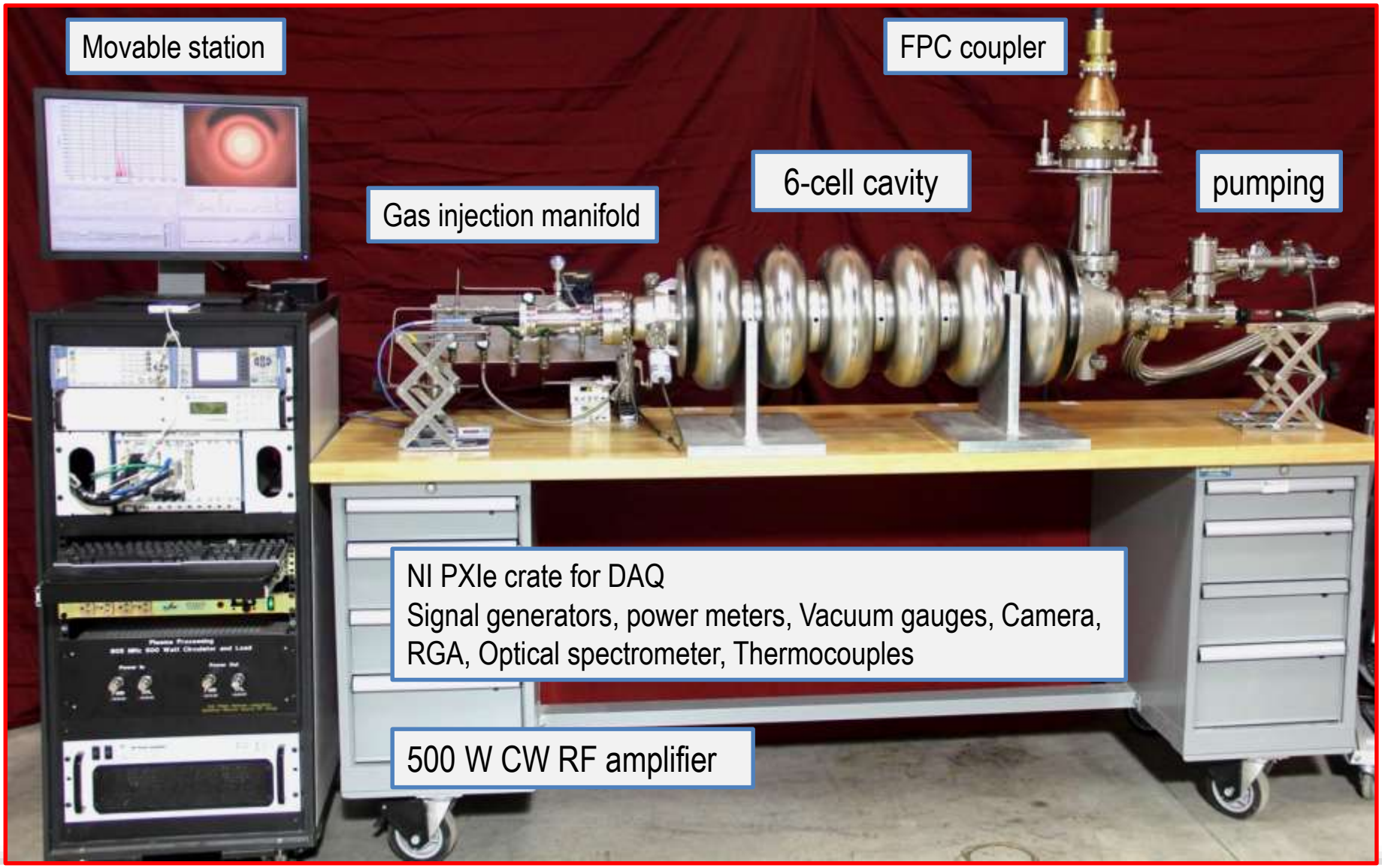
Base material



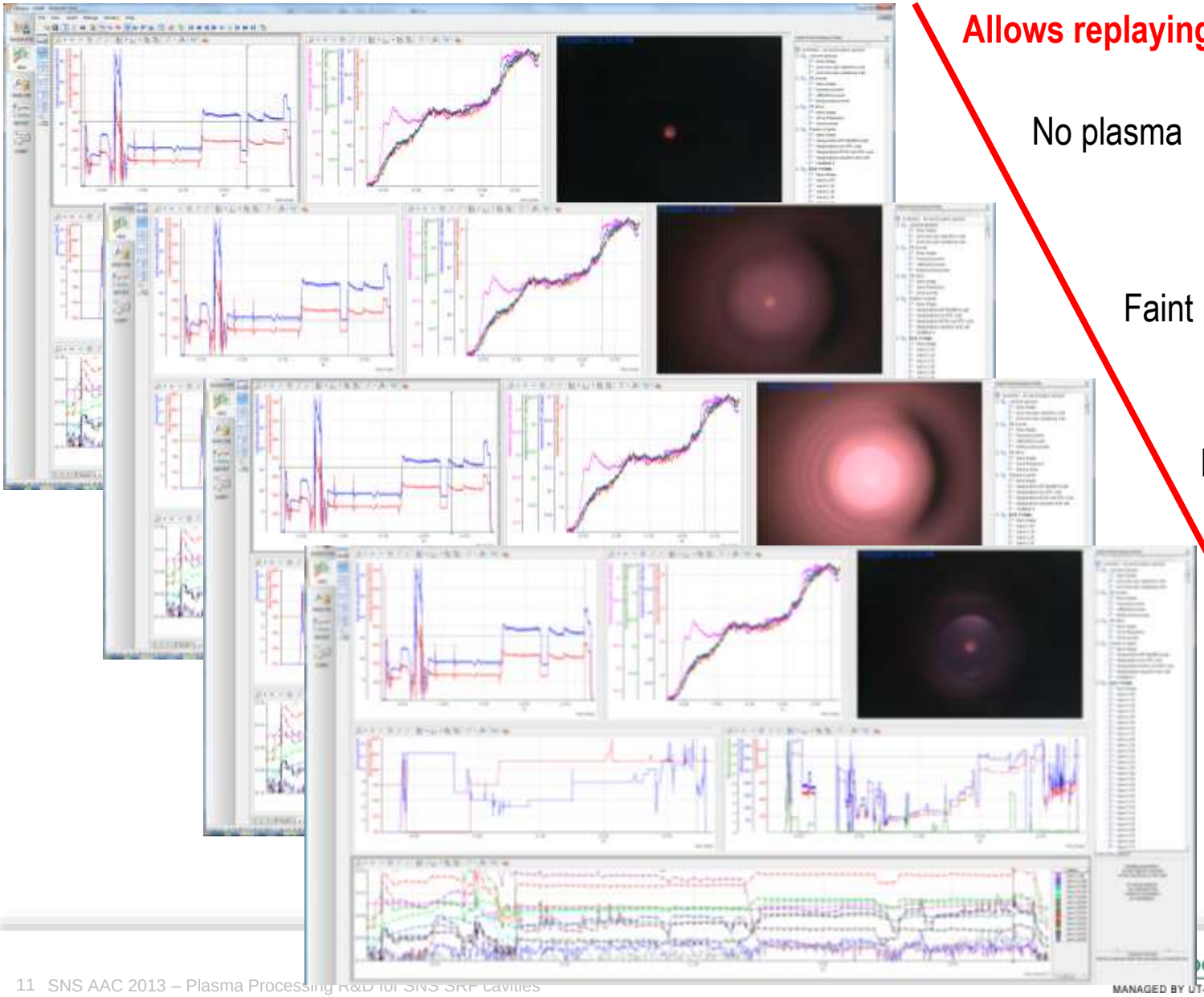


- **Plasma processing R&D**
  - **Cleaning of SRF cavity surfaces but,**
  - **Avoid possible harmful effect such as solid state byproduct and re-deposition**

