FERMILAB-SLIDES-25-0070-SQMS-TD

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Plasma Processing for SSR Cavities

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Material provided by: Bianca Giaccone and Camille Cheney

PIP-II is a partnership of:

- US-DOE
- India-DAE
- Italy-INFN
- UK-STFC-UKRI
- France-CEA, CNRS/IN2P3
- Poland-WUST, WUT, TUL

Outline

- Plasma Processing for SSR1 Cavities
- Plasma Processing for SSR2 Cavities
- Conclusions and Path Forward

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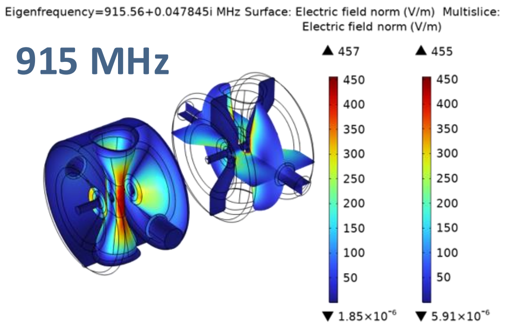
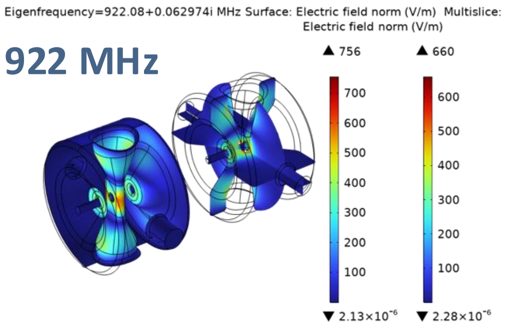
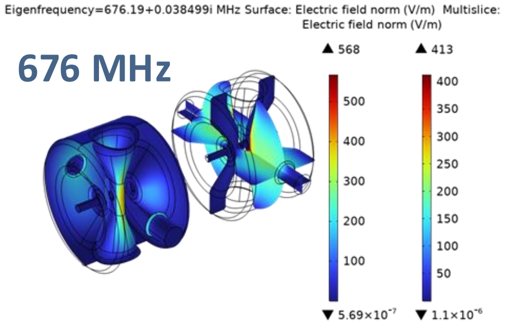
The plasma processing developments for the SSR1 cavity

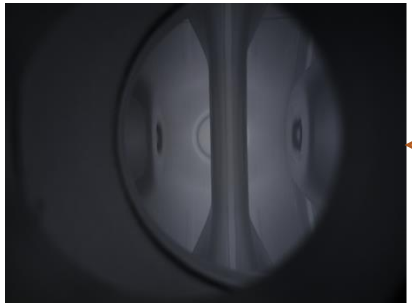
- **3 plasma processing protocols have been developed, targeting different areas**
  - Targeting accelerating gaps
    - Plasma ignition at 915 MHz
    - Increase the frequency to 930 MHz
      - Leading to a mode transition
      - Plasma moves in the accelerating gaps
  - Targeting the spoke sides
    - Plasma ignition at 676 MHz
    - Increase the frequency to 700 MHz
  - Targeting the spoke sides and feet
    - Plasma ignition at 1080 MHz
    - Increase the frequency to 1100 MHz
- **Control parameters**
  - Gas mixture: $Ar/O_2(10\%)$
  - Gas pressure: 2×10^{-2} mbar (15 mTorr)
  - Ignition threshold: 20 to 40 W
  - Plasma follows the $\vec{E}$ filed distribution
  - VNA tracking



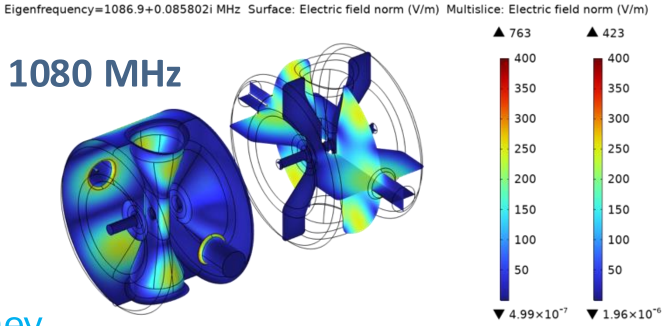


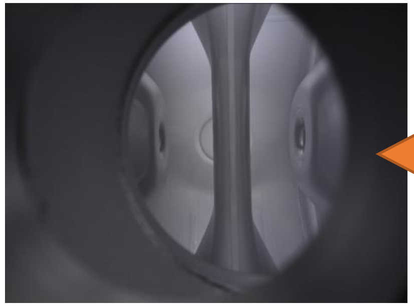
Plasma is located in both accelerating gaps





