R&D status for in-situ plasma surface cleaning of SRF cavities at SNS

PAC11, New York
March 31, 2011

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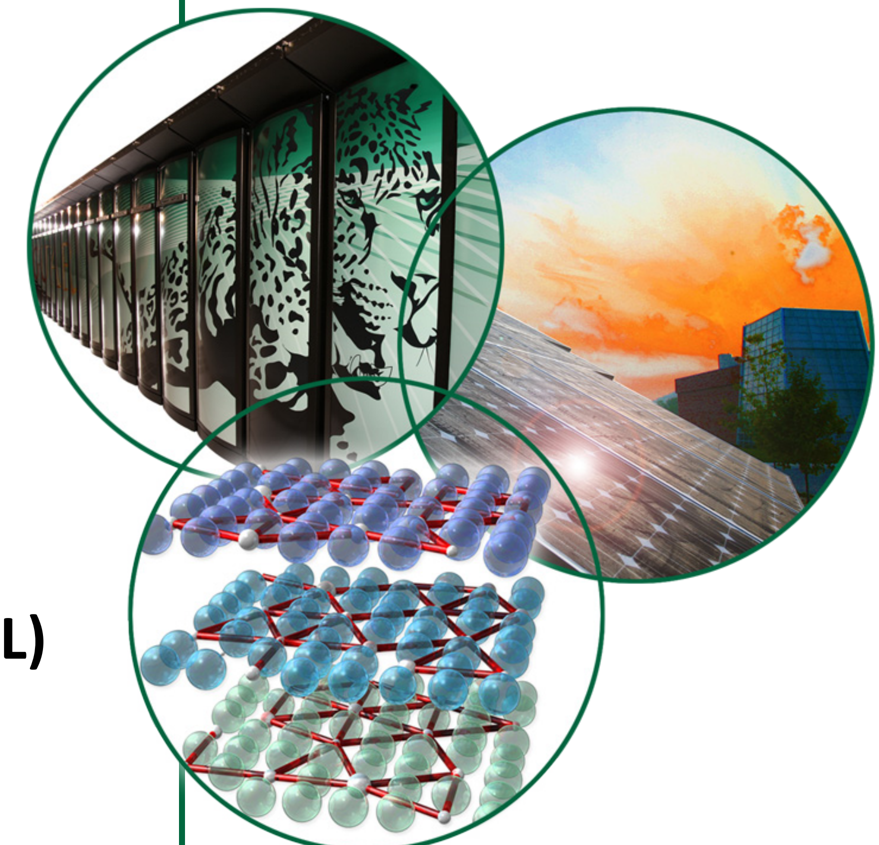

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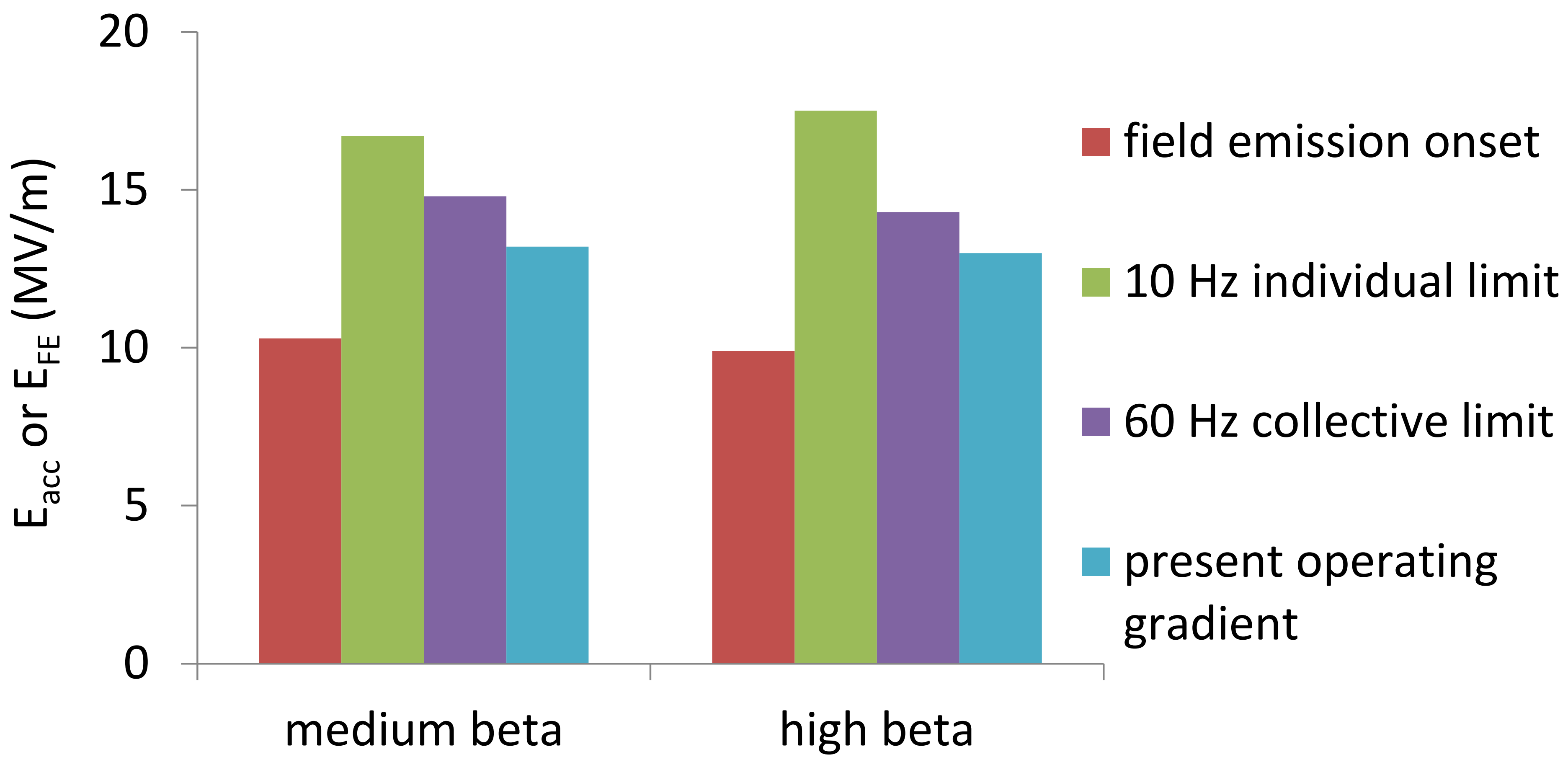
Motivation for in-situ processing

- Medium term
  - Reach 1GeV + energy reserve
  - Increase high beta cavity gradients by about 2 MV/m in average
- Long term
  - 42-mA beam loading with 2nd target station
  - Efficient utilization of RF power: ideally constant RF power/cavity is preferred → narrower performance scattering
- Develop a cost effective method with minimal impact on machine operation

SNS SRF cavity performance statistics

- **Electron loadings (mainly field emission)**
  - **Collective effects**
  - **Thermal instability at the end group**



- **Field emission**
  - **Not a fundamental limit in theory but the major limitation in multi-cell cavities in high-duty operational machines.**
  - **Performance scattering.**
- **Contamination**
  - **Contaminants entered during processing/assembly**
  - **Enhancement of field emission with condensed/ absorbed gases and/or oxide layer/boundary layer**
  - **Locations of field emitters are random/statistical**
- **Field emitter processing characteristics**
  - **may change over time, possibly harder after conditioning/commissioning**

  Ex. Clear improvement at an initial He-processed cavity in VTA

Helium vs. Plasma processing

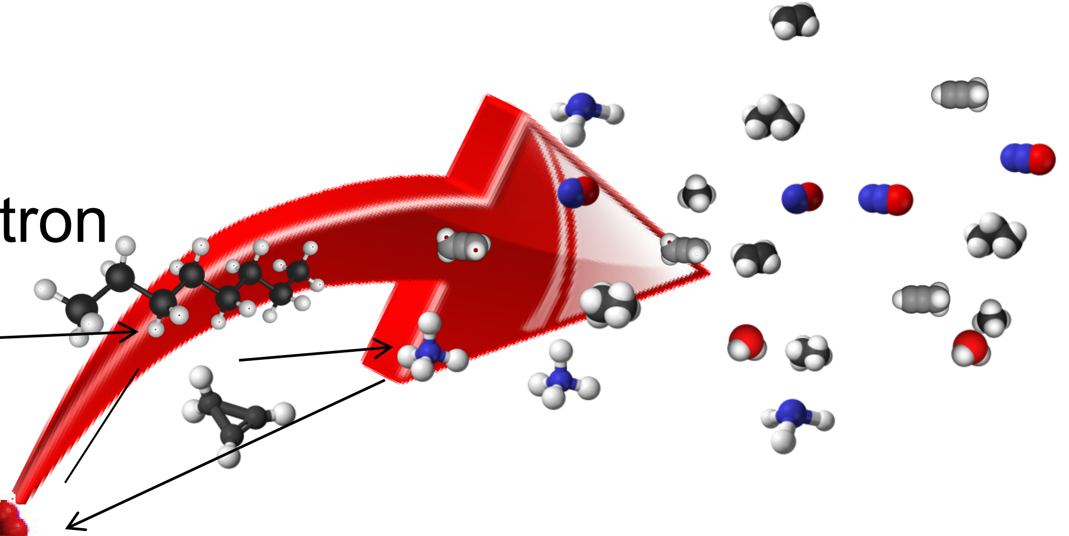
- **He-processing**
  - high gradient, high energy electron (FE), no space plasma,
  - Few statistics on in-situ helium processing at Ea> 10 MV/m
  - No in-situ experience in pulsed mode w/ Couplers
- **Plasma cleaning**
  - low voltage glow discharge, low energy electron, space plasma & radical
  - Lack of experiences w/ SRF cavities
  - Routine & major cleaning method in semi-conductor industry, some of fusion devices and vacuum devices

