Plasma Processing for SRF cavities: Past, Present and Future

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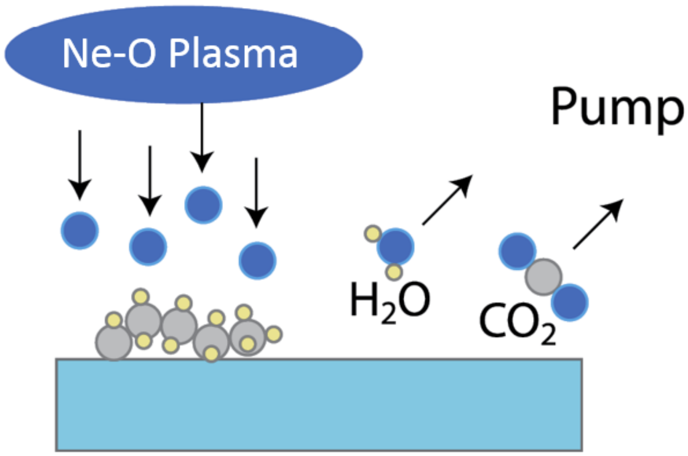
Outline

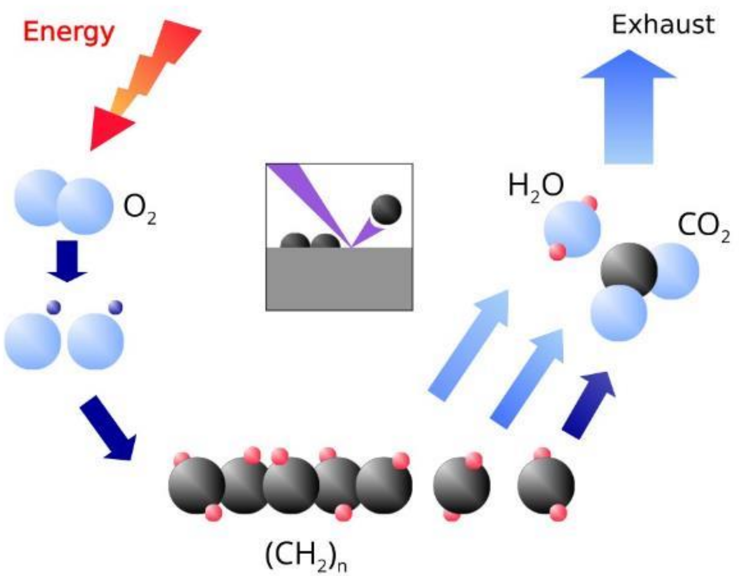
- Plasma cleaning for SRF cavities: in-situ cryomodule processing and its motivations
- First successful application: Ne-Oxygen plasma SNS experience
- Plasma ignition for LCLS-II cavities: dual tone excitation limitations
- Current applications: HOMs plasma ignition for LCLS-II from first cavity test to in-situ CM processing, CEBAF experience on C100 cavities and modules
- On going studies on coaxial resonators (single spoke at FNAL)
- Potential future developments

Plasma Cleaning for SRF Cavities I

- **Oxygen plasma at room temperature** (reactive environment with ions, e-, neutrals, radicals, etc.)
- **Volatile by-products** are formed through oxidation of hydrocarbons and **pumped out** and monitored (RGA)
- **Mixture of Neon-Oxygen:**
  p~100 – 200 mTorr, 2 % O_2
  - $\boldsymbol{Ne}$ → transport gas to create a stable glow discharge (inert/noble)
  - $\boldsymbol{O_2}$ → cleaning agent, react with carbon forming volatile species

$$O_2 + C_xH_y \rightarrow CO + CO_2 + H_2O$$





M. Doleans et al. NIMA 812 (2016) 50-59

Plasma Cleaning for SRF Cavities II

Plasma process at ORNL/SNS focused on:

- **Reducing FE by increasing work function** of cavity RF surface
  - Hydrocarbon contaminants observed on all Nb cavities
  - Hydrocarbons and adsorbates lower work function of Nb
- Enabling operation at higher accelerating gradients

$$j = \beta \frac{AE^2}{\Phi} e^{-B\frac{\Phi^{3/2}}{\beta E}}$$

$$dj = 0 \qquad \frac{dE_{acc}}{E_{acc}} \approx \frac{3}{2}\frac{d\Phi}{\Phi}$$

J: current density
E: surface electric field
Φ: work function
β: enhancement factor (10s to 100s)
A,B: constant

Increasing Φ by 10 % means increasing E_{acc} of about 15 %

M. Doleans et al. NIMA 812 (2016) 50-59

Motivations for in-situ plasma cleaning for LCLS-II

Cavity	Cryomodule Max Gradient* [MV/m]	VTS Max Gradient [MV/m]	Usable Gradient** [MV/m]	FE onset [MV/m]	Cryomodule Q_0 @16MV/m*** Fast Cool Down	Q_0 @16MV/m at VTS
TB9AES021	21.2	23.0	18.2	14.6	2.6e10	3.1e10
TB9AES019	19.0	19.5	18.8	15.6	3.1e10	2.8e10
TB9AES026	19.8	21.5	19.8	19.8	3.6e10	2.6e10
TB9AES024	21.0	22.4	20.5	21.0	3.1e10	3.0e10
TB9AES028	14.9	28.4	14.2	13.9	2.6e10	2.6e10
TB9AES016	17.1	18.0	16.9	14.5	3.3e10	2.8e10
TB9AES022	20.0	21.2	19.4	12.7	3.3e10	2.8e10
TB9AES027	20.0	22.5	17.5	20.0	2.3e10	2.8e10
Average	**19.1**		**18.2**	**16.5**	**3.0e10**	**2.8e10**
Total Voltage	**154.6 MV**		**148.1 MV**			

Acceptance = 128 MV

* Administrative limit 20 MV/m
** Radiation <50 mR/h
*** TB9AES028 Q_0 was at 14 MV/m

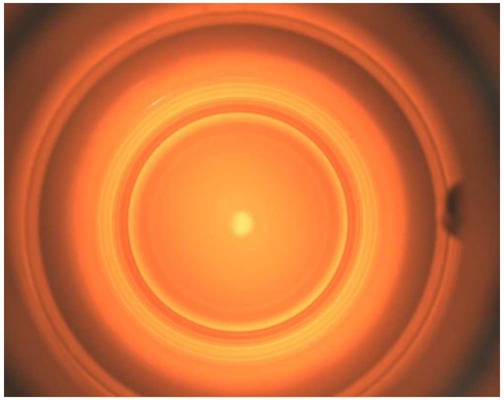
Courtesy of G. Wu

In-situ plasma processing of cryomodules will allow:

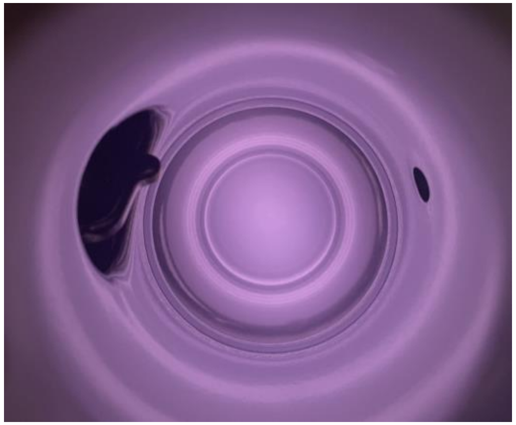
- Increasing maximum gradient
- Reducing radiation level
- Preserving high-Q

In-Situ:
NO NEED OF DISASSEMBLY!!

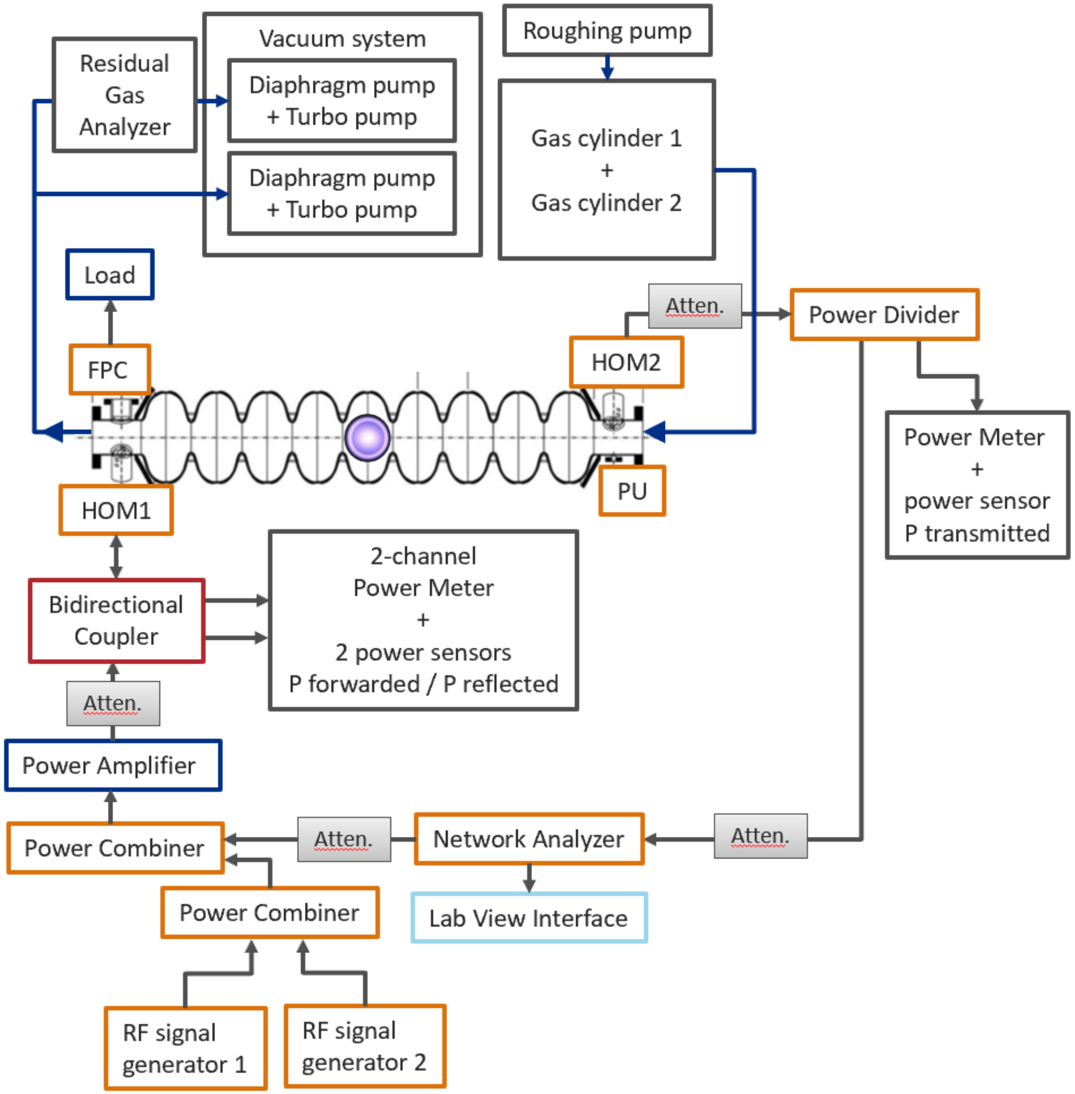
Example of Set-up for Plasma Cleaning on SRF cavity