Plasma is located on both sides of the spoke





Plasma is located on both sides of the spoke + at the spoke feet

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Our vertical cryostat plasma processing set up

Main features:

- Plasma processing can be done in-situ in the vertical cryostat
- Possibility of processing 2 cavities
- Gas flowing through the cavity (beam line)
- Residual Gas Analyzer (RGA) with differential pumping
  - Tracking desorbed hydrocarbons
- Mass Flow Controller (MFC)
  - Keep a constant pressure
  - Continuous gas renewal
- Processing gas
  - Ar/O_2(10%) premixed cylinder

- **Ongoing and future plans:**
  - The SSR1 was cold tested before plasma processing
  - We recently plasma processed the SSR1 in-situ in the vertical cryostat
    - We used the 3 protocols showed previously
  - Cold test after plasma processing will come very soon

This work benefited from funding from IN2P3 and the French State aid under France 2030 (P2I - Graduate School Physique) with the reference ANR-11-IDEX-0003

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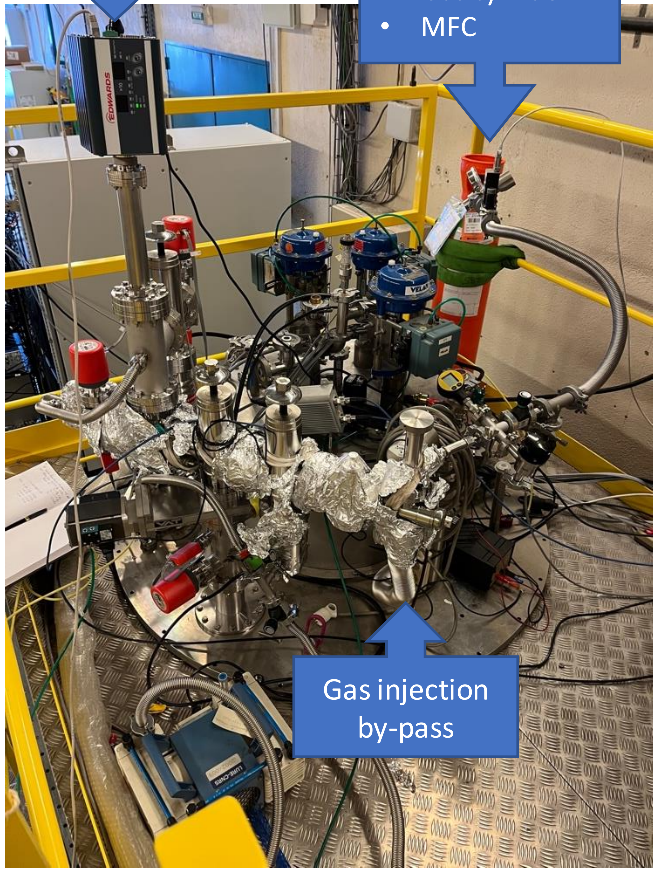