Hardware development: Movable plasma processing station



Software development: Comprehensive data acquisition and postprocessing



Allows replaying through time

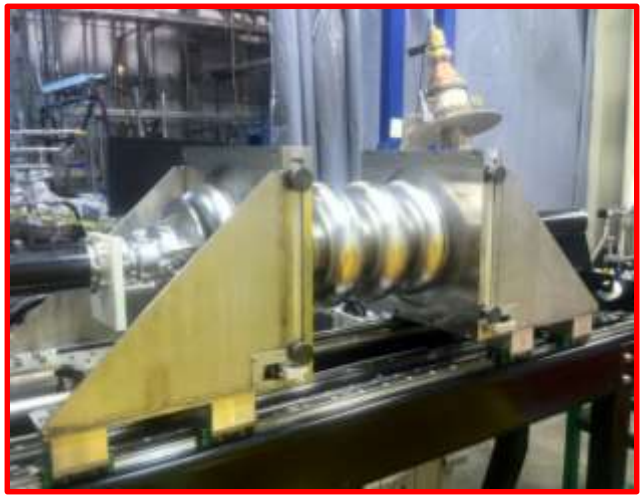
No plasma

Faint plasma in cavity

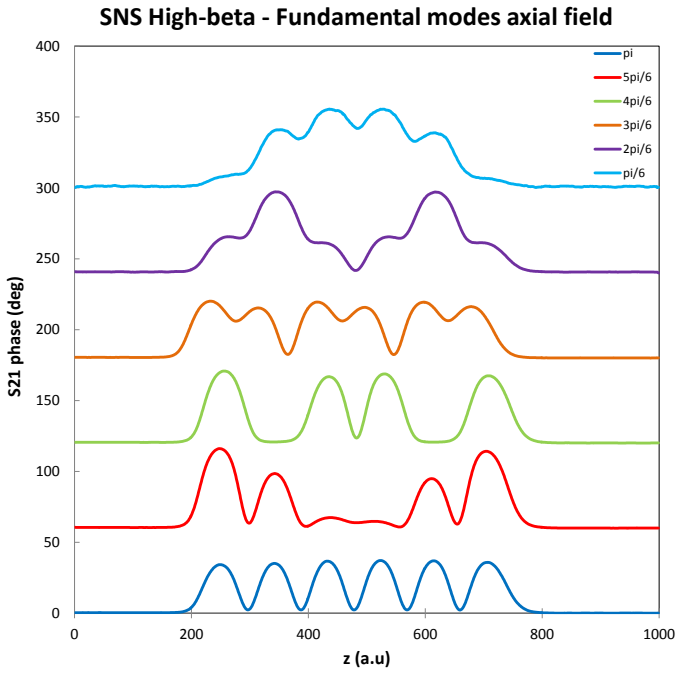
Bright plasma in cavity

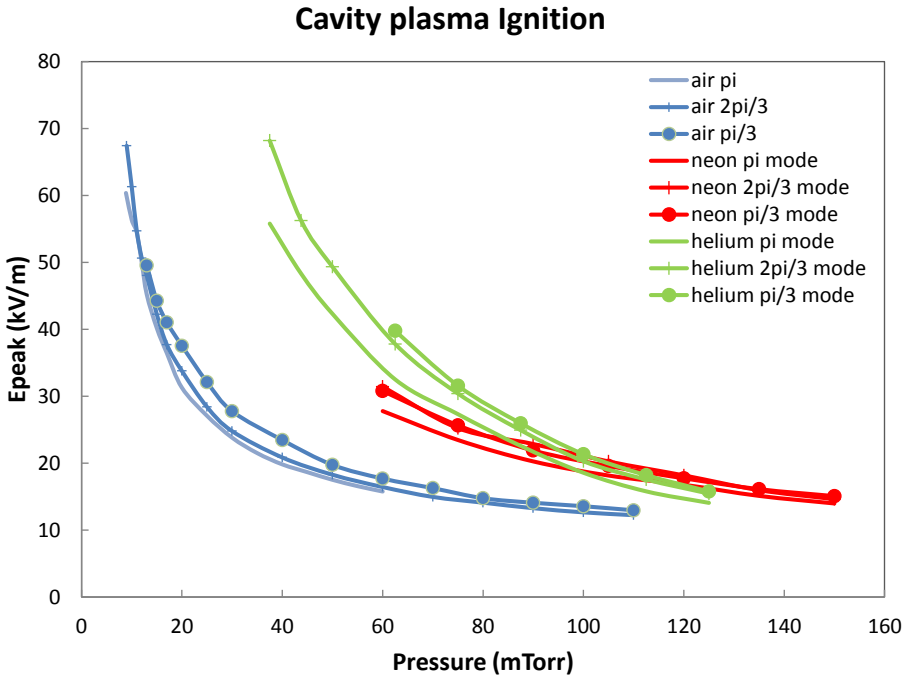