- Ne plasma



- Ar plasma



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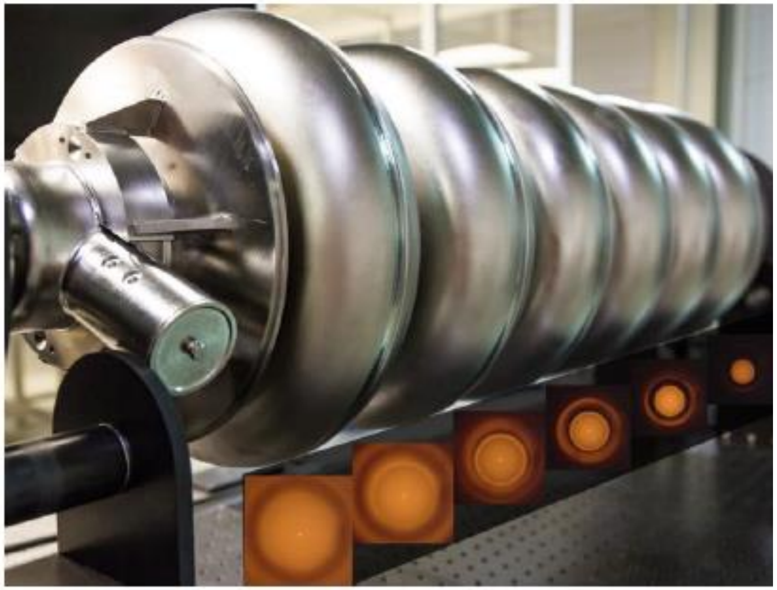
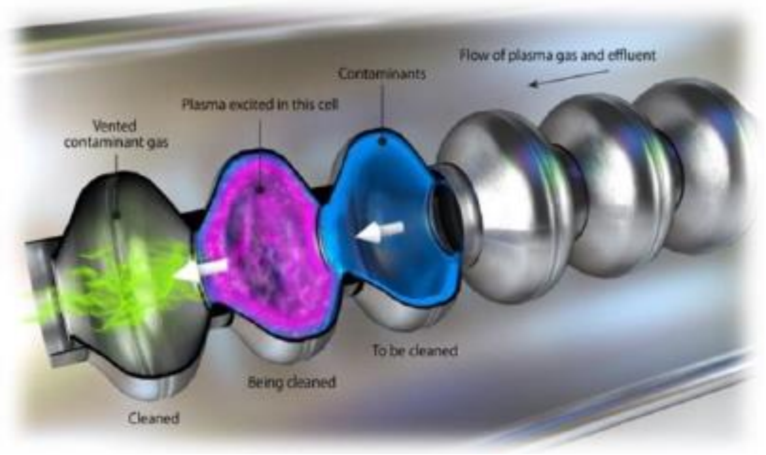
Plasma Processing at ORNL/SNS I

- First studies started around a decade ago in 2013, reported at SRF 2013 by M. Doleans
- Cleaning technique uses a neon gas discharge with reactive oxygen for SRF cavities (805 MHz) at room temperature
- Plasma ignited in each cell of a cavity sequentially
- Oxidation of hydrocarbon surface contaminants creates volatile by products pumped out continuously
- Cleaned surface has increased work function helping mitigating field emission and multipacting



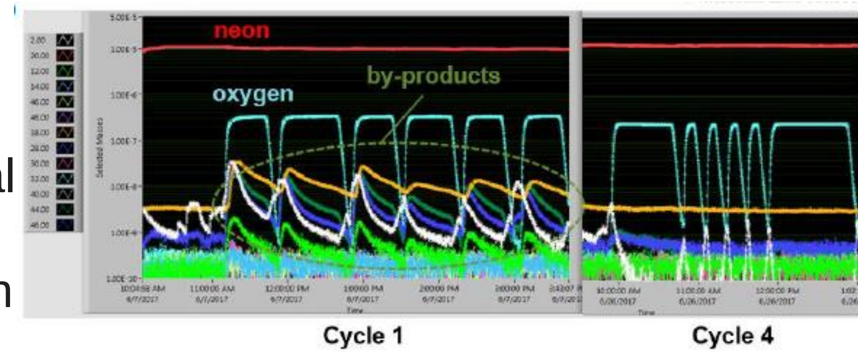


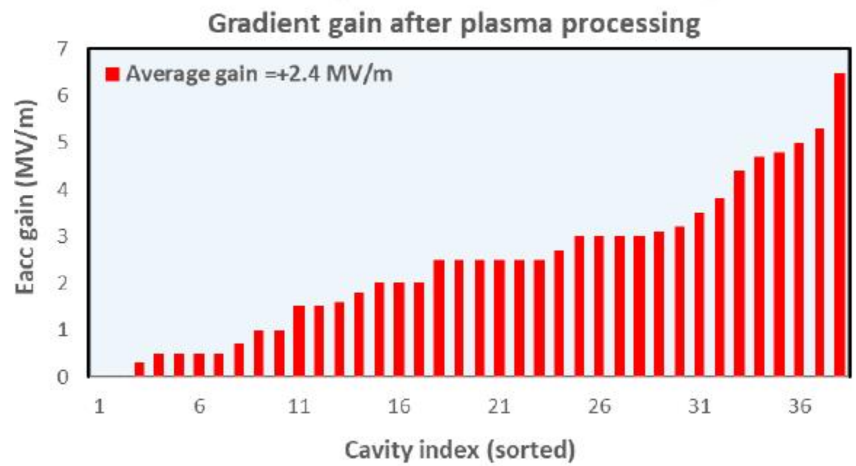
M. Doleans et al., NIMA **812** (2016)
M. Doleans J. Appl. Phys., **120**, 243301 (2016)
P.V. Tyagi et al., Applied Surface Science **369** (2016)

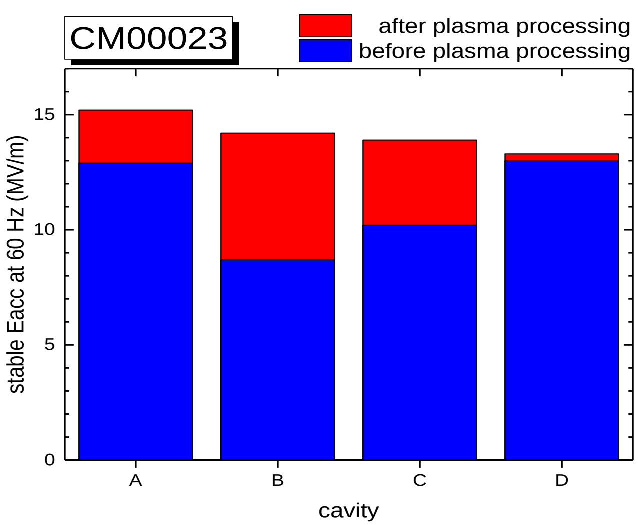
Plasma Processing at ORNL/SNS II

- 10 cryomodules plasma processed at SNS either in offline facilities or directly in the linac tunnel:
  - 8 High beta CMs
  - 2 Medium beta CMs
- Cleaning of the cavity surfaces revealed by the significant reduction of by products partial pressures over time
- 38 cavities plasma processed at SNS with an average Gradient increase of 2.4 MV/m

Oak Ridge National Laboratory







Collaboration for LCLS-II Plasma Processing

Oak Ridge National Laboratory

- Successful experience with plasma processing
- Guidance for design and sample studies for LCLS-II plasma cleaning

SLAC National Accelerator Laboratory

- Simulation for applicability of ORNL plasma processing to LCLS-II cavities
- Use the system to perform cleaning in the accelerator tunnel

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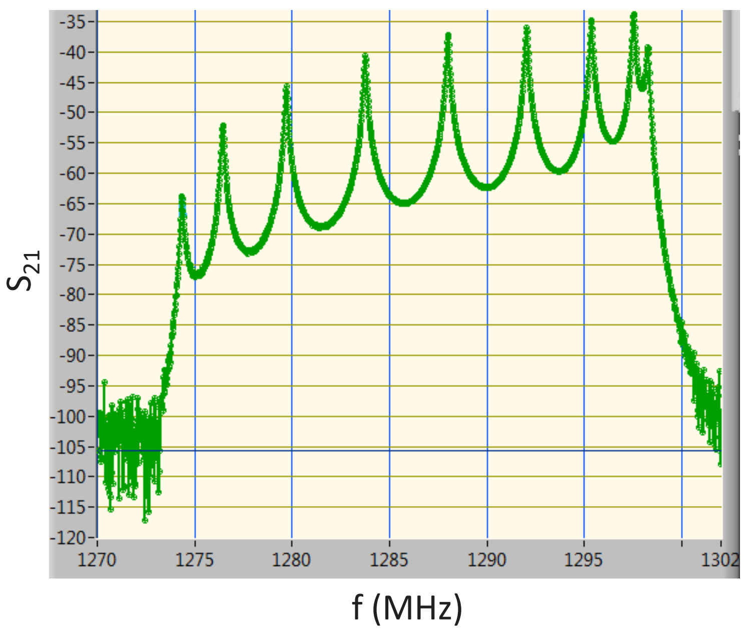
- Adapt the ORNL plasma cleaning technique to LCLS-II cavities and cryomodules
- Provide a system capable of efficiently process LCLS-II cavities/cryomodules