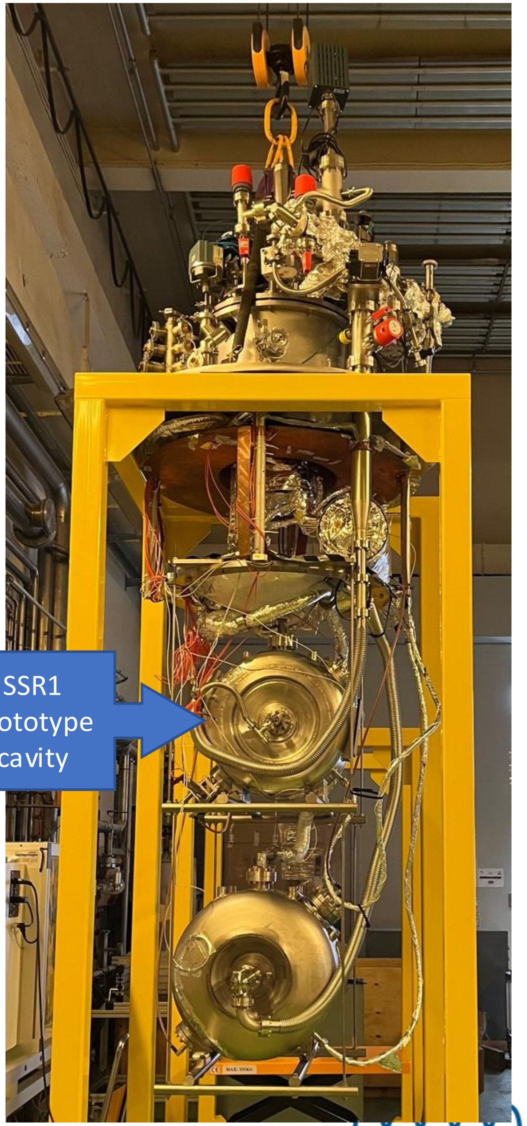

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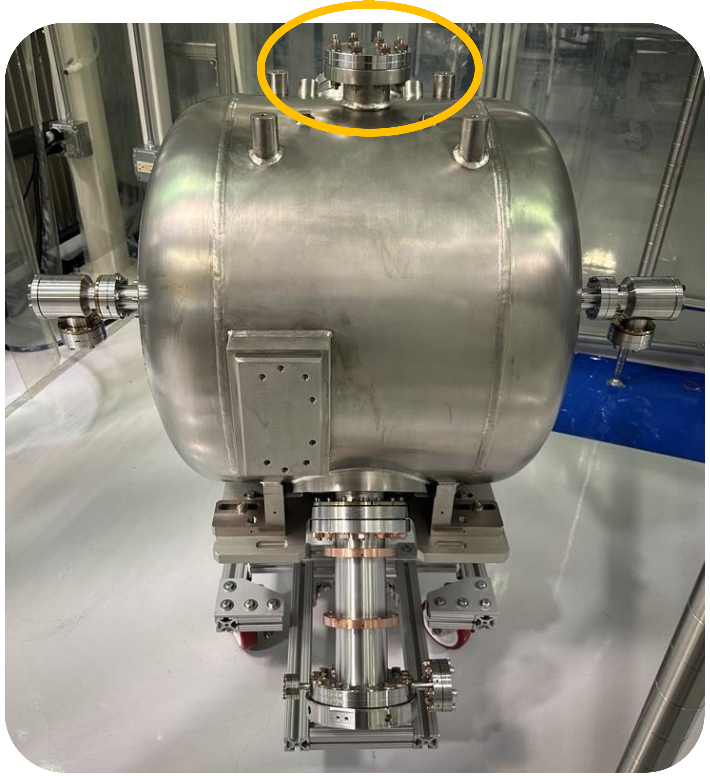
Plasma Ignition Studies on S2-ZA-005

- Cavity assembled with:
  - Vacuum part of high power coupler + N-type adapter
  - Field probe and view port
  - Right angle valves on both beam tubes to enable gas flow
- For gas flow: Argon at pressures between 40 - 80 mTorr, with and without Oxygen
- Plasma processing setup:
  - Plasma cart for gas flow and RGA monitoring
  - RF system with multiple RF generators to superimpose and tune modes
  - Camera positioned on viewport to monitor plasma ignition and location