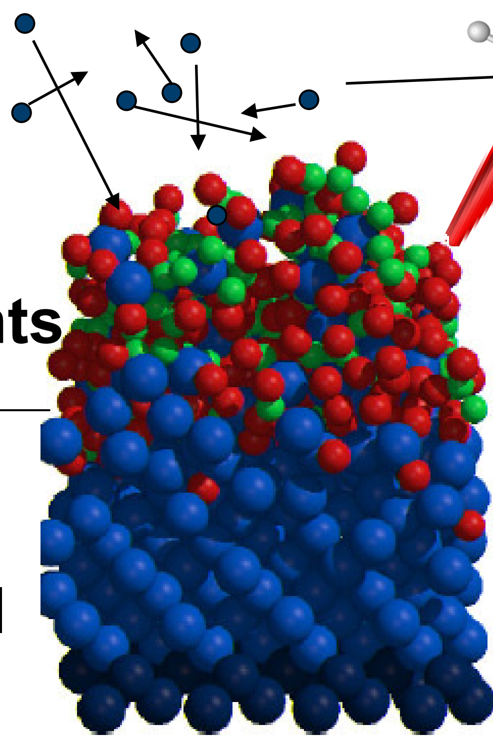
Helium processing with H01

- H01: worst performing CM. Largest x-rays
  - Lowest operating gradients (~10 MV/m or less for operation) limited by field emission
- Tried with cavity A in H01
- Helium processing is not adequate for SNS CM
  - Initial Start-up; Showed about same behavior as baseline → at ~9MV/m quench (end group)
  - Both Thermal Diodes (TDs) on HOMA and HOMB showed spikes up to 8K
  - Ended at ~8 MV/m after several hours of trials
  - Aggressive MP at HOM couplers → stop helium processing

Plasma cleaning

Ion, molecule (radical), electron



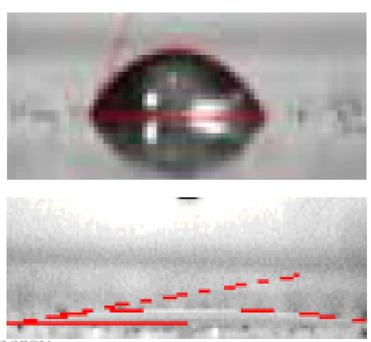


contaminants

Base material

- **Cleaning**
  - **Soft**
  - **hard**
- **Activation**
- **Crosslinking**
- **Deposition**
- **Etching**