Plasma in power coupler

Plasma ignition using different modes



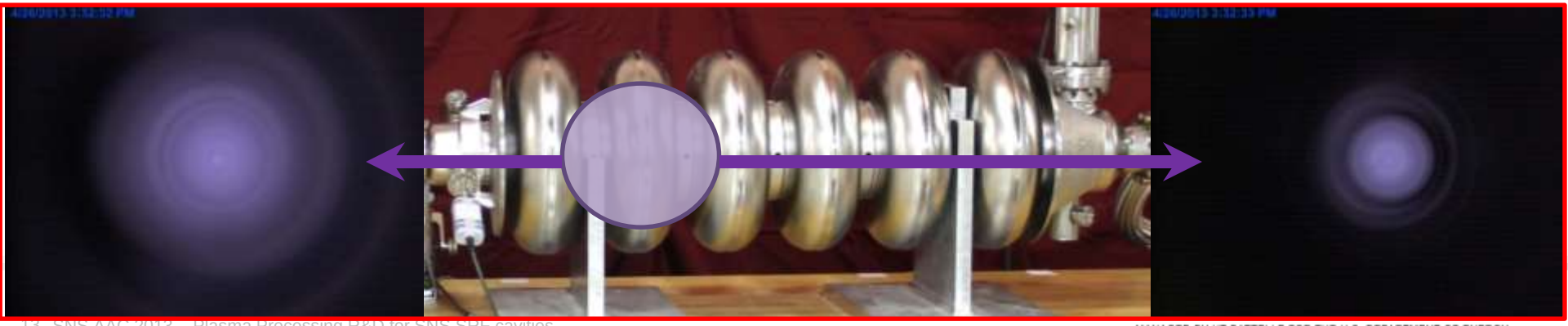
- 6 pass band modes can be used for generating a plasma
- Field at ignition depends on the gas specie and pressure
- The location of plasma ignition in the cavity depends on the mode field profile