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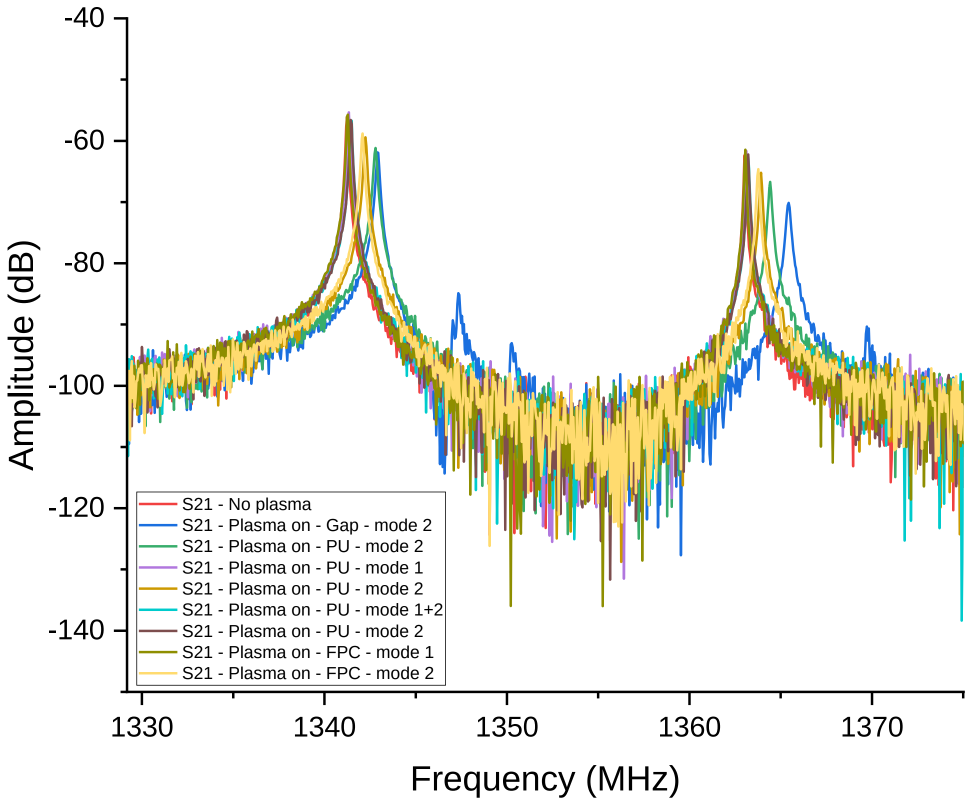
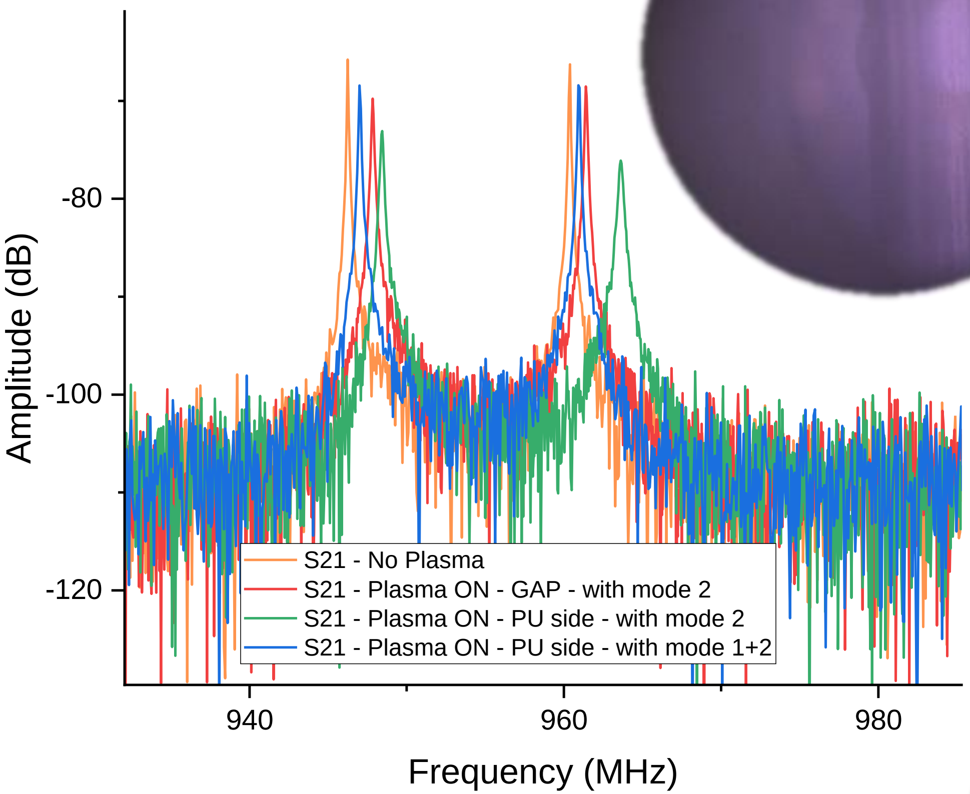
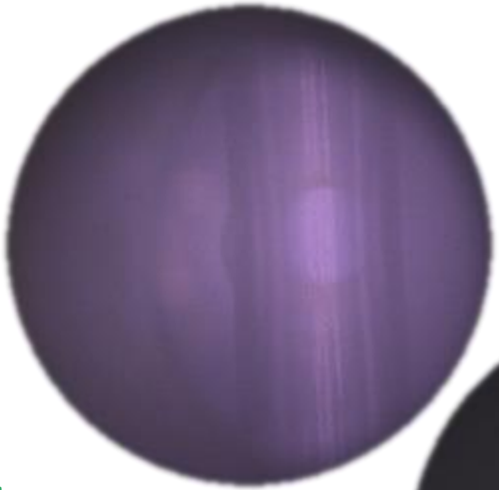
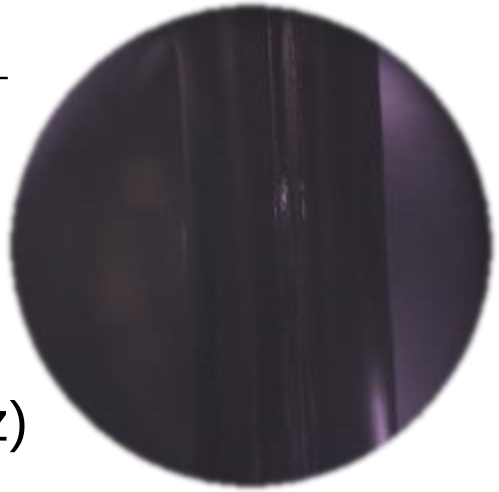
Developing PP method for SSR2









- Started PP studies with Argon in range 40 - 80 mTorr
- Using variations in VNA spectrum to identify plasma location in cell (following method developed by P. Berrutti for 1.3GHz)

