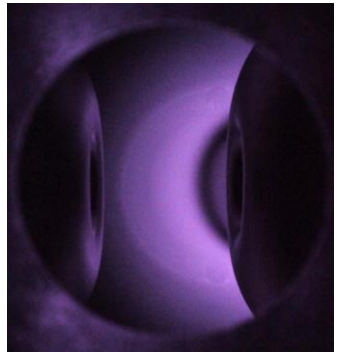
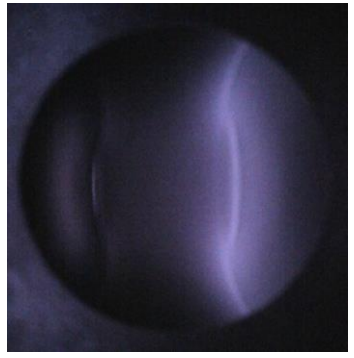


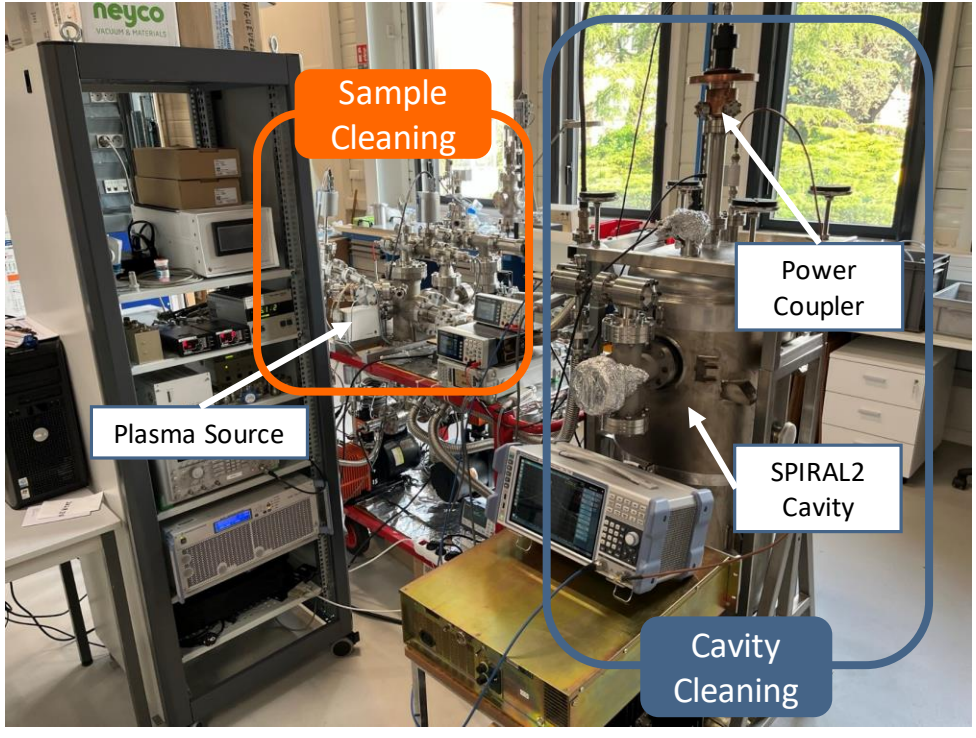


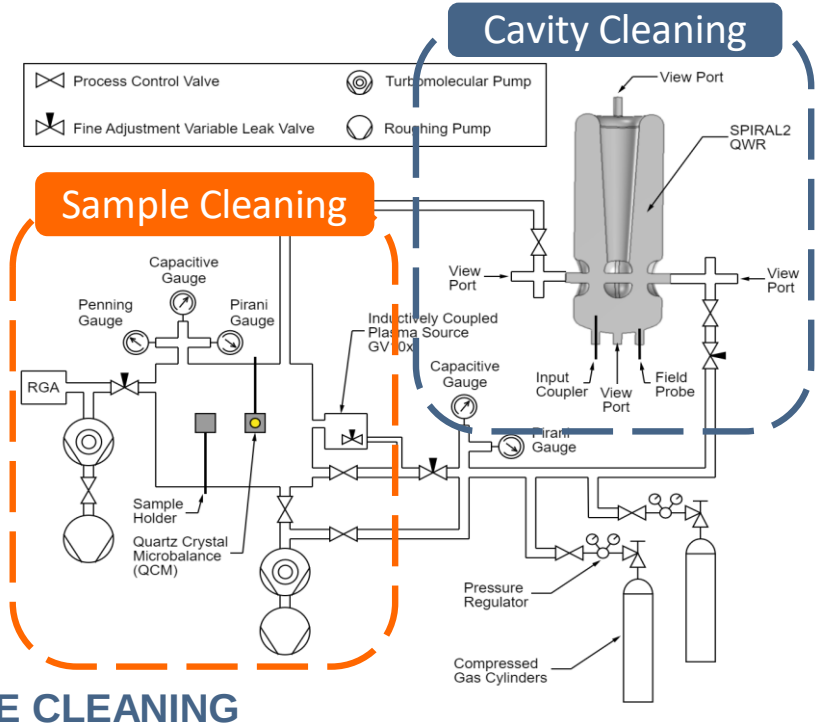
# Overview of Plasma Processing Activities at IJCLab