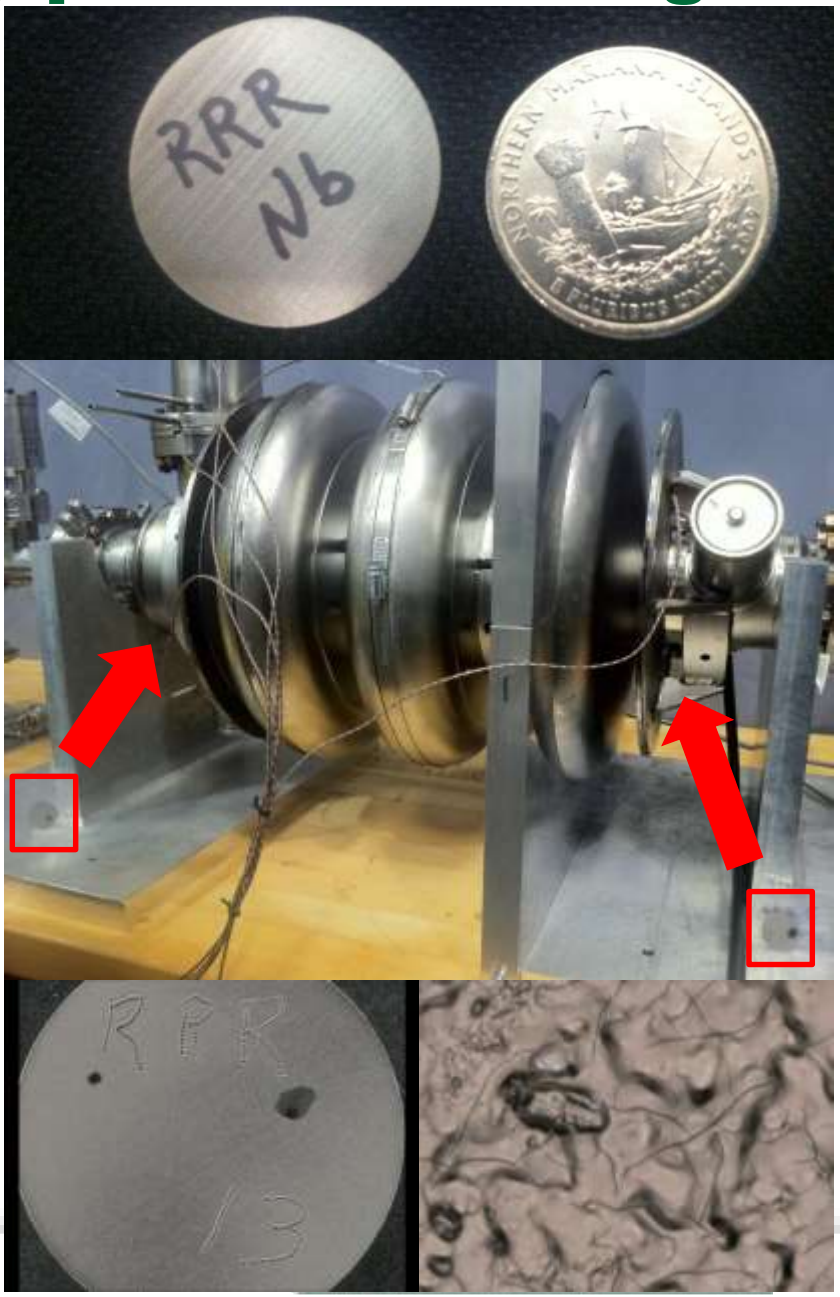
Plasma generation in a multicell cavity

- In SNS 6-cell cavities the plasma tends to ignite in discrete cells
- Need to optimize procedure to be capable of processing the entire cavity surface
  - Plasma tuning, multiple mode excitation, and/or sequence of single-mode excitations are being investigated