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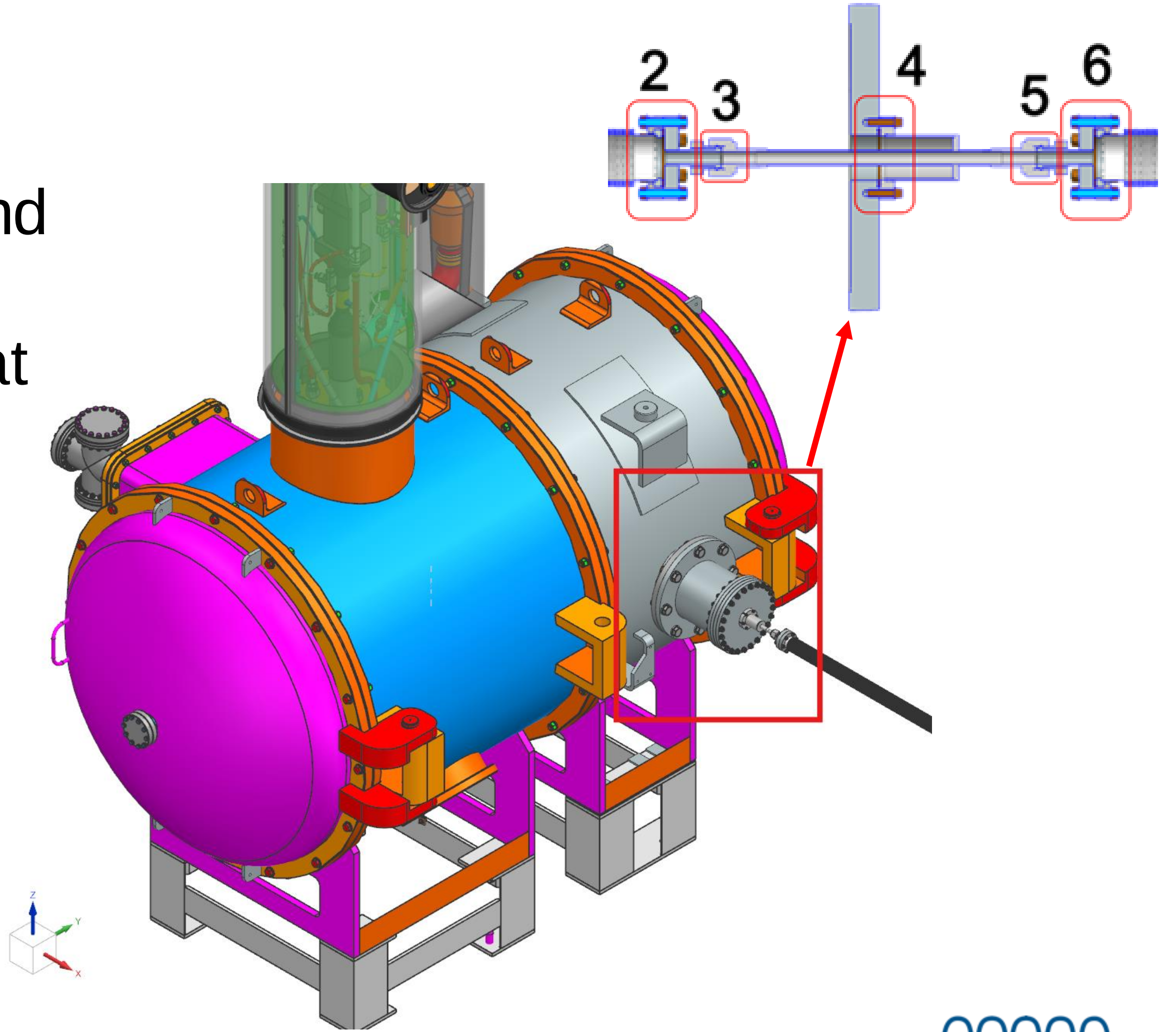
Plasma Processing Deployment on SSR2 in Cryostat (1)

- **Goal:** apply plasma processing on SSR2 cavity installed in cryostat to minimize vacuum connections, time, and costs
- **Steps:**
  - Bring plasma equipment (RF, vacuum and gas system) to cryostat cave
  - Install gas feedthrough flange on cryostat