TESLA Technology Collaboration Meeting
Fermilab
Dec 5-8, 2023

Camille CHENEY
PhD student

# Our Plasma Cleaning Bench




- **SAMPLE CLEANING**
  - ICP plasma source (ibss Group GV 10x DS Ahser)
  - Quartz Crystal Microbalance (QCM) + Carbon coating
  - Removal rate measurements: varying gas mixture, pressure, gas flow, RF power
- **CAVITY CLEANING**
  - SPIRAL2 QWR cavity (with fundamental power coupler)
  - Study plasma ignition, plasma shape

# IJCLab Plasma Processing Timeline

## 2021: THE BEGINNINGS

- Setting up a test bench

## 2022: FIRST EXPERIMENTS

- People involved:
  - Post-doctoral student (not full time)
  - MSc degree intern (5 months)
  - D. Longuevergne (supervisor)
- Removal rate measurements of carbon coating
  - Testing various gas mixtures
- First tests on a SPIRAL2 QWR
  - Fundamental mode
  - Custom length antennae

## 2023: MORE INVESTIGATIONS

- People involved:
  - Myself (5 months intern → full time PhD)
  - D. Longuevergne (PhD supervisor)
- SPIRAL2 QWR deeper study
  - Fundamental Power Coupler (FPC)
  - Higher Order Modes (HOM)
    - Coupling measurements
    - Plasma ignition/distribution study
    - **COUPLER BREAKDOWN**
      - Understand
      - Mitigate/delay

# What is coupler breakdown?

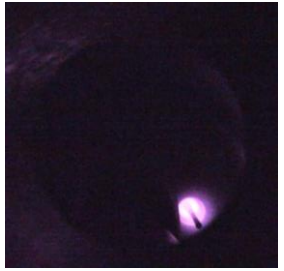
- **Definition:**
  - Phenomenon happening during plasma processing when plasma confines around the powered antenna (FPC or HOM coupler).
  - It appears above some RF power threshold.
- **Is it an issue?**
  - **YES (for HWRs and ellipticals)**
    - Sputtering of antenna material onto Nb = pollution (*Cf.* FRIB HWRs [1] and JLab elliptical [2])
    - Can damage isolating ceramic leading to vacuum leaks (*Cf.* IMP/CiADS HWRs [3])
  - **Maybe NO for QWRs (at least for plasma processing effectiveness)**
    - Field emission onset is delayed after processing, despite breakdown! (*Cf.* FRIB QWRs [1]) *"we did not observe damage to the coupler even after more than 10 hours of cumulative coupler plasma processing"*
    - No damage/sputtering observed for SPIRAL2 QWR as well
- **⚠Must be avoided anyway, because it's very risky for cavity and coupler integrity**
- **Any explanation?**
  - Not yet fully understood
  - We have some hypothesis


[1] W. Hartung *et al.*, "Investigation of Plasma Processing for Coaxial Resonators"
[2] T. Powers *et al.* "Plasma Processing of SRF cavities"
[3] A.D. Wu *et al.*, "The Destructive Effects to the RF Coupler by the Plasma Discharge"