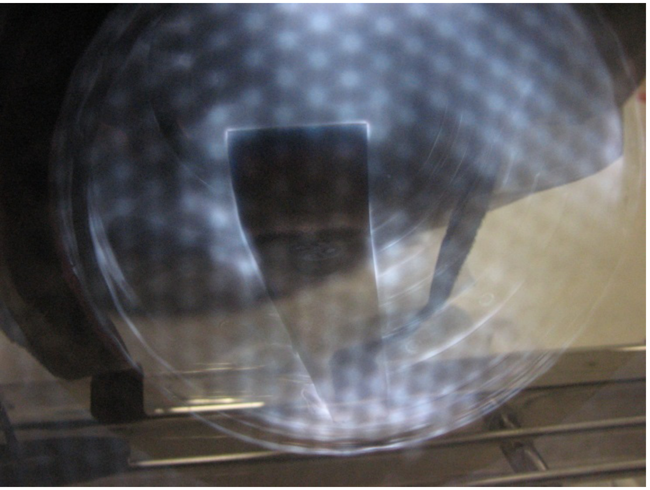
wettability

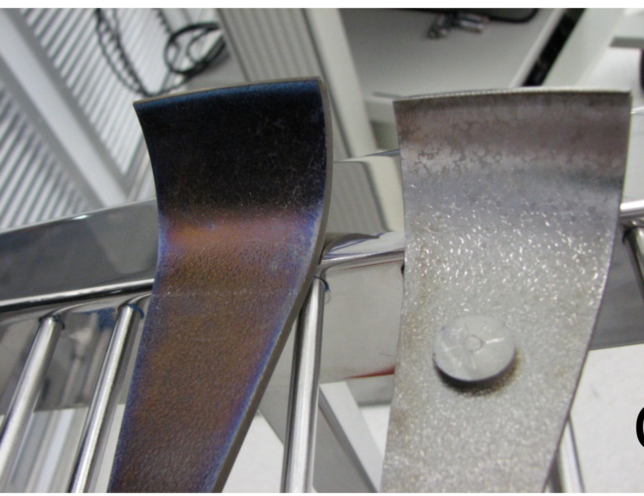


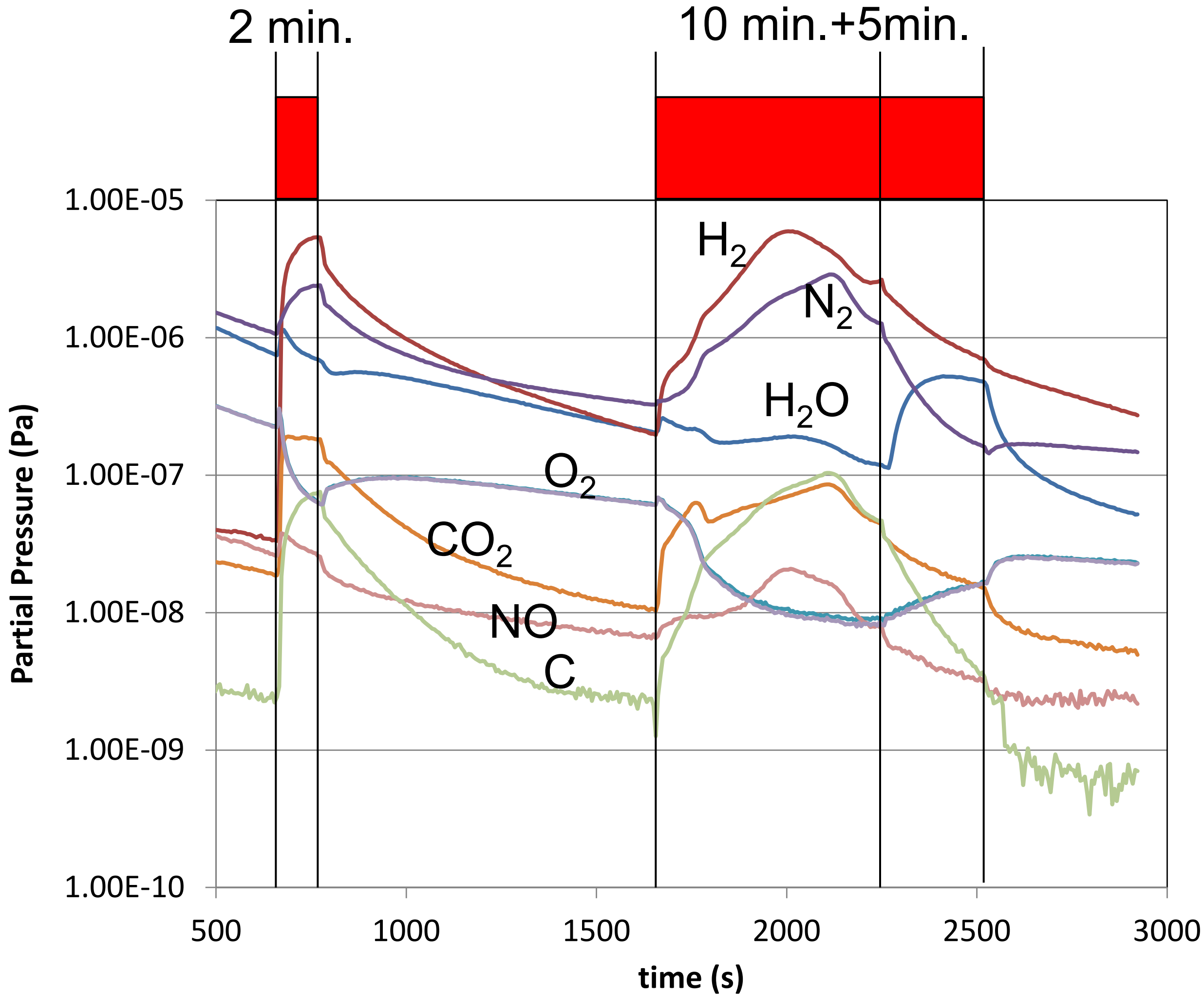
before

after

Preliminary experiment





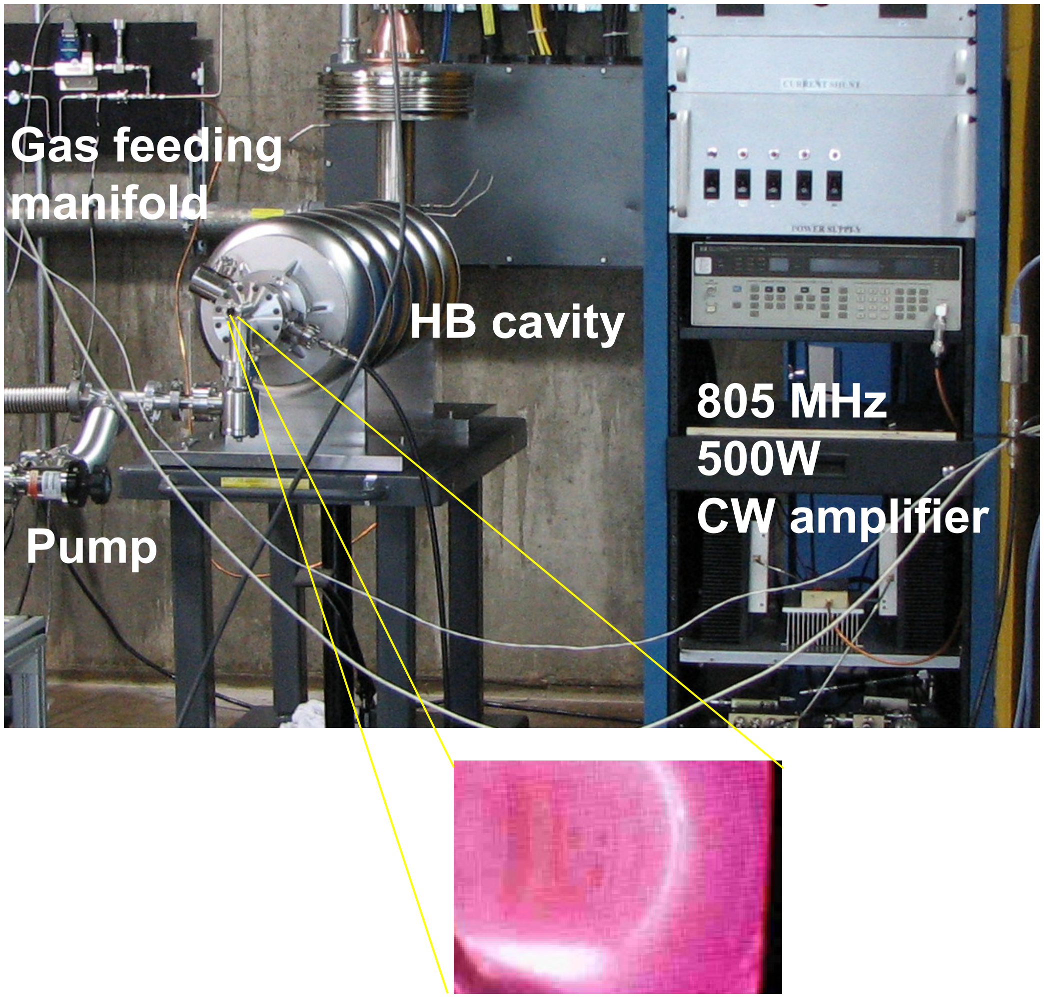


Complete removal of carbon/oxide layer

+Removal of absorbed/trapped (H2, H2O)

+Some effect similar with baking

Preliminary experiment for plasma generation in the SNS cavity

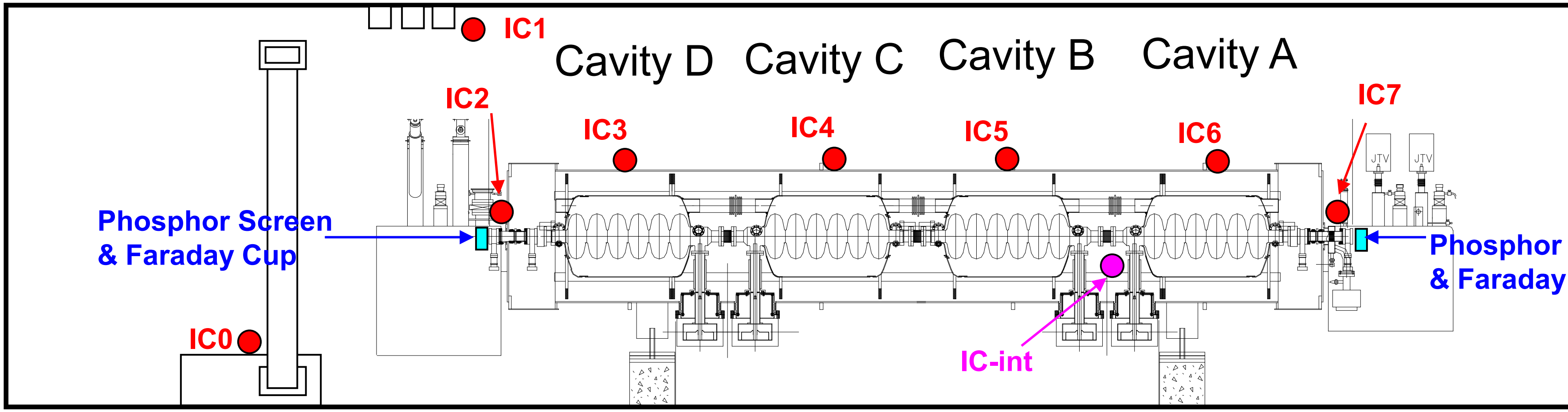


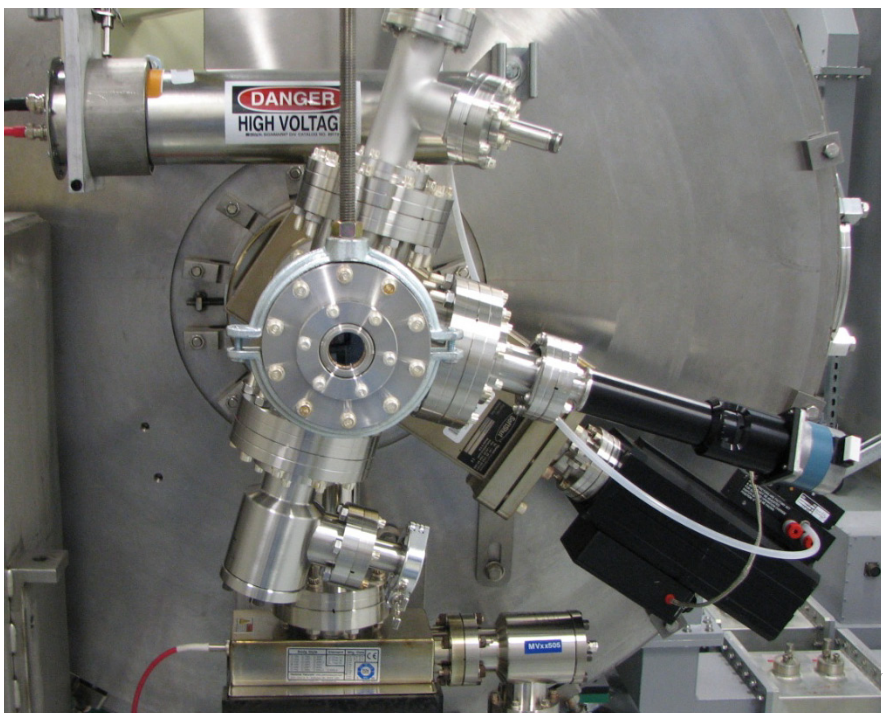
300W forward
200W reflected
1e-4 torr

Plasma processing with H01 test (First Attempt)

- Investigate possible in-situ processing
- The First attempt for the SNS cryomodules
  - No optimization studies
  - Explore the possibility
  - Comparisons of radiation before and after processing
- Very mild attempt
- Some unknowns
  - Copper damage (FPC, HOM feedthrough)?
  - Coupler window coating?
  - Unknown solid-state byproducts?