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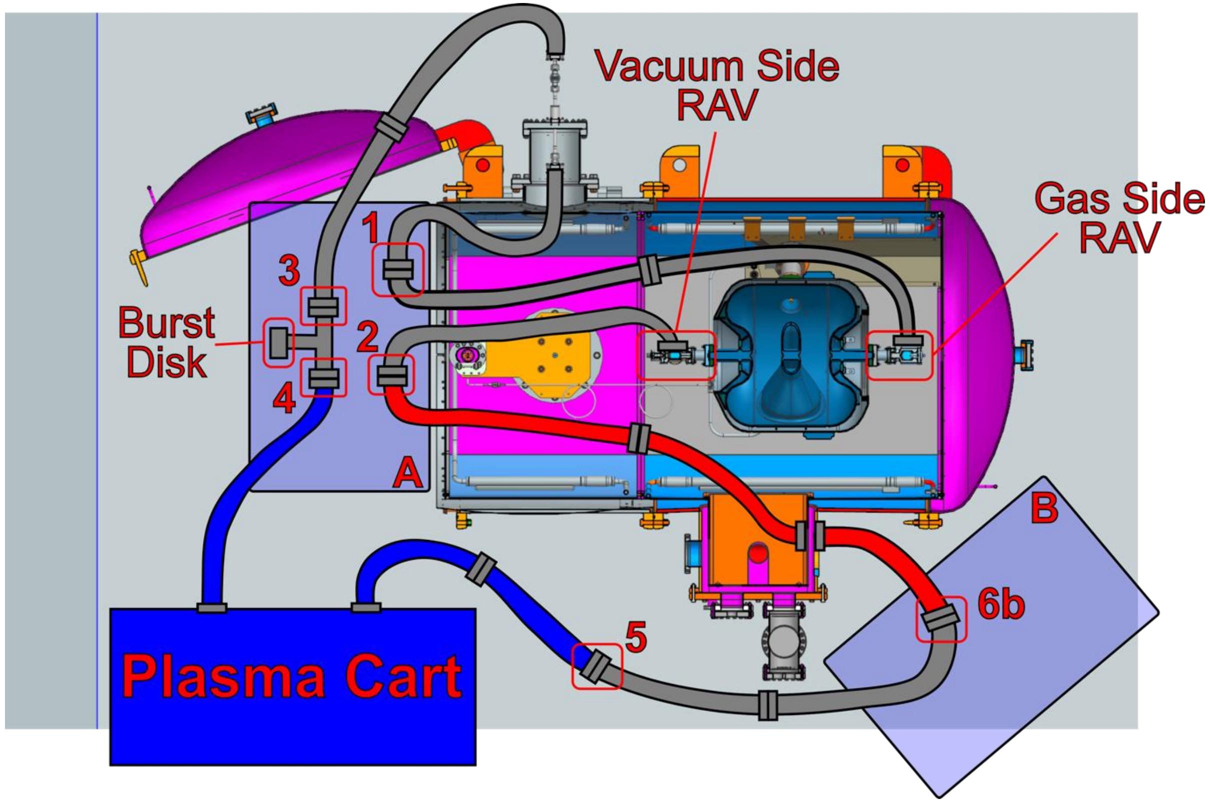
Plasma Processing Deployment on SSR2 in Cryostat

- **Goal:** apply plasma processing on SSR2 cavity installed in cryostat to minimize vacuum connections, time, and costs
- **Steps:**
  - Bring plasma equipment (RF, vacuum and gas system) to cryostat cave
  - Install gas feedthrough flange on cryostat
  - Connect plasma cart to gas injection and evacuation line through the cryostat
  - Disconnect CTC vacuum cart
  - Connect plasma cart to gas injection and evacuation line through the cryostat and to the cavity