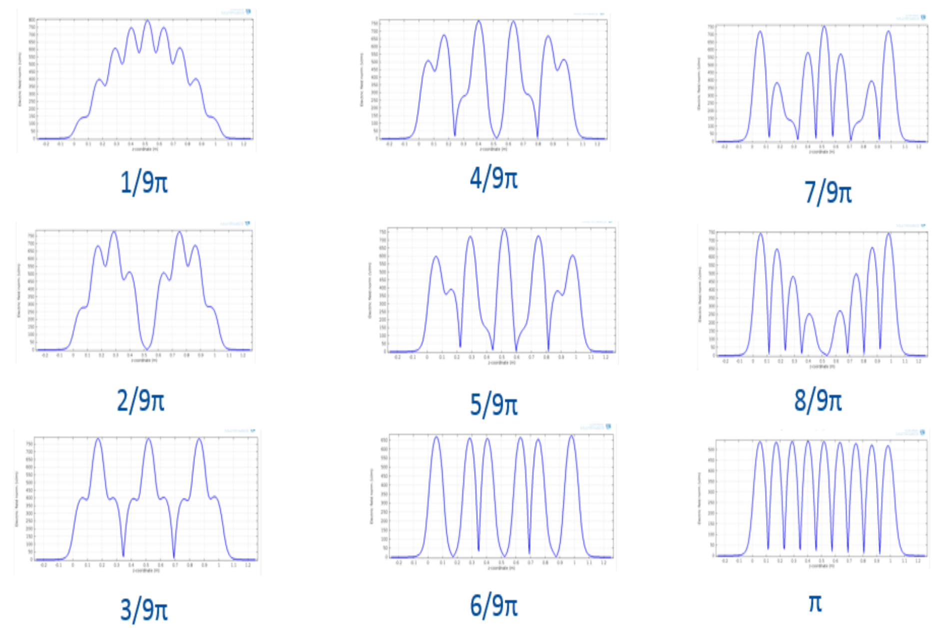
Project supported by DOE - Basic Energy Sciences (BES)

Plasma Ignition in LCLS-II Cavities with TM_{010} modes

- Plasma ignited sequentially cell-by-cell
- **Dual tone excitation** to ignite plasma in the desired cell (M. Doleans, J. Appl. Phys. 120, 243301 (2016))
  - <u>2 fundamental modes mixed</u> to increase field amplitude in one cell (and its mirror images)
  - <u>Off-resonance excitation</u> introduce asymmetry in the cell amplitude

LCLS-II 9-cells - 1st pass-band modes





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  - 2 fundamental modes mixed to increase field amplitude in one cell (and its mirror images)
  - Off-resonance excitation introduce asymmetry in the cell amplitude

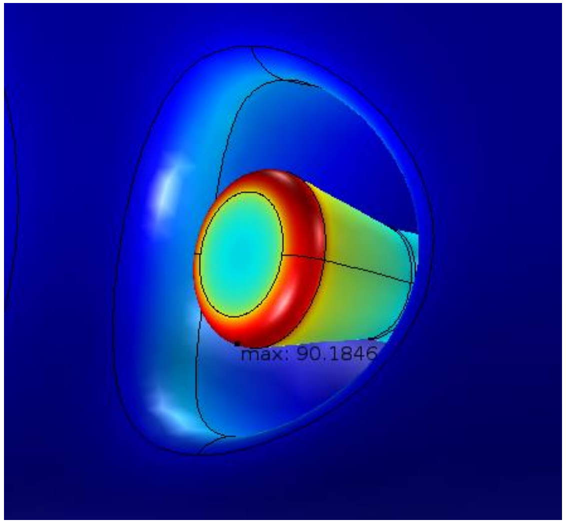
To obtain 10 kV/m, **more power is needed** comparing with SNS cavities:

- 9-cells instead of 6
- Larger mismatch at room T:
  - $Q_0 = 1 \cdot 10^4$ for Nb
  - SNS FPC: $Q_{ext} = 7 \cdot 10^5$
  - LCLS-II FPC: $Q_{ext} = 3 \cdot 10^7$
  - For LCLS-II only 1% of the power is transmitted to the cavity

Cell #	Mode 1	Amp	dF (HBW)	Mode 2	Amp	dF (HBW)	Pf FPC (W)
1	8/9 pi	0.67	0	pi	0.33	1.5	**160**
2	8/9 pi	0.75	-1.5	3/9 pi	0.25	0	**200**
3	5/9 pi	0.75	0	8/9 pi	0.25	-1.5	**130**
4	7/9 pi	0.58	1.5	4/9 pi	0.42	1.5	**280**
5	7/9 pi	0.75	0	5/9 pi	0.25	0	**80**
6	7/9 pi	0.5	-1.5	4/9 pi	0.5	-1.5	**310**
7	5/9 pi	0.75	0	8/9 pi	0.25	1.5	**130**
8	8/9 pi	0.71	1.5	3/9 pi	0.29	0	**200**
9	8/9 pi	0.67	-1.5	pi	0.33	-1.5	**160**

Field Enhancement at the LCLS-II FPC

- **Field enhancement** at the coupler due to **larger mismatch at room T and different FPC geometry**



9-cell plasma ignition	
Total P_f [W]	350
$E_{coupler}$ [kV/m]	90
E_{cavity} [kV/m]	12

Field enhancement at the coupler ~ 7.5 (for SNS ~ 3)

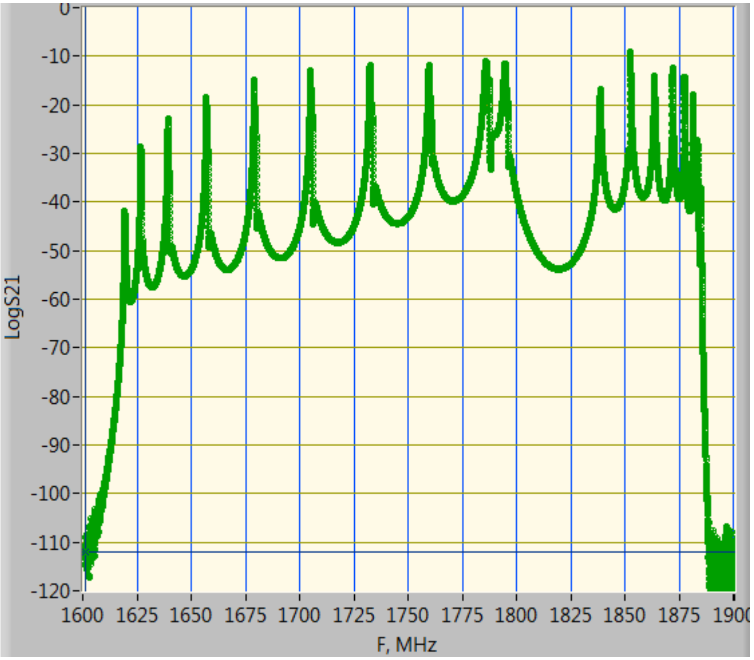
- Suggest larger probability to ignite the plasma at the coupler

$$\beta = \frac{Q_0}{Q_{ext}} \approx 0.003 \rightarrow |\Gamma|^2 \approx 0.99$$

New Idea: Plasma Ignition Using HOMs

- 1st pass-band modes capable of building electric field in each cell.
- Poor coupling at room temperature represents a limitation.
- Is there an efficient way of coupling power to the cavity at room temperature?

HOM couplers are designed to extract power at HOMs frequencies: Good coupling also at room temperature!



For the first monopole pass-band:

$$\beta = \frac{Q_0}{Q_{ext}} \approx 0.003 \rightarrow |\Gamma|^2 \approx 0.99$$

For the first two HOM pass-bands:

$$0.01 < \beta < 1.17 \rightarrow 0.006 < |\Gamma|^2 < 0.94$$

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Plasma Ignition with HOMs superposition I

<u>Solution to avoid ignition of the FPC:</u>

→ **Use mixture of HOMs instead of the FPB modes to ignite plasma**

- For the **first pass-band** <u>only 1% of the power transmitted to the cavity</u>
- Most dipoles of 1st and 2nd passband almost <u>all power gets to the cavity</u> (very good coupling at room T)
- **Plasma will be still ignited sequentially cell-by-cell using HOMS**

	CELL #		1	2	3	4	5	6	7	8	9
HOMs plasma ignition	MODE1	MODE#	2-4	2-6	2-2	2-5	2-1	2-5	2-2	2-6	2-4
		AMP	0.51	0.89	0.94	0.4	1	0.9	0.84	0.76	0.5
	MODE2	MODE#	1-6	1-4	1-3	1-4	-	1-3	1-4	1-9	1-4
		AMP	0.49	0.11	0.06	0.6	-	0.1	0.16	0.24	0.5
	Pf TOT W		**4.71**	**8.97**	**6.35**	**5.89**	**2.97**	**7.78**	**6.02**	**7.23**	**7.28**

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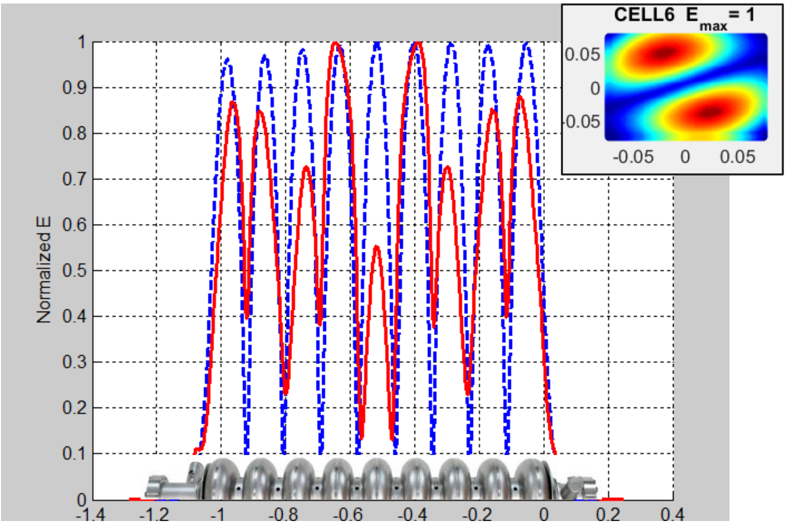
Plasma Ignition with HOMs superposition (example)



5th of 2nd dipole pass band (2-5)

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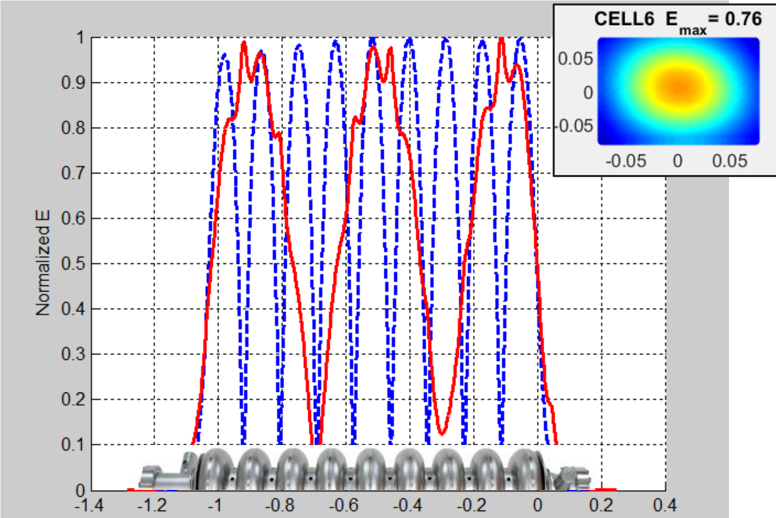