Radiation/electron activity diagnostics in the Test Cave

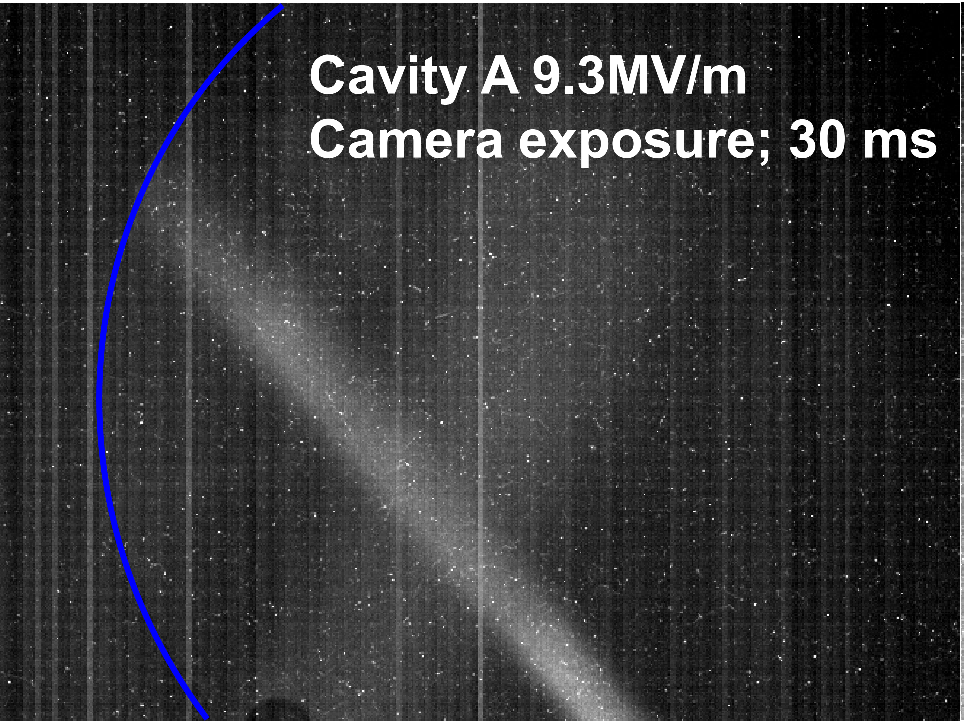


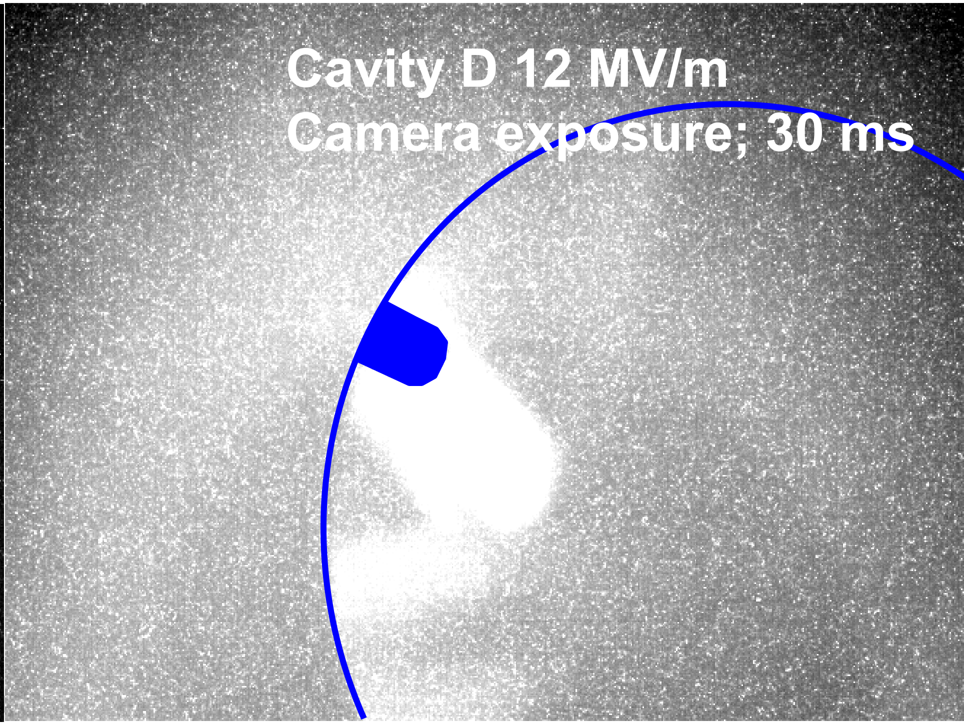


- Ionization Chamber
- Internal Ionization Chamber
- Phosphor Screen, Camera, Faraday Cup

H01 baseline test in the Test Cave

- All four cavities showed large amount radiations (onset ~6MV/m)