# Coupler Breakdown: Every Resonator Suffer

## QWR

### SPIRAL2 88 MHz

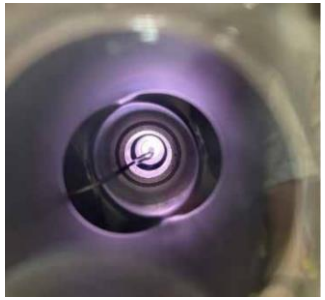


## HWR

### FRIB 322 MHz

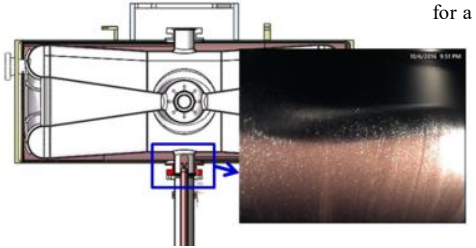
W. Hartung *et al.*, "Investigation of Plasma Processing for Coaxial Resonators"

### ATLAS 172 MHz



M.E. McIntyre *et al.*, "Plasma Processing: Ignition Testing and Simulation Models for a 172 MHz HWR Cavity"

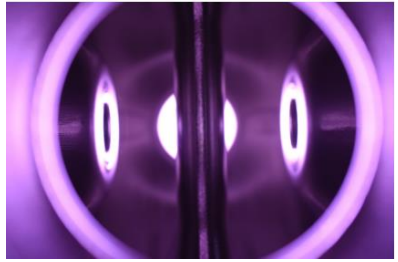
### CiADS 162.5 MHz



A.D. Wu *et al.*, "The Destructive Effects to the RF Coupler by the Plasma Discharge"

## Spoke

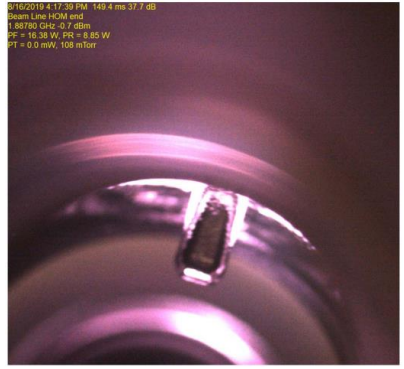
### PIPII SSR1 325 MHz



P. Berurtti., "Plasma Cleaning at FNAL: LCLS-II HE vCM Results and Ongoing Studies on Spoke Resonators"

## Elliptical

### CEBAF C100 1.5 GHz



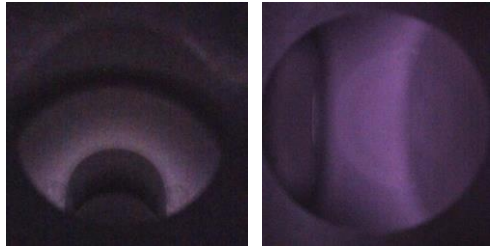

T. Powers *et al.* "Plasma Processing of SRF cavities"

# SPIRAL2 QWR Coupler Breakdown

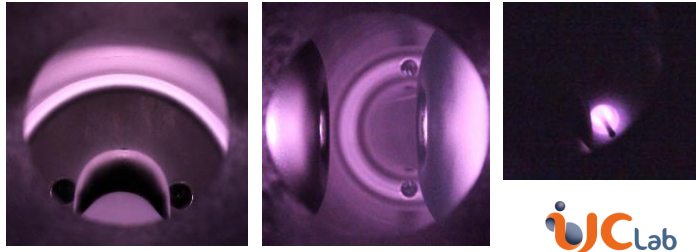
Increasing RF power

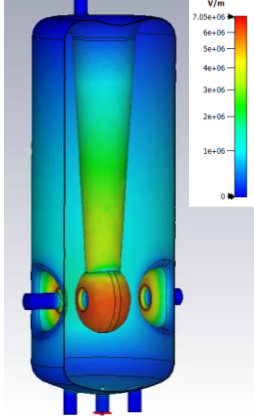
- **1st Regime: No plasma**
  - No ignition
  - “standard” behavior of an RF cavity

- **2nd Regime: Cavity plasma ignition**
  - Plasma ignites in the cavity volume
  - Plasma follows high E field regions



- **3rd Regime: Coupler Breakdown**
  - Plasma confines around the power coupler
  - **No visible traces of sputtering**





SPIRAL2 QWR
Mode 1 E field

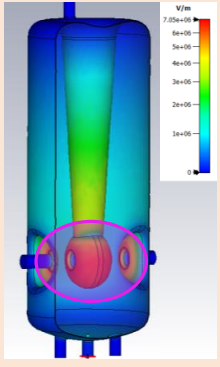
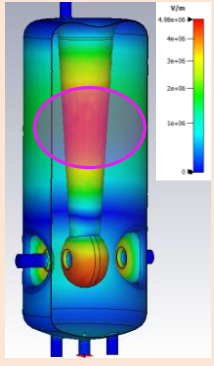
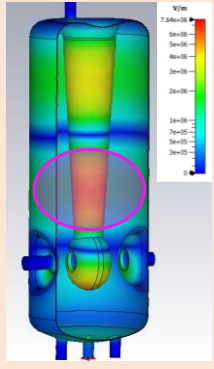
# How to delay coupler breakdown? (1/4)