3th of 1st dipole pass band (1-3)

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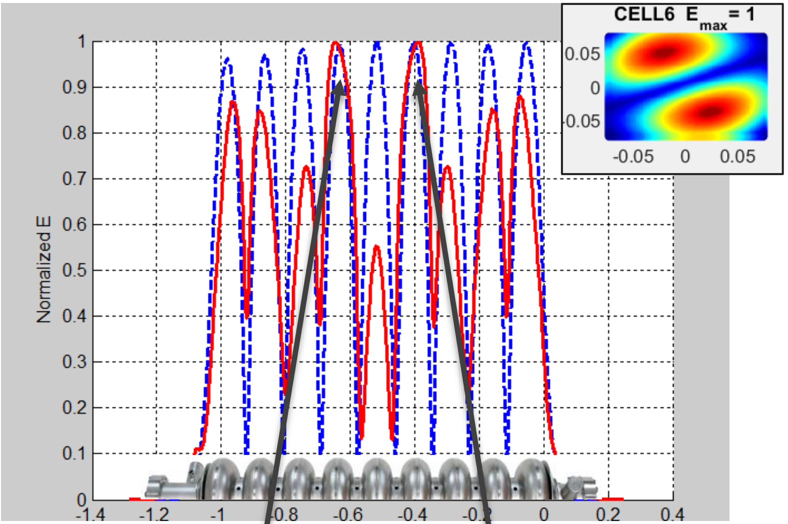
Plasma Ignition with HOMs superposition (example)



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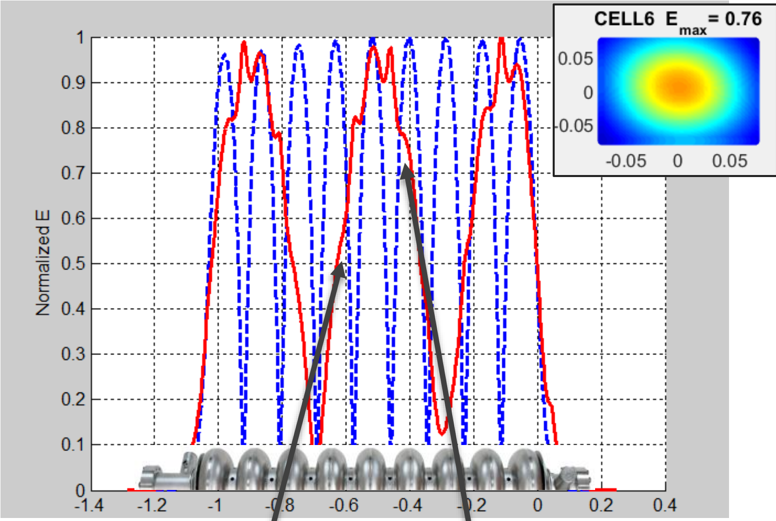
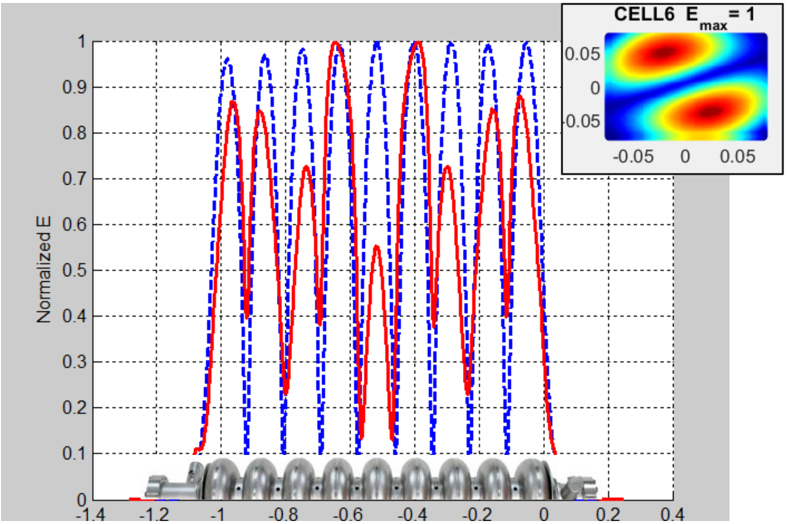


3th of 1st dipole pass band (1-3)

Maximize field in cells #4 and #6

Creates the asymmetry needed to maximize the field only in one of the cell (in this case cell #6)

Plasma Ignition with HOMs superposition (example)



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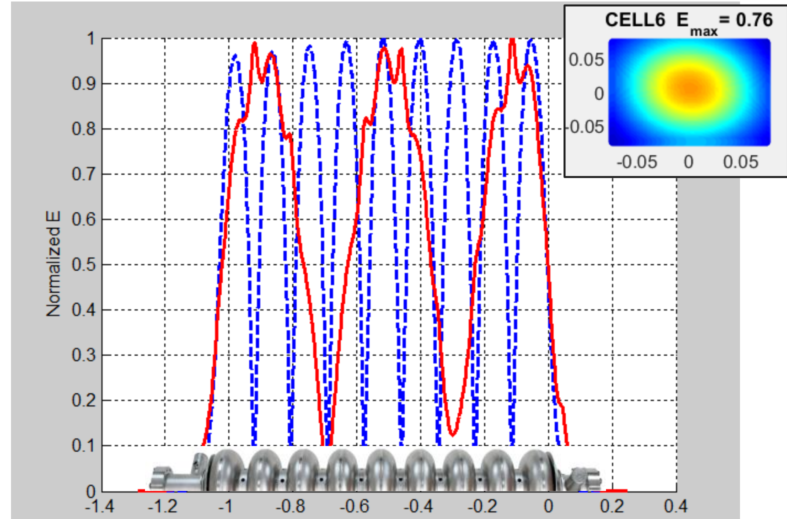

3th of 1st dipole pass band (1-3)

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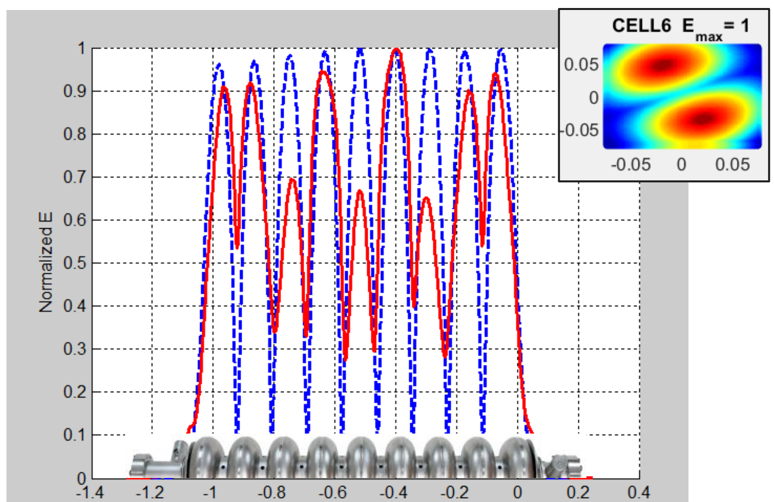
Field amplitude maximized in cell #6



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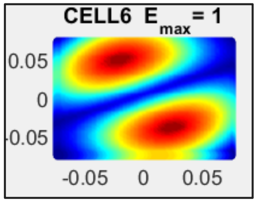
Mode selection to improve plasma homogeneity

Ignition in cell # 6

5th of 2nd DPB



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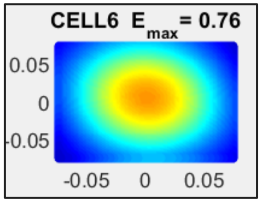
3rd of 1st DPB



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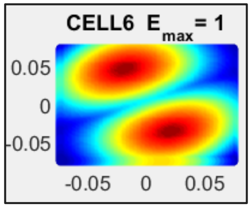

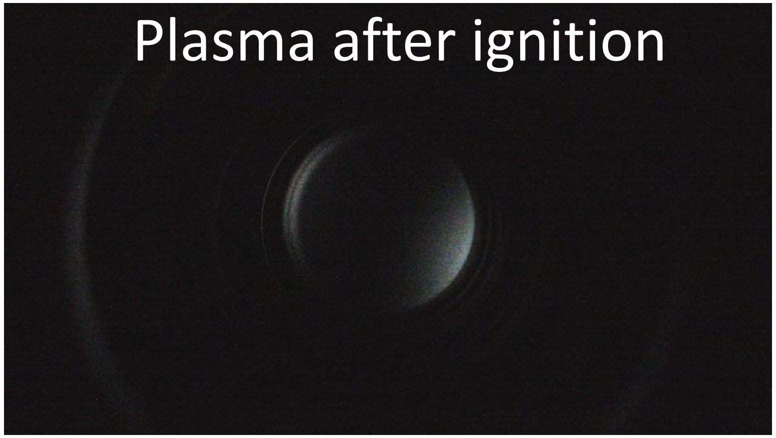

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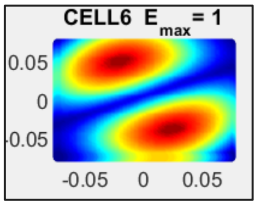

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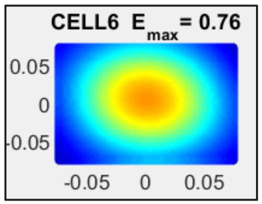
3rd of 1st DPB



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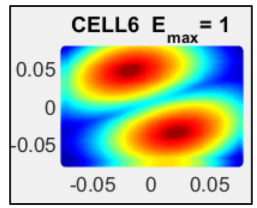
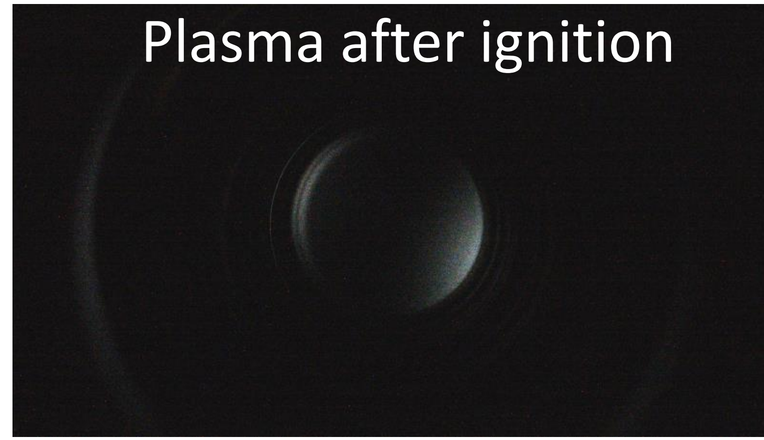
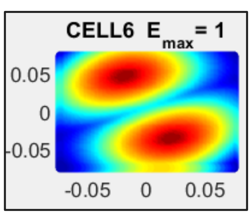




After ignition, it is possible to pick a mode with uniform field distribution in the ignited cell and use it for plasma tuning. For example in cell #6: shut off 1-3, add 1-6 and shut off 2-5.