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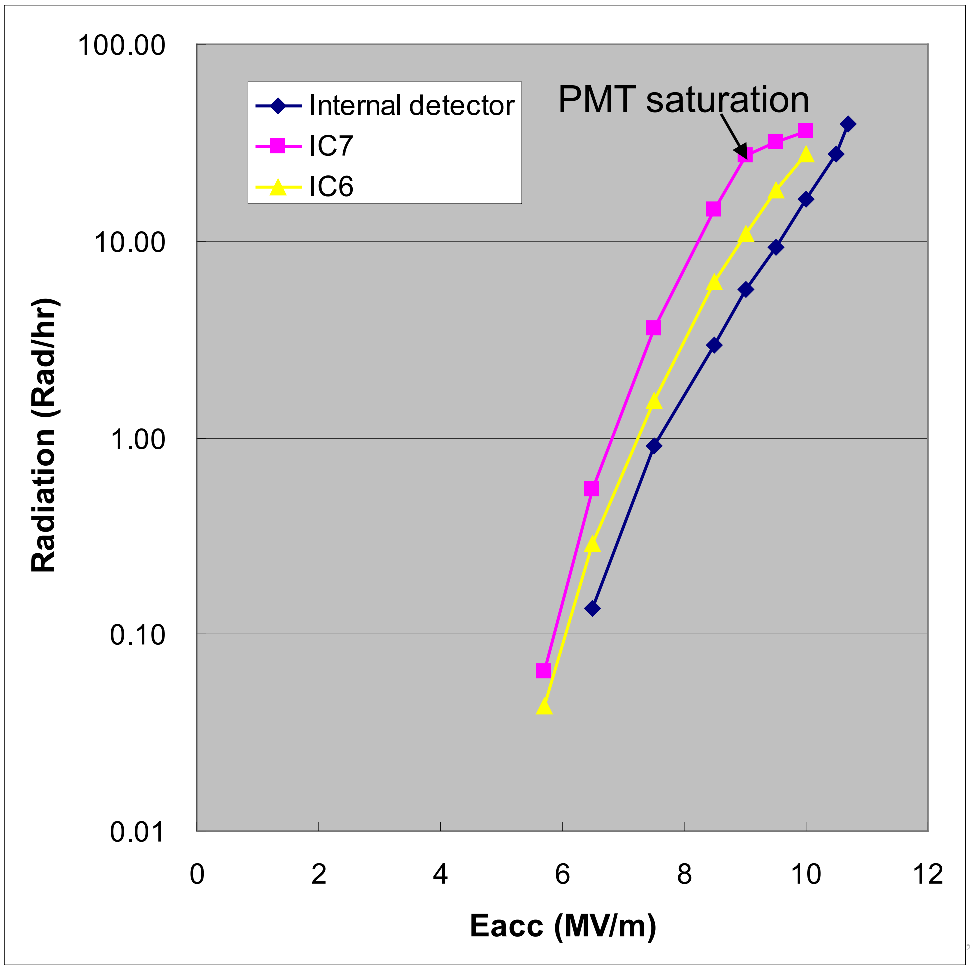
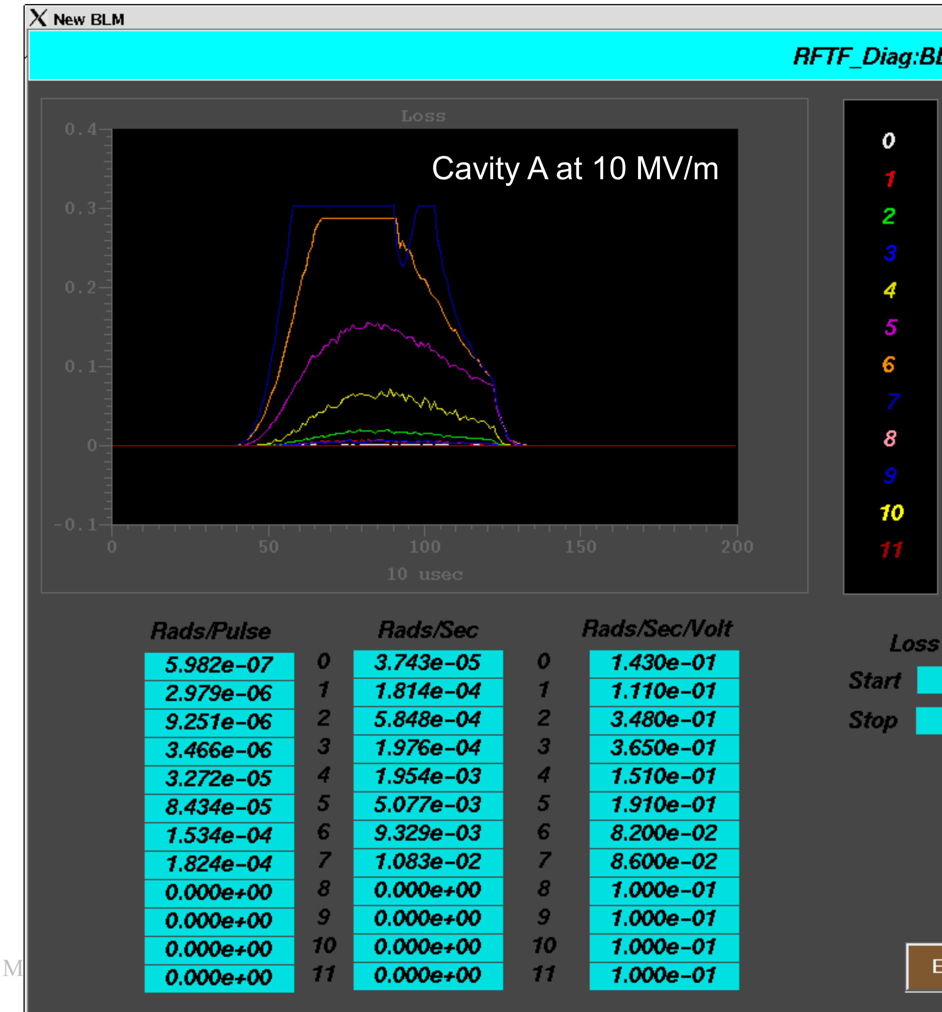
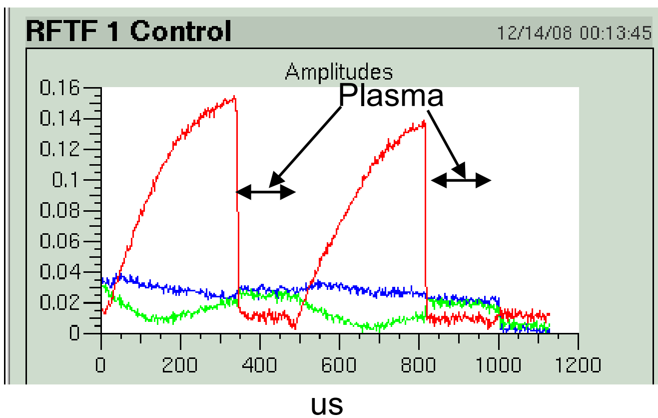
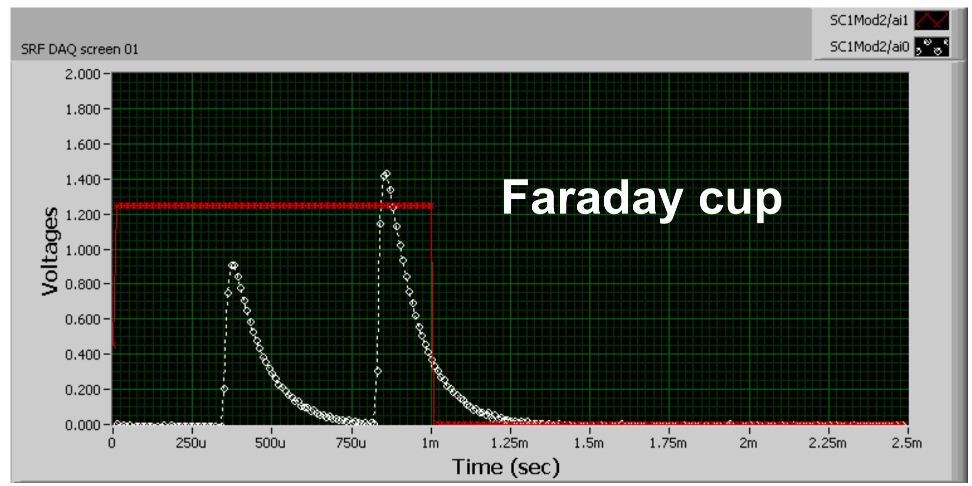


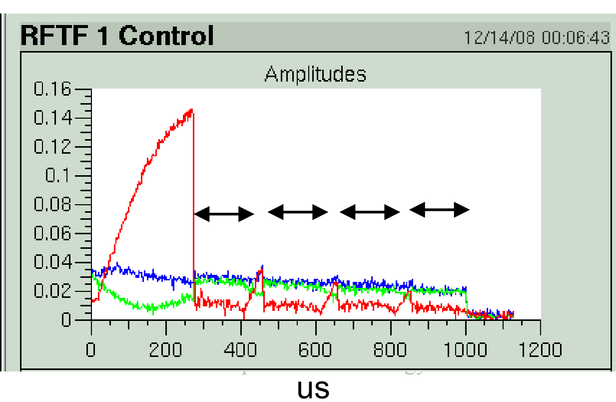


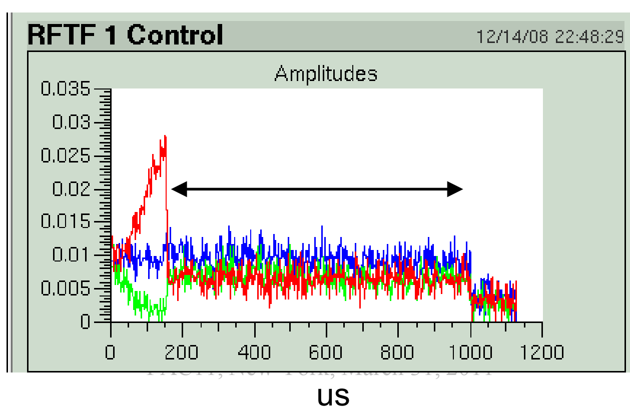
Plasma Processing

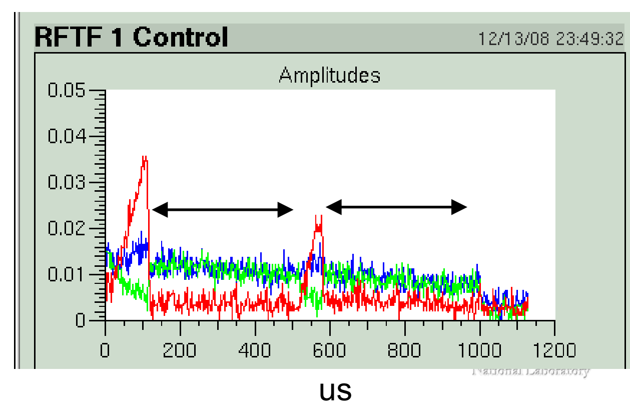
- **Very mild attempt; 10-20 W forward power, 60 Hz, 1-ms pulse at 4K, 1e-4 torr with helium gas**
- **Performed processing on 3 out of 4 cavities for < 5 min.**