## At IJCLab, we played on:

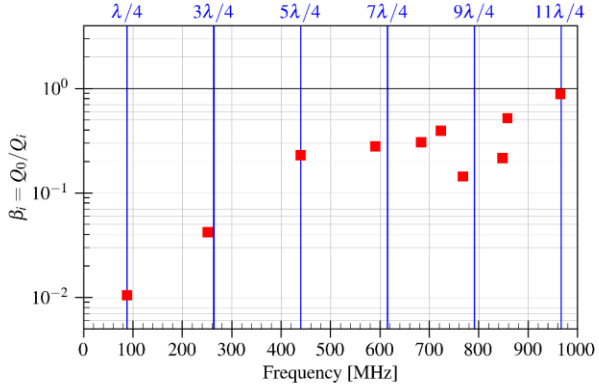
1. Frequency
2. Pressure
3. DC bias of the power coupler

# How to delay coupler breakdown? (2/4)

## 1. FREQUENCY

| | Mode 1 – 88 MHz | Mode 2 – 251 MHz | Mode 5 – 439 MHz |
|---|---|---|---|
| CST Microwave Studio E field surface plot<br>Plasma location*<br>*with RF power ramp |  |  |  |
| Plasma ignited in the cavity volume **$Ar/O_2$(10%) $10^{-1}$ mbar** | $P_{FWD}$~[0.2 ; 3]W | $P_{FWD}$~[1 ; 30]W | $P_{FWD}$~[10 ; > 100]W |

VNA input coupling measurements (with FPC)