2-5 and 1-3

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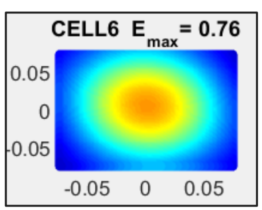

3rd of 1st DPB

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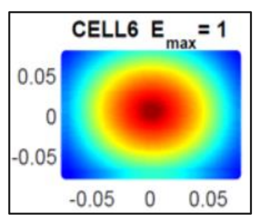

6th of 1st DPB

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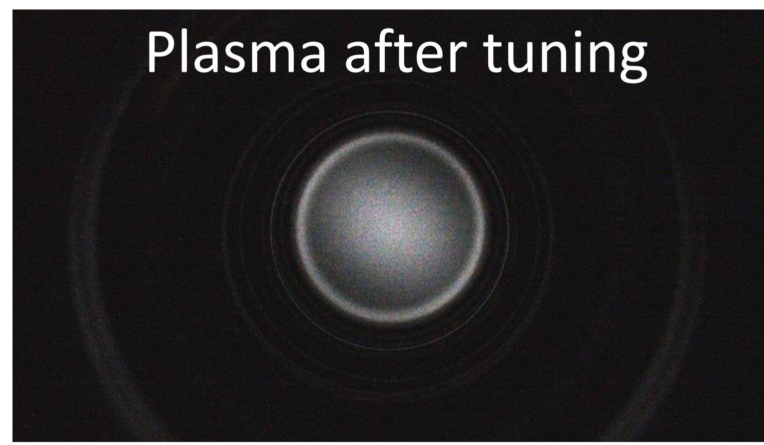
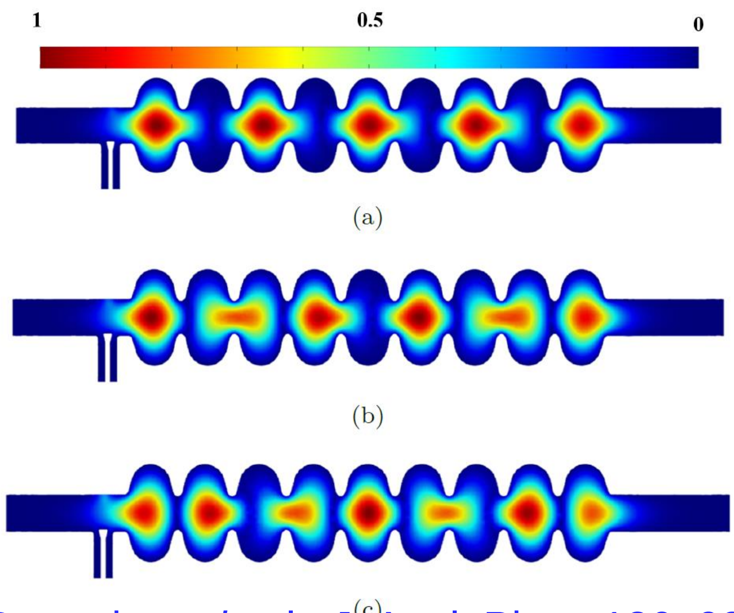
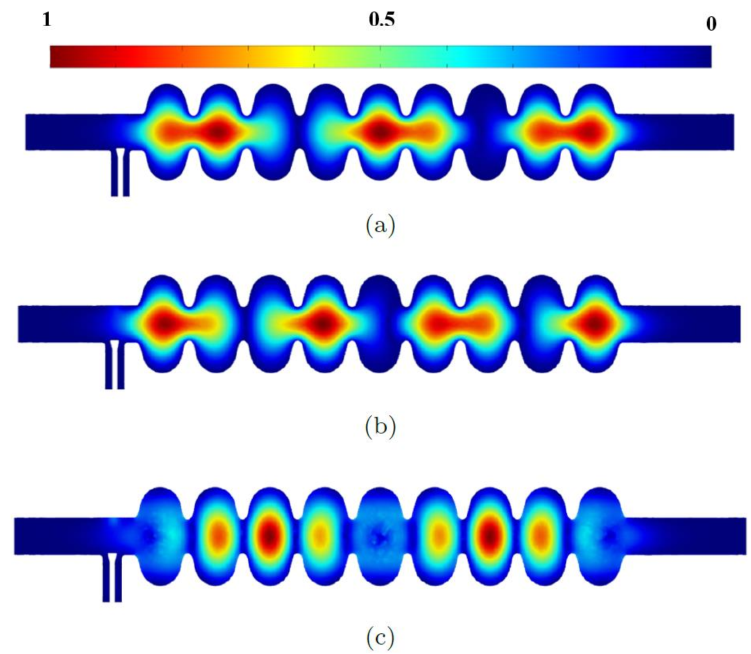


HOMs superposition drawbacks and Plasma Bridging

- HOMs are not tuned like the first monopole passband → frequency and field distribution may vary from cavity to cavity → relying on local asymmetries is not ideal
- Some HOMs have a very uneven electric field distribution → need to select a mode with uniform field distribution after ignition
- Alternative idea: ignite always cell #5 and transfer the plasma from cell to cell, not relying on localized maximum for cell ignition.





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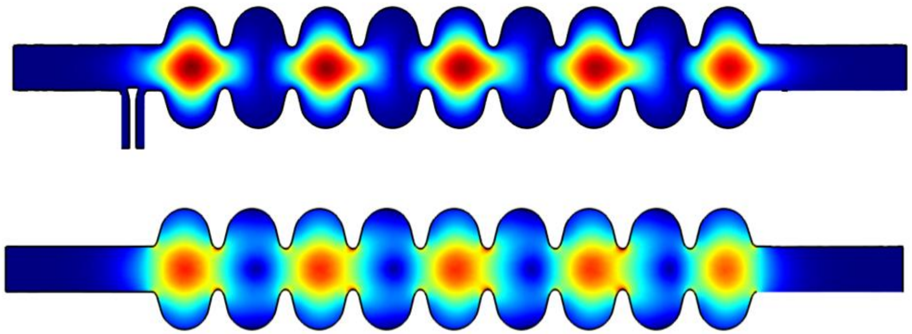
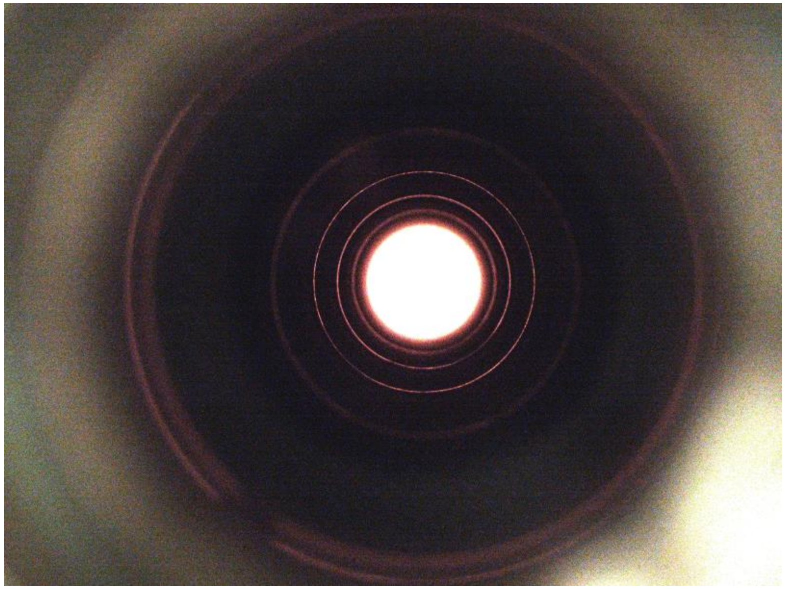
1st dipole pass-band: monopole-like