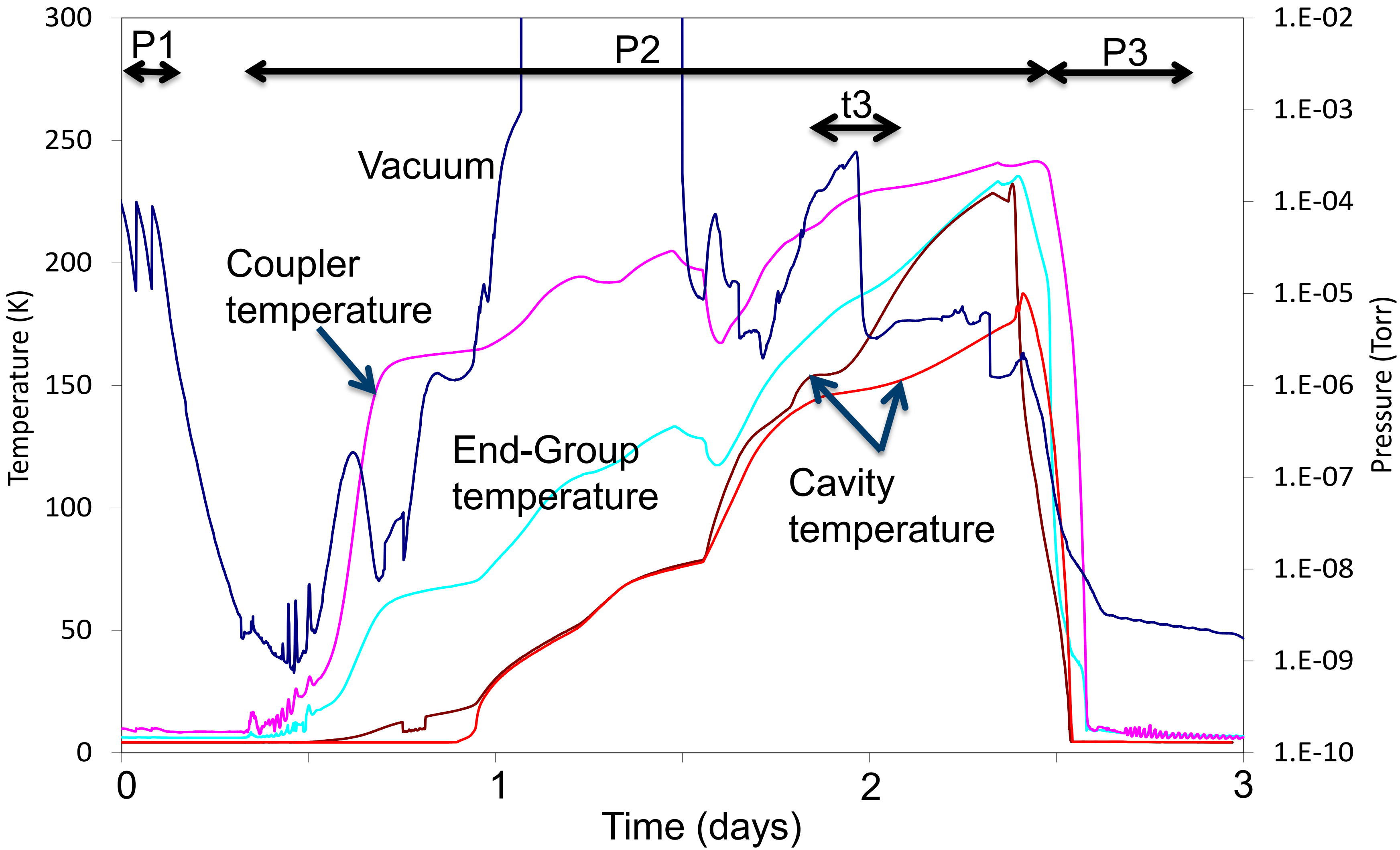




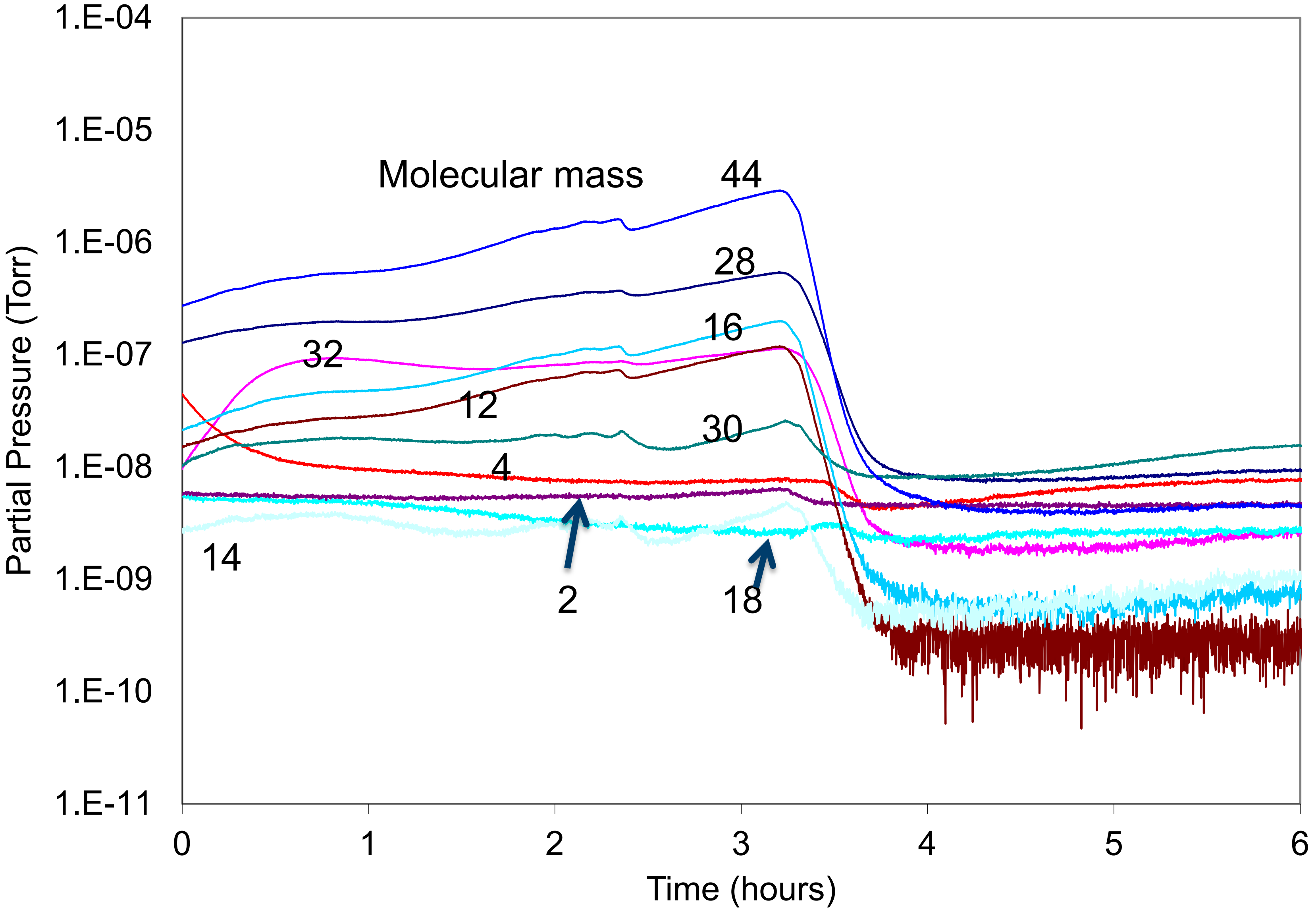
Partial warm history after processing

Much bigger amount of gases than normal warm-up (lots of H2, O2 and hydro-carbons)

Continued until 150 C



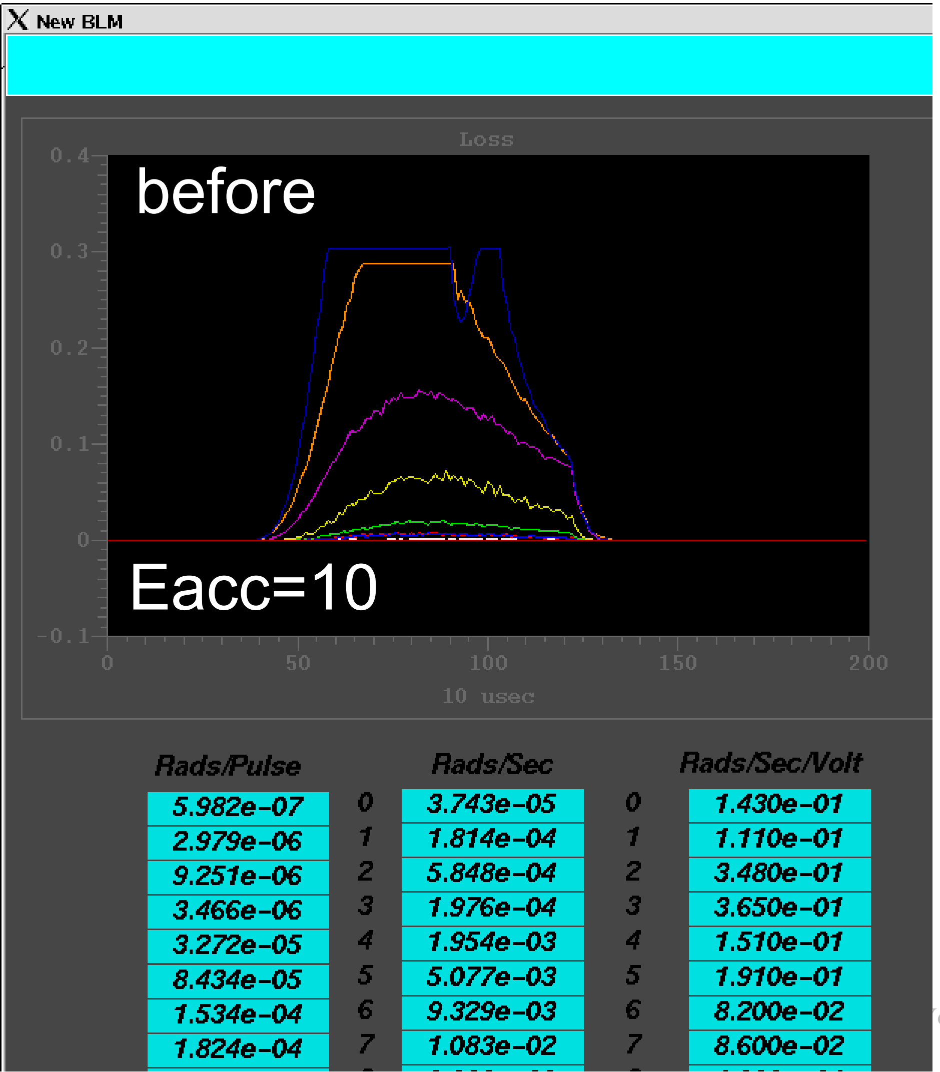
Hydro carbon (44) and its fragments at around 150 C