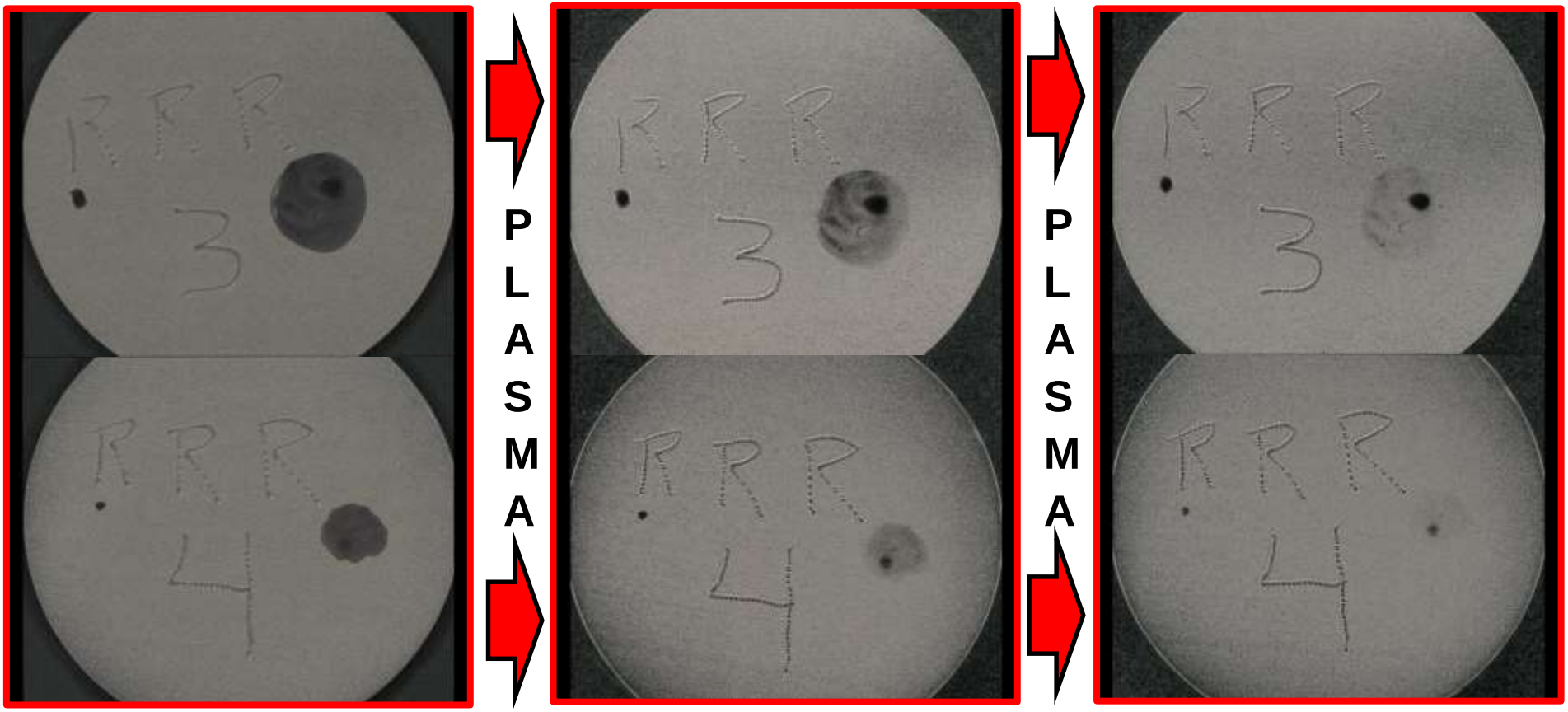
Niobium samples to study plasma cleaning

- Used quarter-size Niobium samples in 3-cell cavity
- Purposefully contaminated samples
  - Hydrocarbon chains
  - Very large contamination compared to the residual contamination in operating cavities
- Introduce samples into cavity to undergo plasma processing
- Detailed analysis of samples before and after plasma processing
- 10-20 mTorr air plasma showed promising results to clean contaminated samples
  - Other gas mixtures (e.g. H and noble gas) are also being investigated



First evidence of plasma cleaning

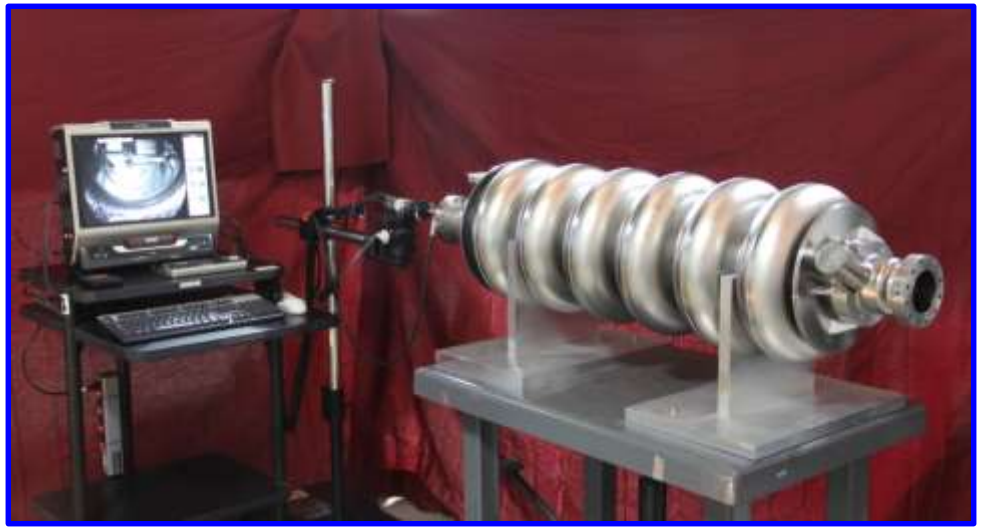
- Plasma processing with air successfully removes hydrocarbon contamination
- Samples at both end of the 3-cell cavity show similar response to processing