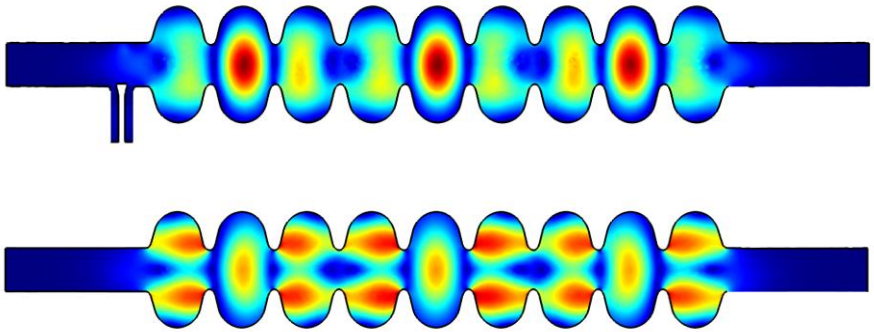
Mode 1-5

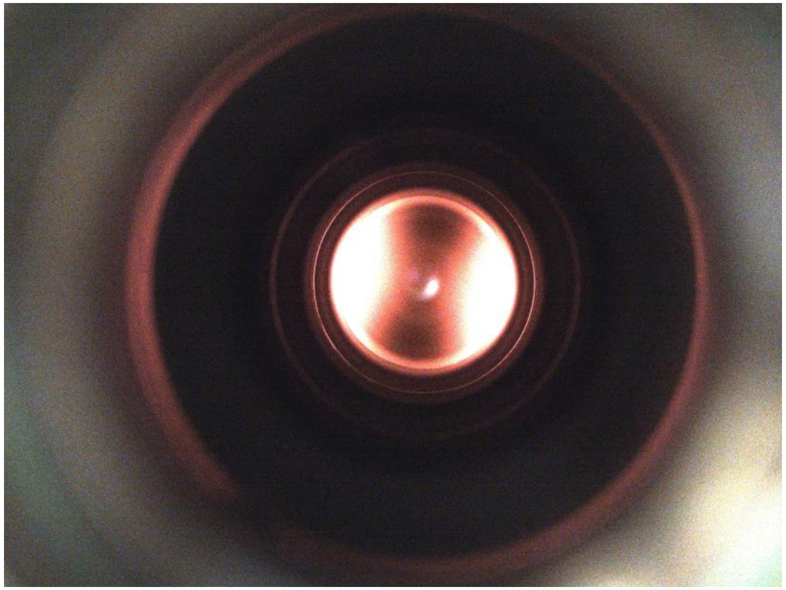




2nd dipole pass-band: more dipole-like

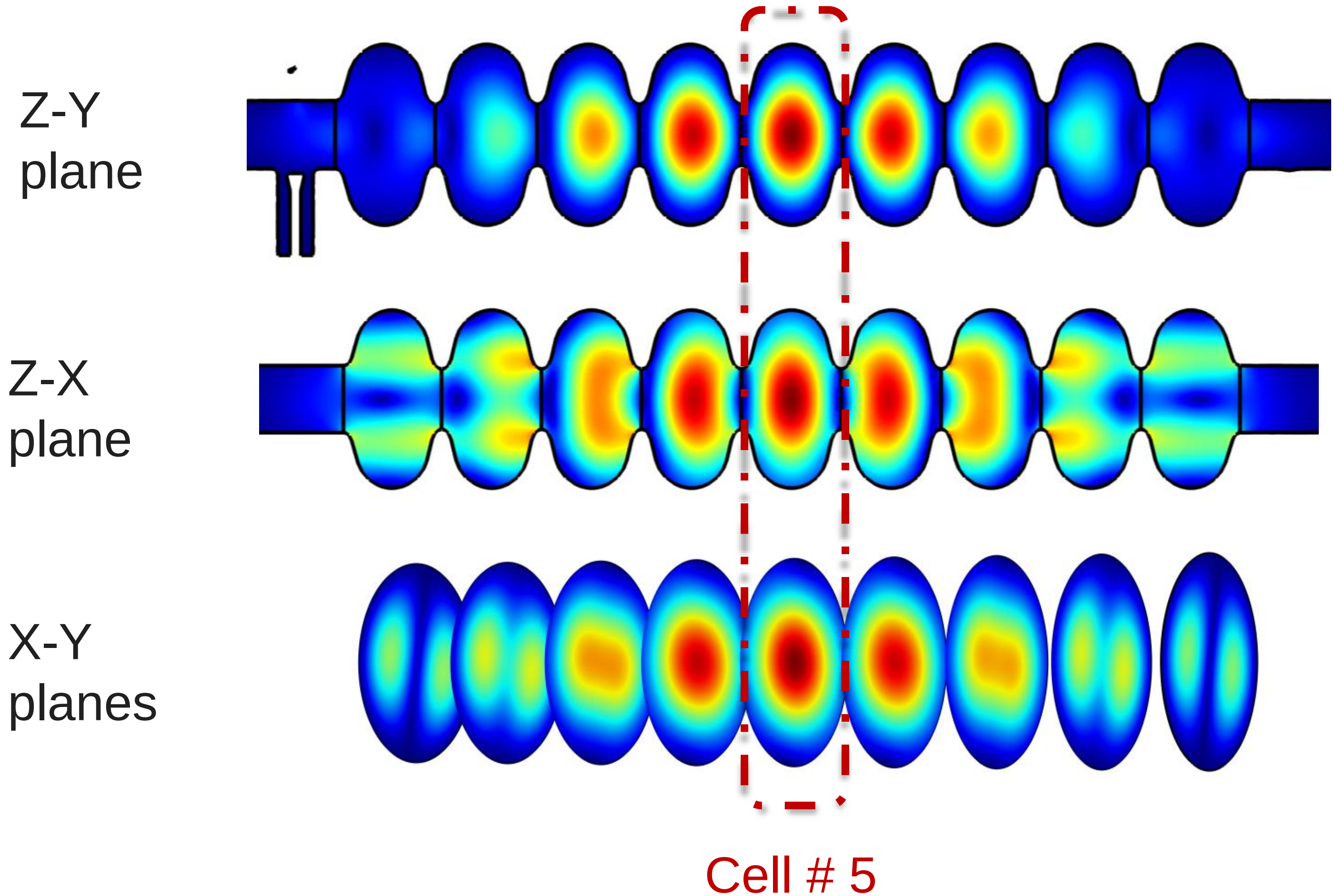
Mode 2-3





Plasma bridging I: ignition

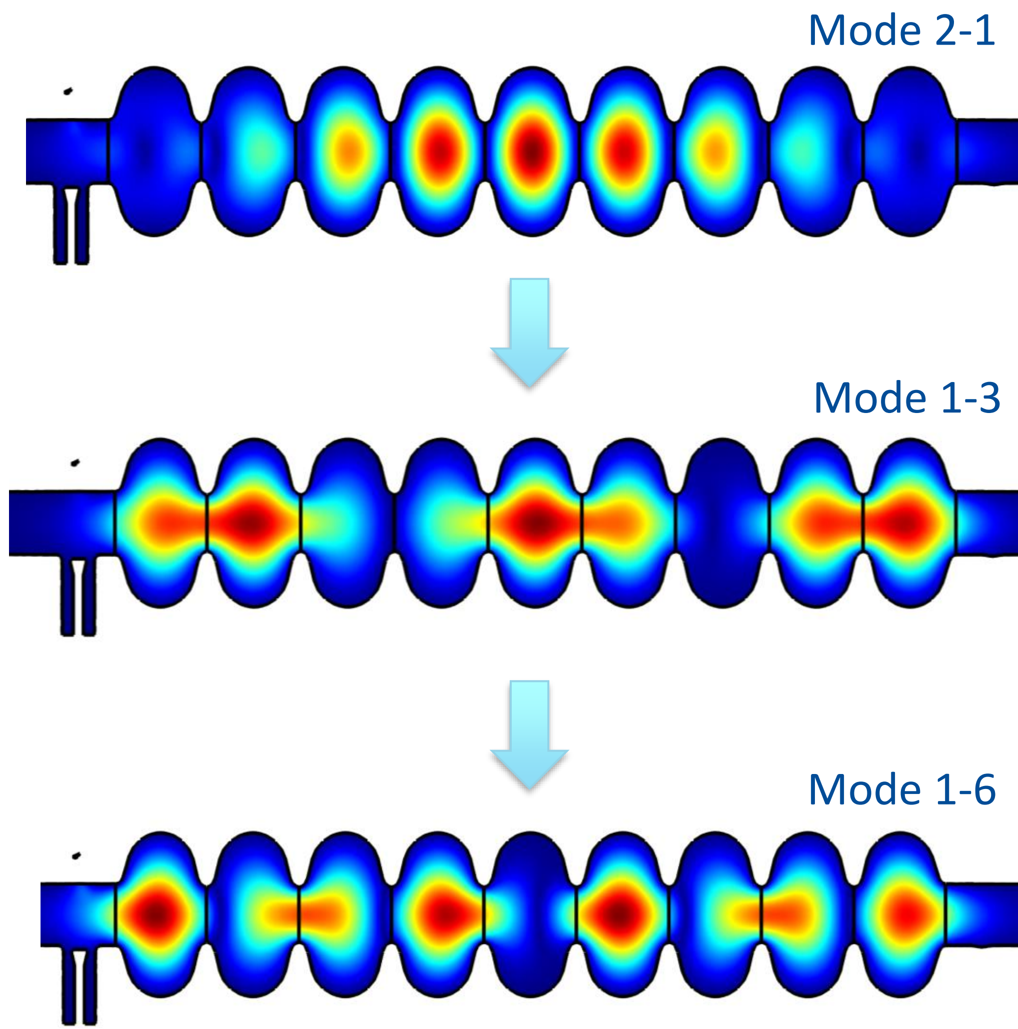
Initial plasma ignition in cell #5 using mode 2-1



P. Berrutti, *et al.*, al., J. Appl. Phys. 126, 023302

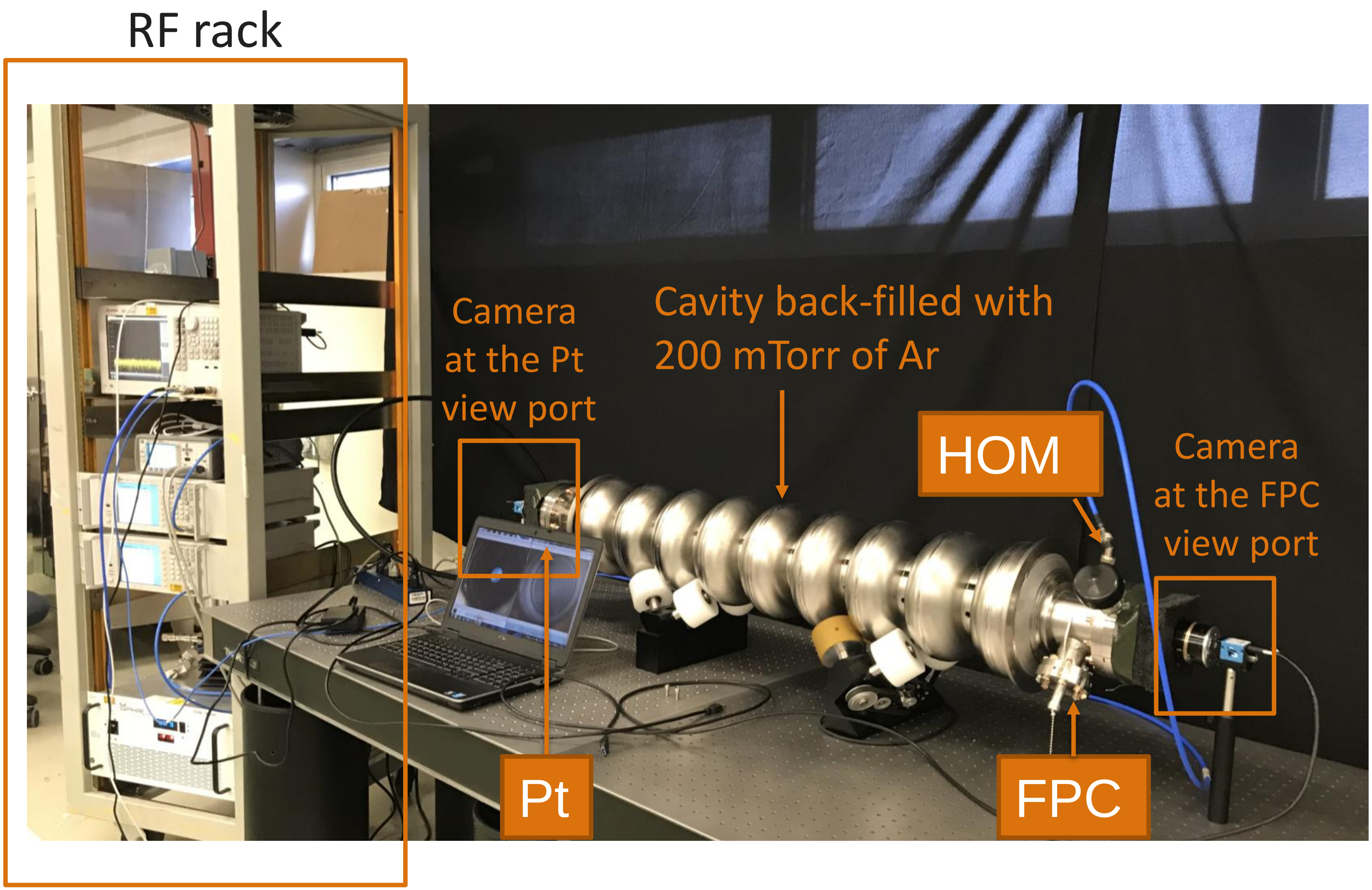
Plasma bridging II: plasma transfer #5 to #6 (example)

1. Cell #5 is ignited with **mode 2-1**
2. **Mode 1-3** is added to create unbalance between cell #4 and cell #6 but the E field is still maximum in cell #5
3. **Mode 2-1** can now be switched off and the plasma remains ignited in cell #5
4. Add **mode 1-6** to 1-3: E field is maximum in cell #6, the plasma moves from 5 to 6
5. Switch off mode 1-3, plasma remains ignited in cell #6.