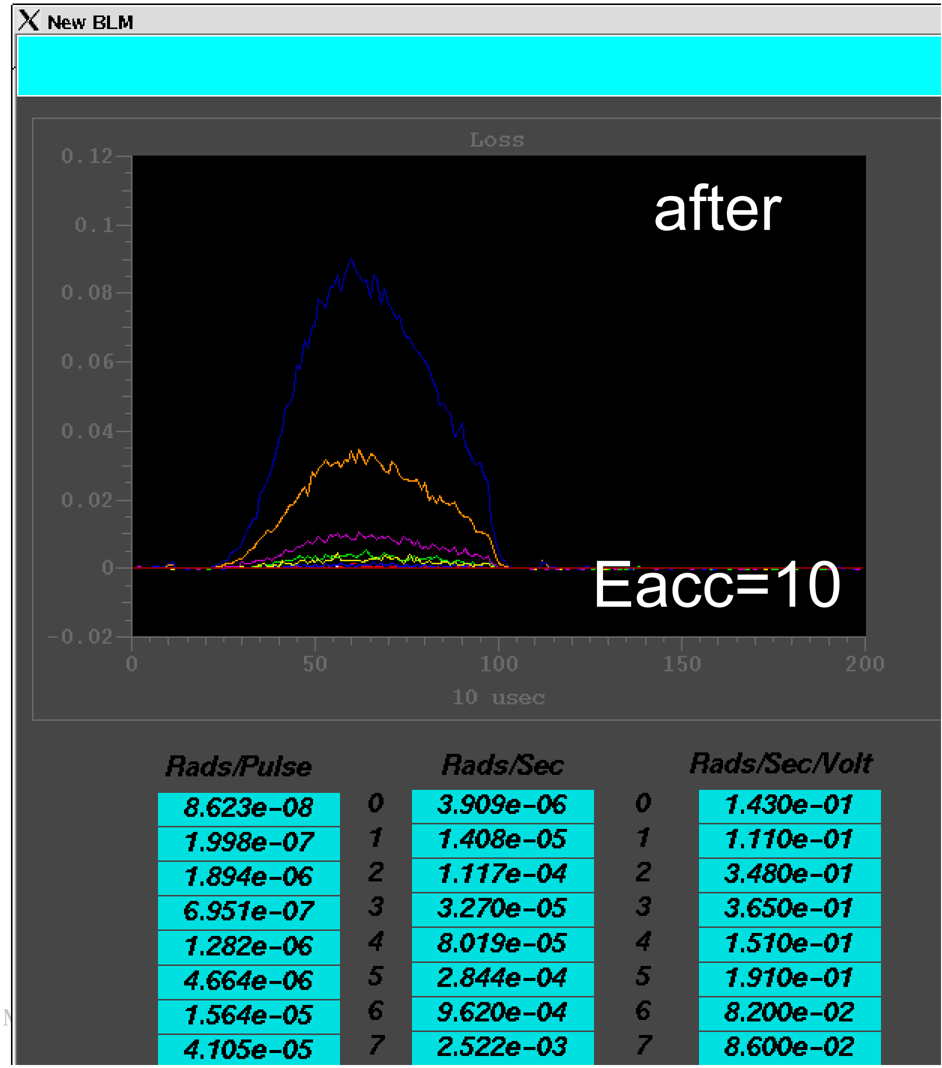


Radiation (before and after processing)

Radiation reduced by factor of 100

Showed promising results for in-situ processing





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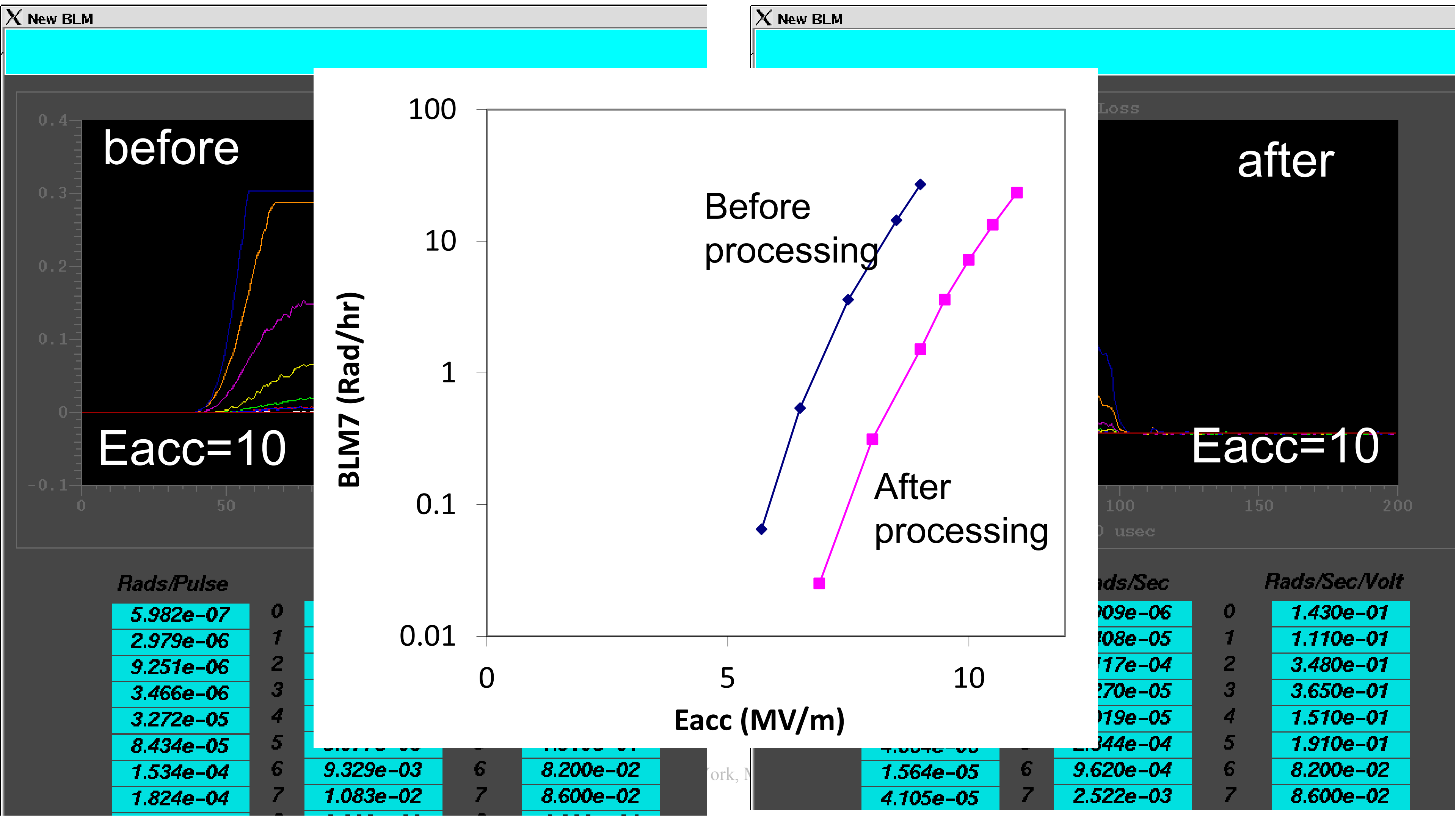