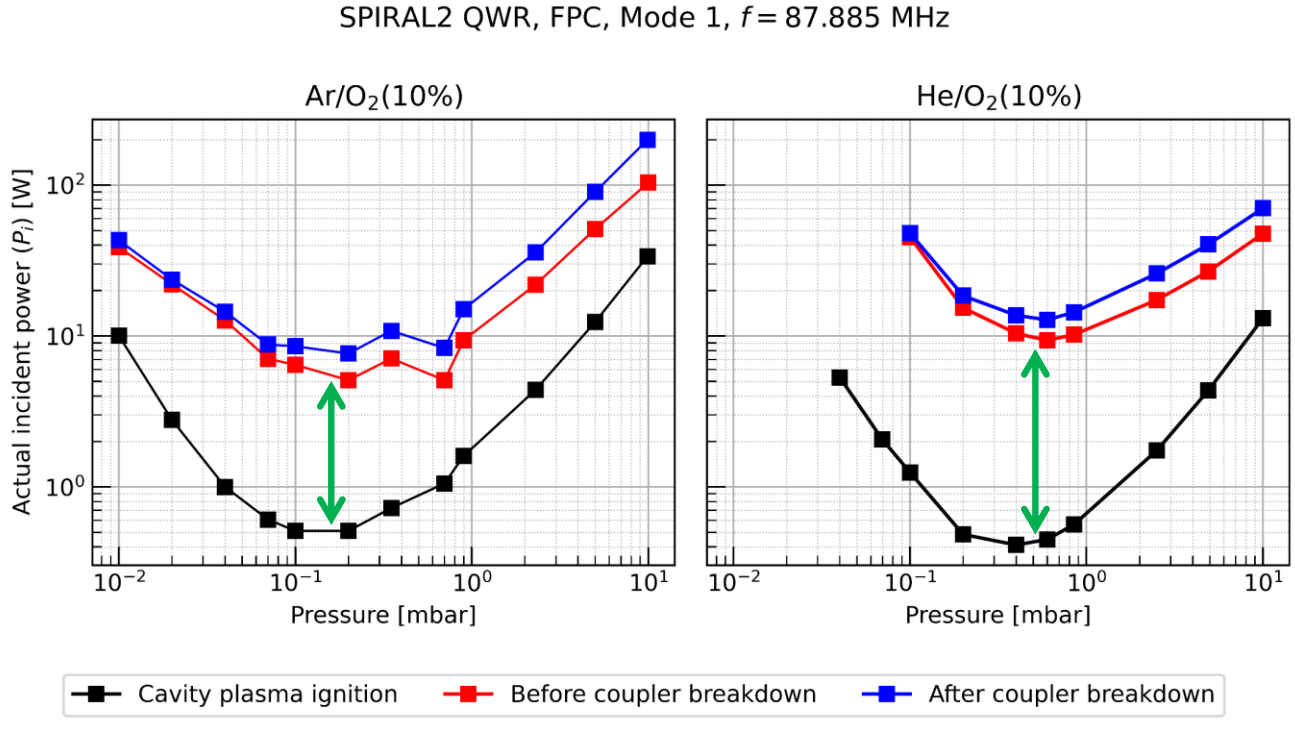


# How to delay coupler breakdown? (3/4)

## 2. PRESSURE

- Both cavity and coupler ignition follow Paschen law
- $He/O_2(10\%)$ has the larger power margin between cavity plasma ignition and coupler breakdown

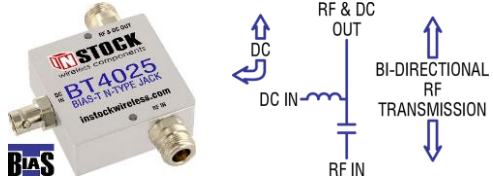
| Gas | 1st ionization energy |
|---|---|
| He | 24.587 eV |
| Ar | 15.759 eV |
| O | 13.618 eV |

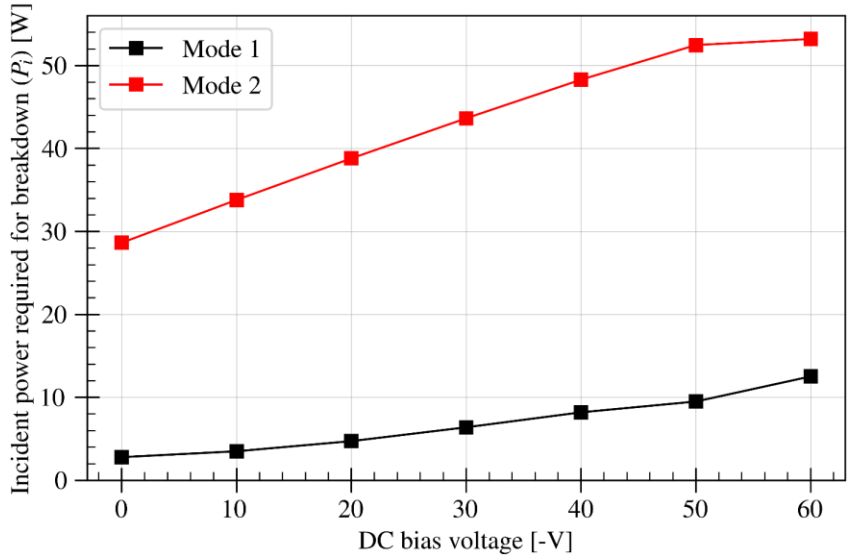


# How to delay coupler breakdown? (4/4)

## 3. DC BIAS OF THE POWER COUPLER

- Negative DC bias applied to the power coupler
- The lower the $V_{DC}$, the higher the power required for breakdown
- Mode 5 is not showed due to bias tee power limitation (100W)
- On the contrary, positive bias tends to favor coupler breakdown



# Summary

- Coupler breakdown is identified as the main risk and limiting factor of plasma processing
- We are studying coupler breakdown to understand what is causing it, and how to delay/avoid it
- Higher frequencies, as well as negative DC bias look favorable
- Coupler breakdown tends to follow Paschen law

- **FUTURE PLANS:**
  - Plasma computer simulations
  - Set up plasma diagnostics (Langmuir probe, OES)

## Acknowledgments


- Vacuum people at IJCLab
- G. Curley and S. Guilet for their plasma expertise
- Plasma processing teams at Fermilab, FRIB, Jefferson Lab for useful discussions, information sharing, and suggestions
- Special thanks to T. Powers, T. Ganey, N. Raut and A-M. Valente Feliciano for welcoming me at Jefferson Lab
- This work was partially supported by the European Union's Horizon Europe Marie Sklodowska-Curie Staff Exchanges programme under grant agreement no. 101086276.


Co-funded by the European Union

# Thank you for your attention!