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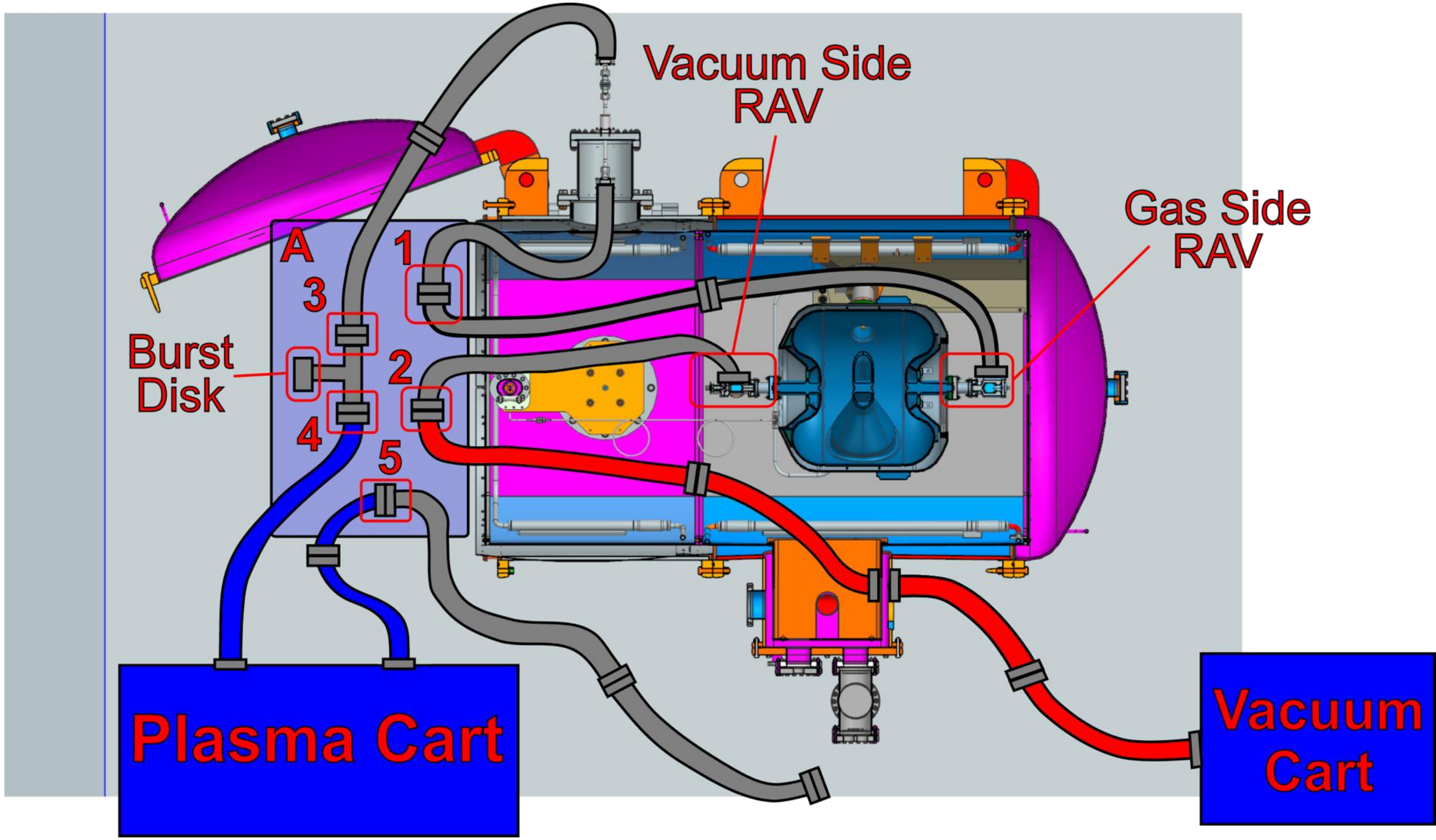
Configuration actually used for plasma processing

- Gas (Neon+Oxygen) injected from plasma cart
- Gas is flown through the cavity
- Pumping done from CTC vacuum cart
- Gas is also injected through the plasma cart bypass line to use RGA to monitor oxygen percentage
- Not possible to monitor the byproducts!!



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Plasma processing setup at CTC

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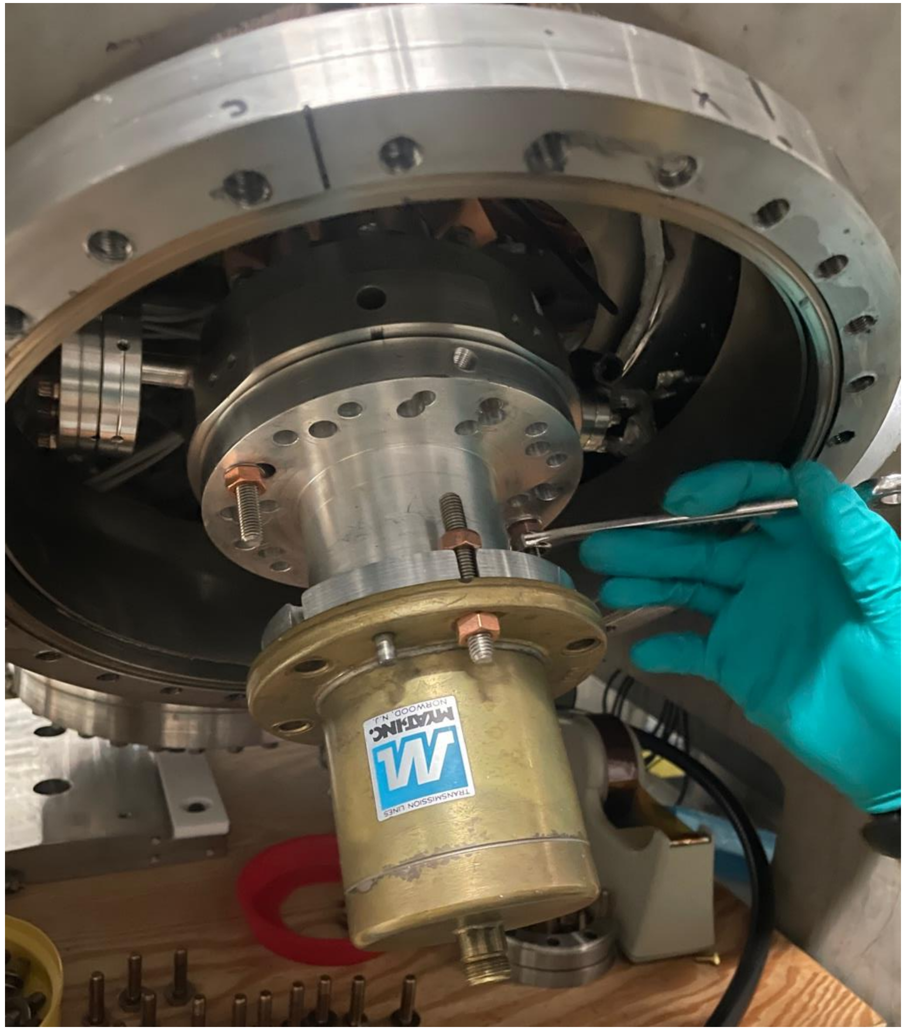
Coupler assemblies