R&D Main Objectives

- Apply plasma surface modification to decrease effect of field emission on superconducting niobium surfaces
  - Room temperature processing
  - Processing parameter optimization
    - Uniform processing
    - Repetitive processing
    - Understanding of processing
  - Systematic study
    - Figure out what we can do/can't do
    - Find a statistically optimal procedure

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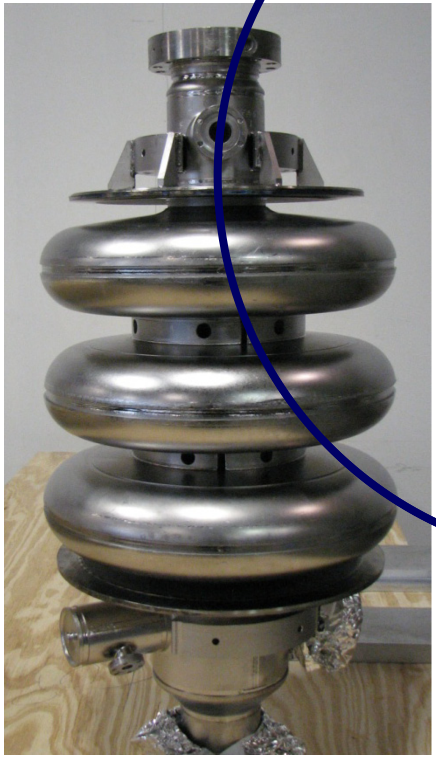
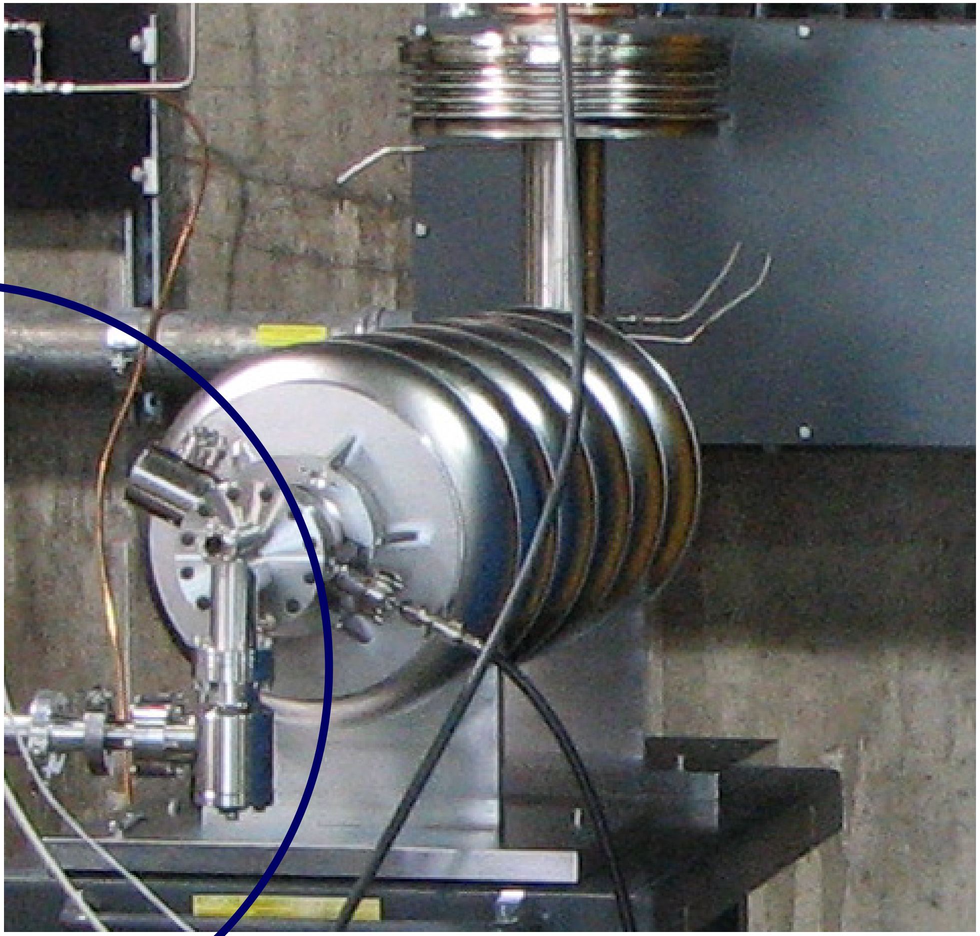
Tools



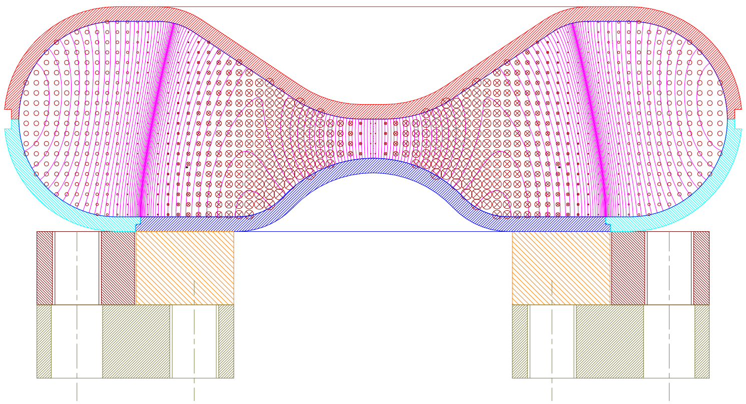


In-situ Processing

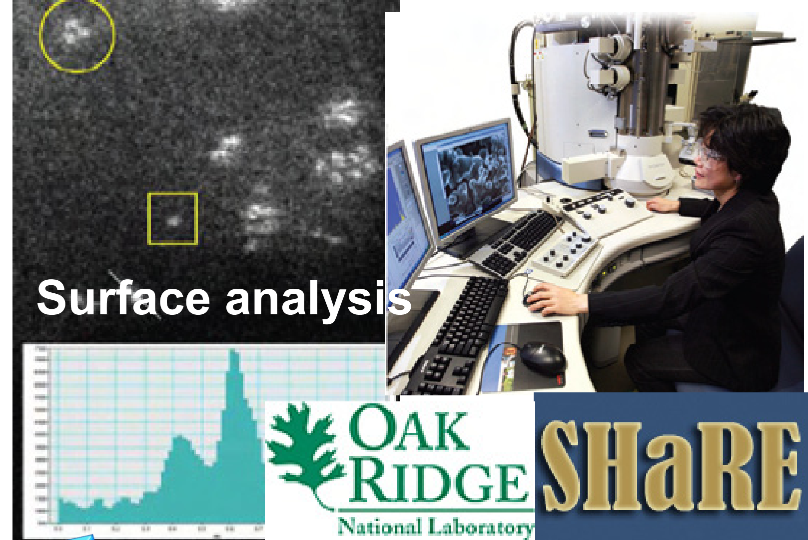
Test Cavity

3.3 GHz, TM020 mode
Ep/Bp=1.12 (MV/m)/mT
Ex. Ep=50 MV/m, Bp=56 mT
P_{diss}=36 W at 4.2 K

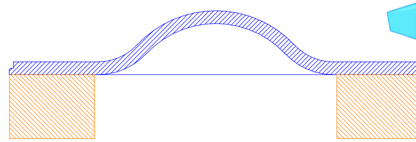
OD: 150 mm



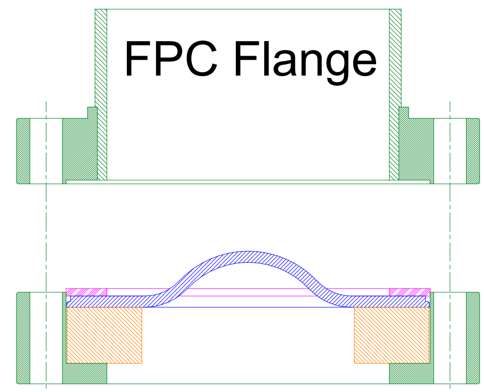
-Cold test
w/ dual mode (CW or pulse)
-Plasma processing



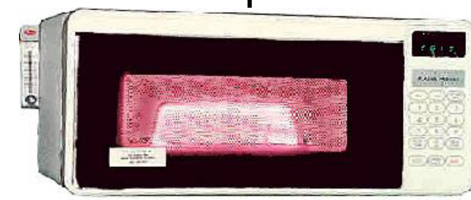
Demountable
witness plate



Witness Sample for Chemistry



Microwave
Plasma processor



Summary

- The first attempt of plasma processing w/ H01
  - Promising results
- R&D program
  - Hardware set-ups are in progress
  - Develop a procedure for statistical improvements
  - Expected gains (preliminary)
    - Removal of absorbed/trapped gases
    - Removal of oxide layer
    - Removal of small-size contaminants via physical bombardment or chemical reaction
    - Low temperature baking effect