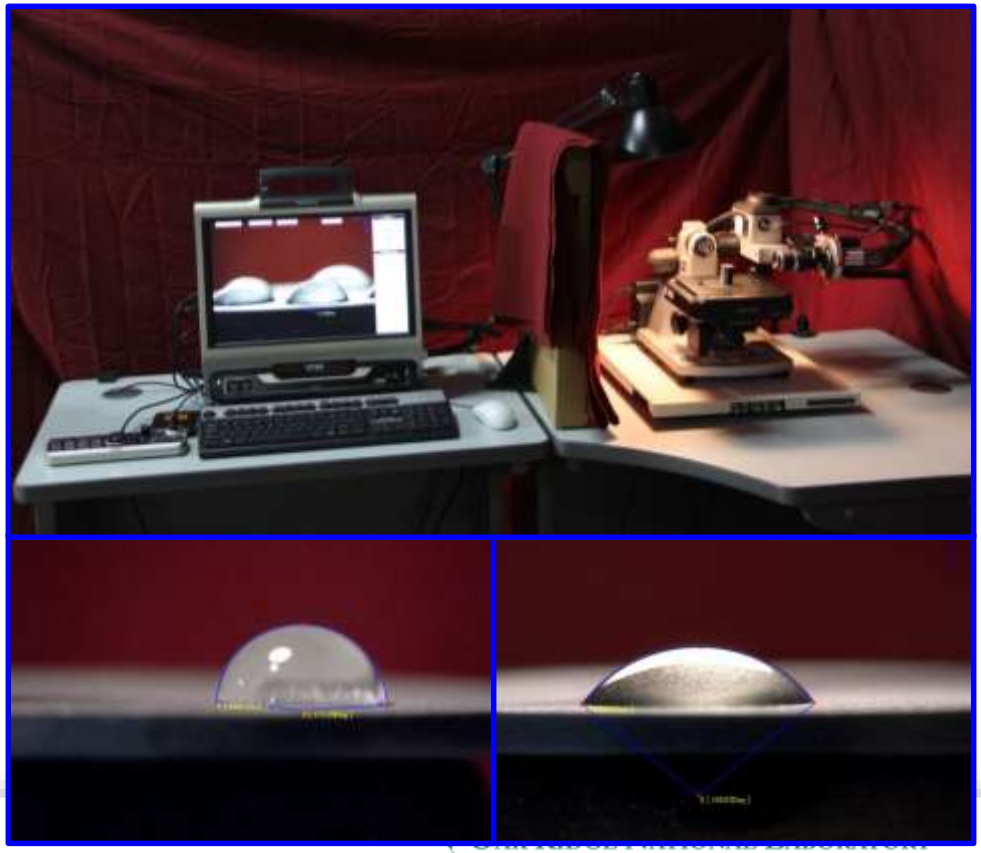


- Different types of contaminants are being investigated (e.g. oil, oxide layer…)
- Similar studies started in 6-cell cavities

Surface cleanliness characterization for R&D

- Rapid assessment of the niobium surface cleanliness is key during R&D
  - Direct imaging of Niobium samples using digital microscope when suitable
  - Imaging of cavity surface using borescope to monitor re-deposition of contaminants
  - Contact angle measurement of Niobium before and after plasma processing
  - Infrared spectroscopy for rapid evaluation of molecular contamination of Niobium samples





Preparing for phase 2 and cold test (FY 14)

- HTA and HB 59 preparation
  - Helium vessel welding on HB59 cavity completed
  - HTA to host HB59 for cold test is at vendor
  - Plasma processing and cold tests of HB59 are planned for FY14

Conclusion

- In-situ plasma processing technique for HB cavities is being developed at SNS and is part of plan to reach1.4 MW
- Four progressive phases from R&D on bare cavities to in-situ processing of cryomodules to optimize the new technique and minimize potential risks
- Phase 1 is on-going and shows promising results
- Preparation for phase 2 is on-going and cold tests are planned for FY14
- Deployment of the technique in SC linac is planned for FY16 and FY17