Coupler: Vacuum part



Coupler: Vacuum part + Air part

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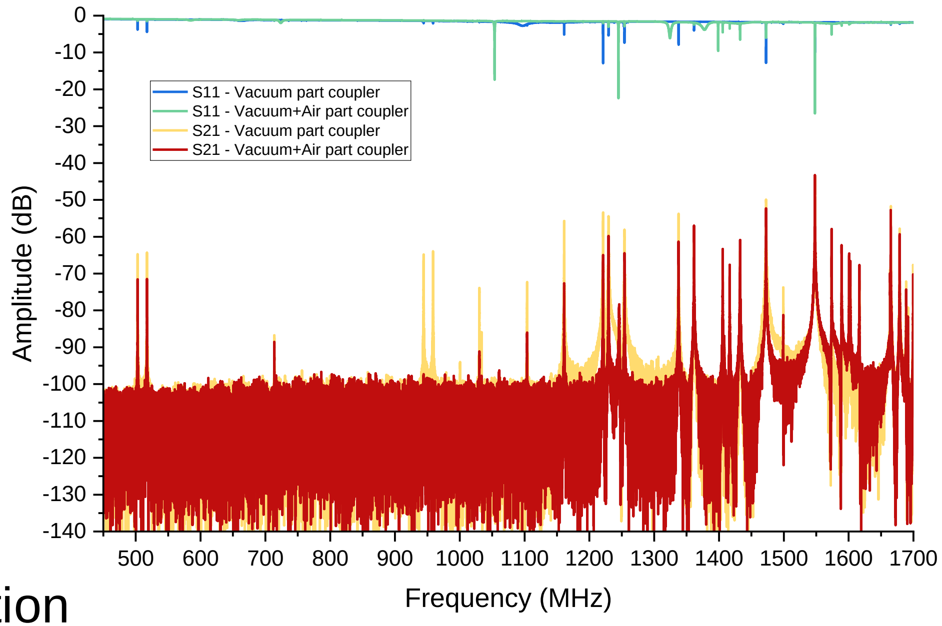
Plasma Processing applied in Cryostat



- Gas pressure between 75 - 140 mTorr
- Neon + approximately 6% Oxygen
- Ignited plasma for a total of 4h + 3h
- Used both configurations of coupler assembly
  1. With Vacuum part + Air Part + N-type adapter:
     - Useful modes not sufficiently coupled with this configuration
     - Used modes that were decently coupled rather than modes with interesting field profiles
     - Ignited plasma at coupler once while two modes were superimposed
  2. With Vacuum part + Air Part + N-type adapter:
     - Used same modes as during PP development on S2-ZA-005
     - Studied maximum plasma tunability and stabilized plasma at max density to improve hydrocarbon removal
     - Attempted to ignite plasma in central volume (PU and FPC side) and toward Gap
     - Need to analyze VNA spectra to confirm plasma ignition locations

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Conclusions and Path Forward

- **For SSR1:**
  - PP ignition studies performed on multiple SSR1 cavities at Fermilab and IJCLab
  - IJCLab performed PP simulations and optimization
  - IJCLab developed setup for PP deployment on Vertical Insert
  - Plasma Processing was successfully applied in situ in cryostat and performance will be compared through RF cold tests

- **For SSR2:**
  - PP ignition studies on S2-ZA-005 showed a promising path forward
  - Fermilab developed setup for PP deployment in Cryostat
  - Plasma Processing was successfully applied in situ in cryostat and performance was compared through RF cold tests
  - Further studies are still needed to define a “final” optimized processing method