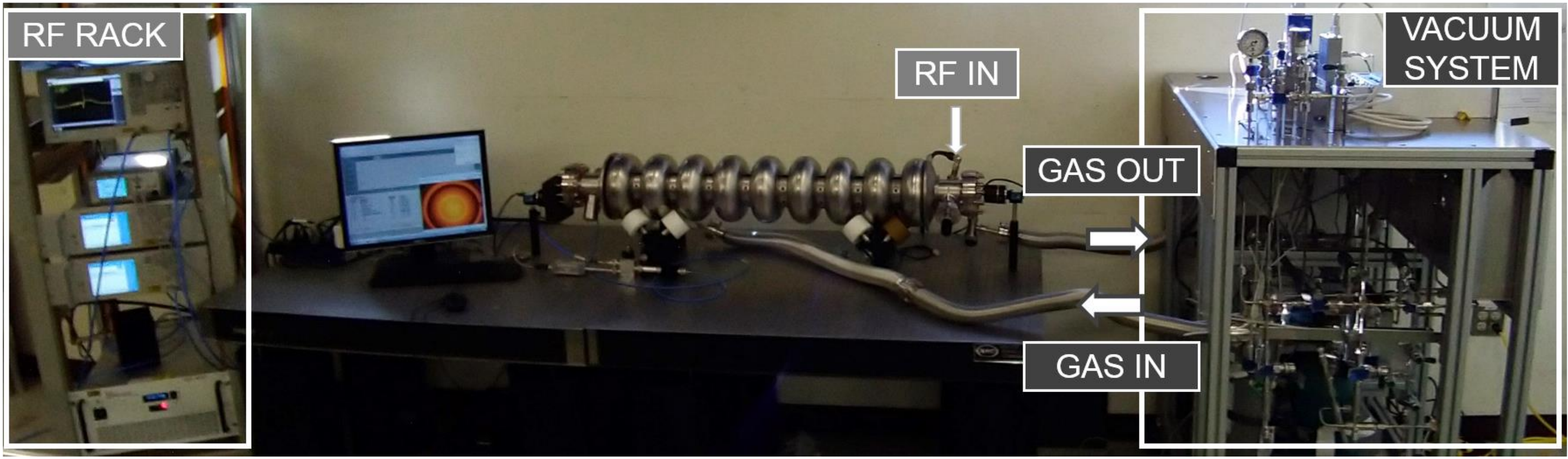


P. Berrutti, *et al.*, al., J. Appl. Phys. 126, 023302

Set-up Plasma Ignition Studies for LCLS-II



Set-up Plasma Ignition Studies for LCLS-II

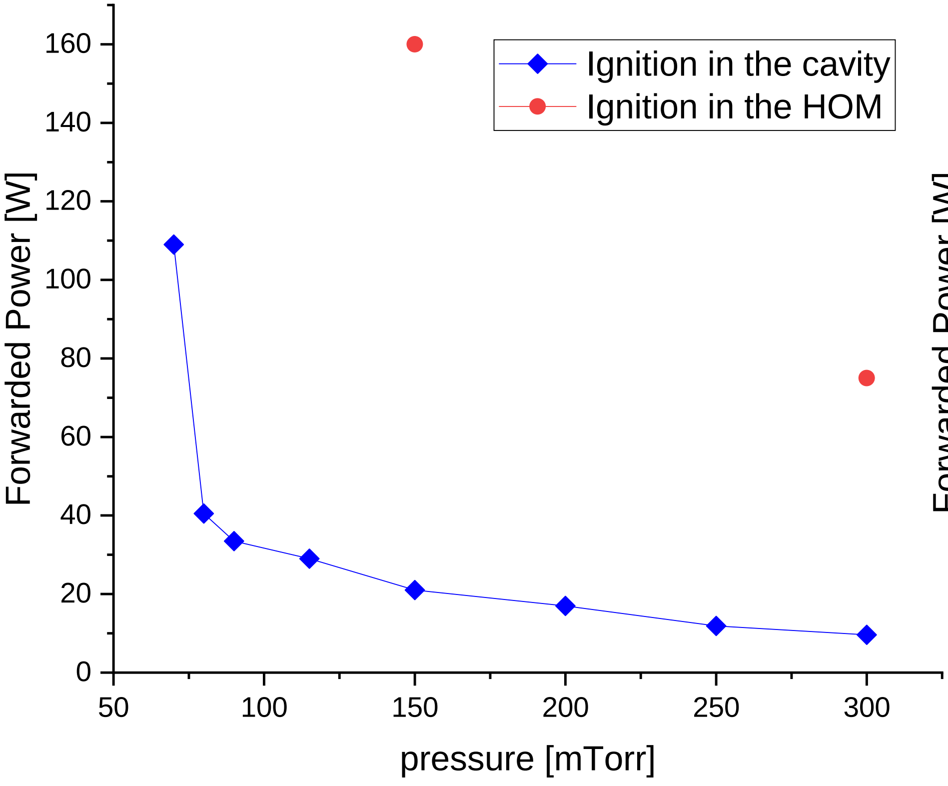


- Cleaning is performed at room temperature with 75-200 mTorr of Ne-O_2
- Cavities are assembled with valves on both end sides, for injection and evacuation of the gas
- Neon and Oxygen are sent to the cavity mixed (few % of O_2)
- RGA is used to analyze by-products

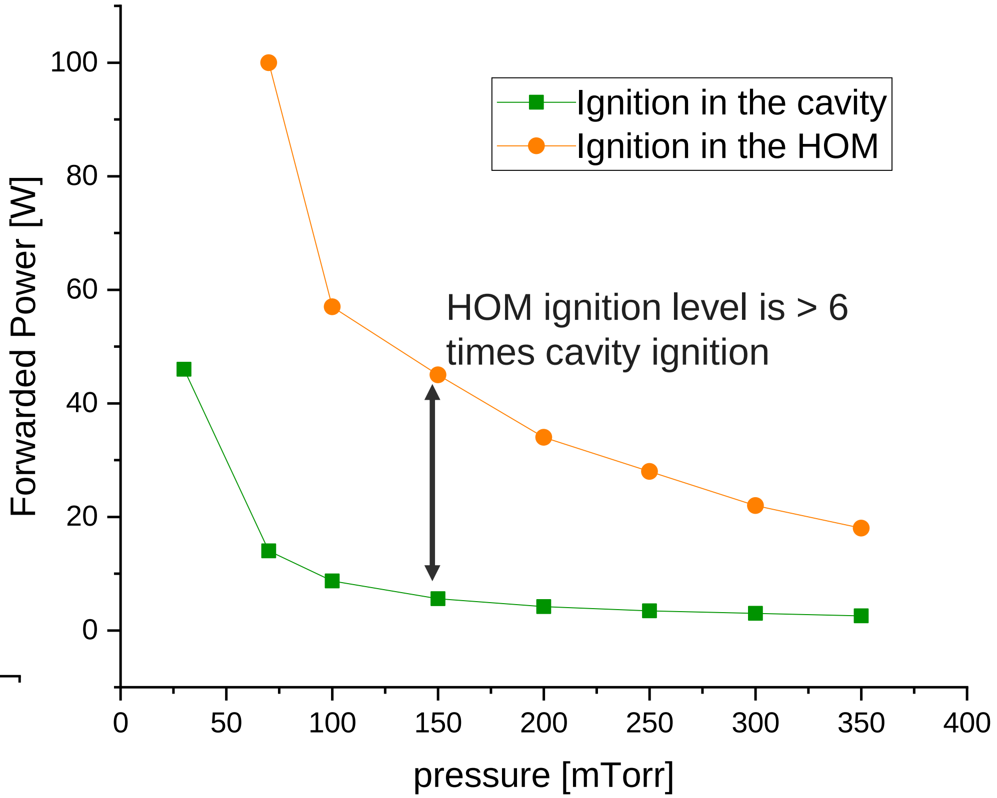
Ne and Ar ignition curves

- Plasma ignition as a function of pressure monitored for both Neon and Argon
- Verified that the risk of igniting the plasma at the HOM coupler is negligible

Curve of plasma ignition using **Neon**

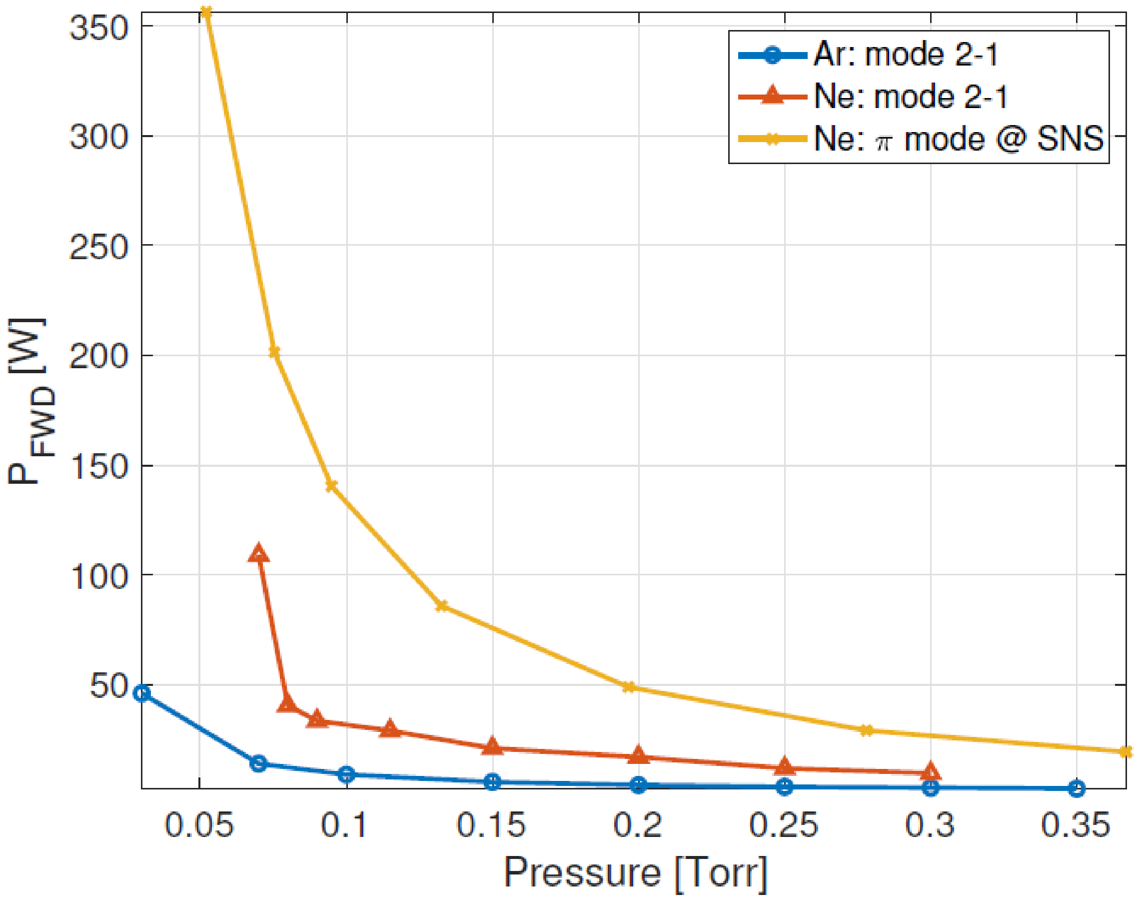


Curve of plasma ignition using **Argon**

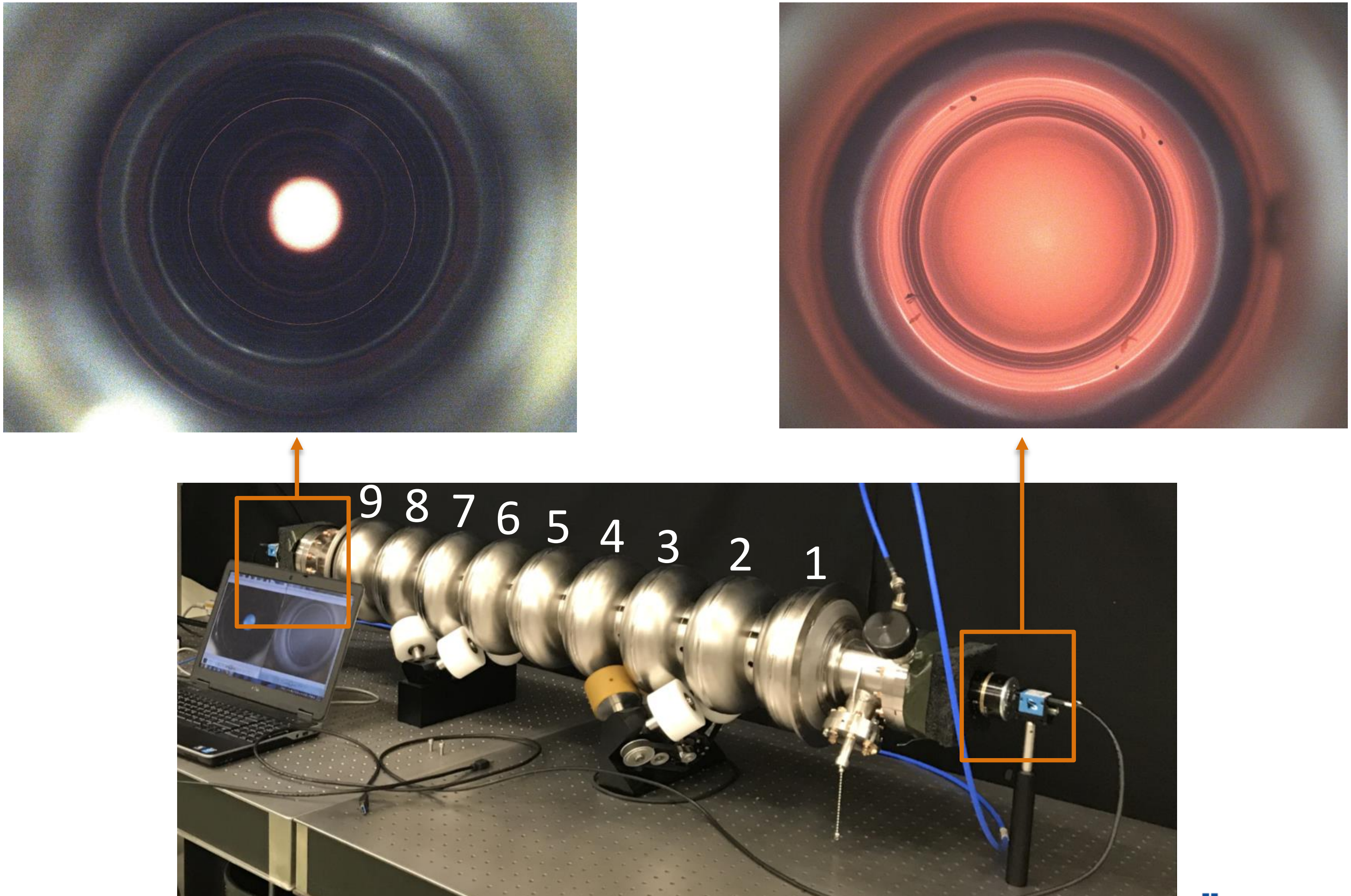


Plasma ignition comparison with Dual Tone excitation

- Total forward RF power needed for HOMs plasma ignition (LCLS-II) is compared with SNS pi-mode power

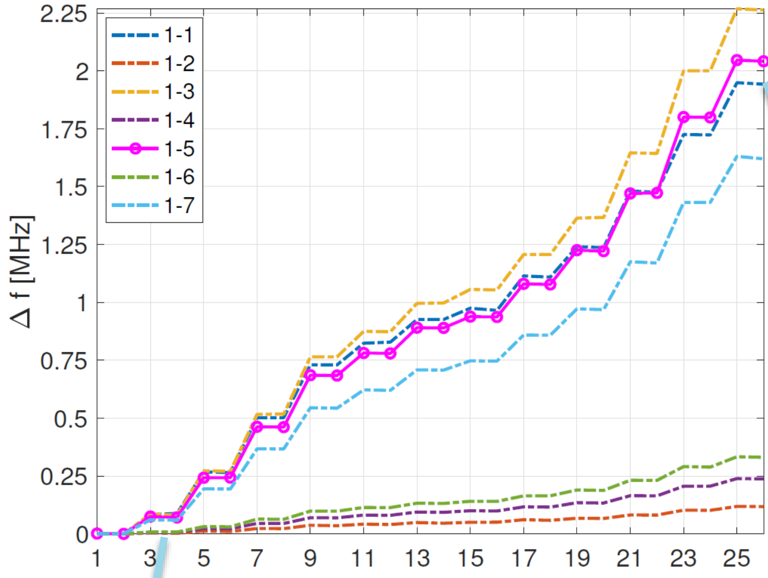


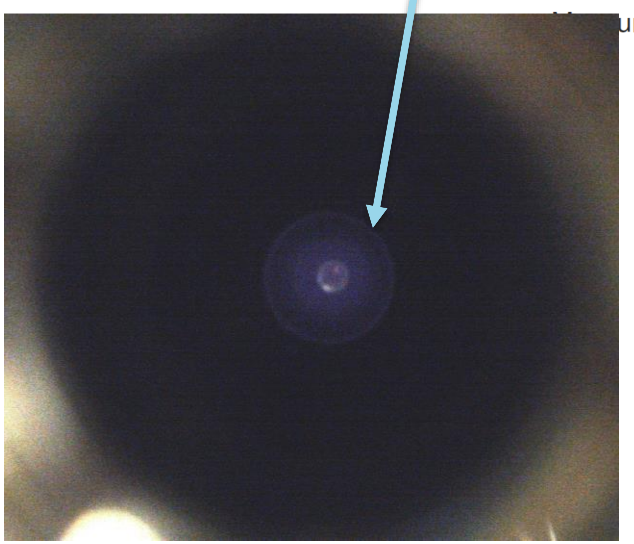
Selective Plasma ignition in 9-cell cavities

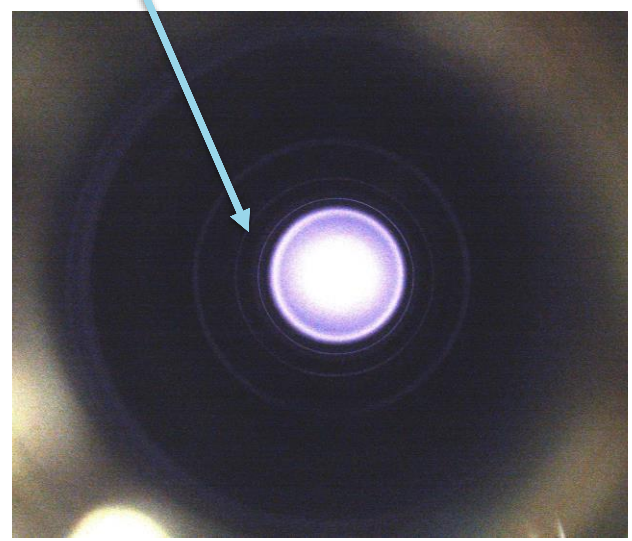


Fermilab

Plasma tuning using HOMs I







To tune the intensity can be varied:

- P_{FWD}
- ω_{RF}

sent to the cavity

$\Delta f_{max} \approx$ 15-20MHz

Plasma tuning using HOMs II

Plasma density n_e is related to $\delta\omega$ of the cavity modes, through the plasma frequency and Slater's theorem:

$$\frac{\delta\omega}{\omega} \approx \frac{1}{2}\frac{\iiint_{plasma} \eta E^2 dV}{\iiint_{cavity} E^2 dV}, \qquad \eta = \frac{\omega_{pl}^2}{\omega_{RF}^2} = 1 - \varepsilon$$

$$\omega_{pl} = \sqrt{\frac{n_e\, e^2}{\varepsilon_0\, m}} \Rightarrow n_e \approx \frac{\delta\omega}{\omega}\frac{2\varepsilon_0\, m\omega_{rf}^2}{e^2}\frac{\int_{cavity} E^2 dV}{\int_{plasma} E^2 dV}$$

Plasma detection via RF measurements I

Method to locate the cell where plasma is ignited without use of cameras:

1. The frequency shift $\delta\omega$ of the first dipole pass-band due to plasma ignition is measured

$\delta\omega$ depends on:

- Change in dielectric constant due to plasma ($\epsilon \propto \eta$)
- Intensity of the electric field of the mode in the cell of ignition

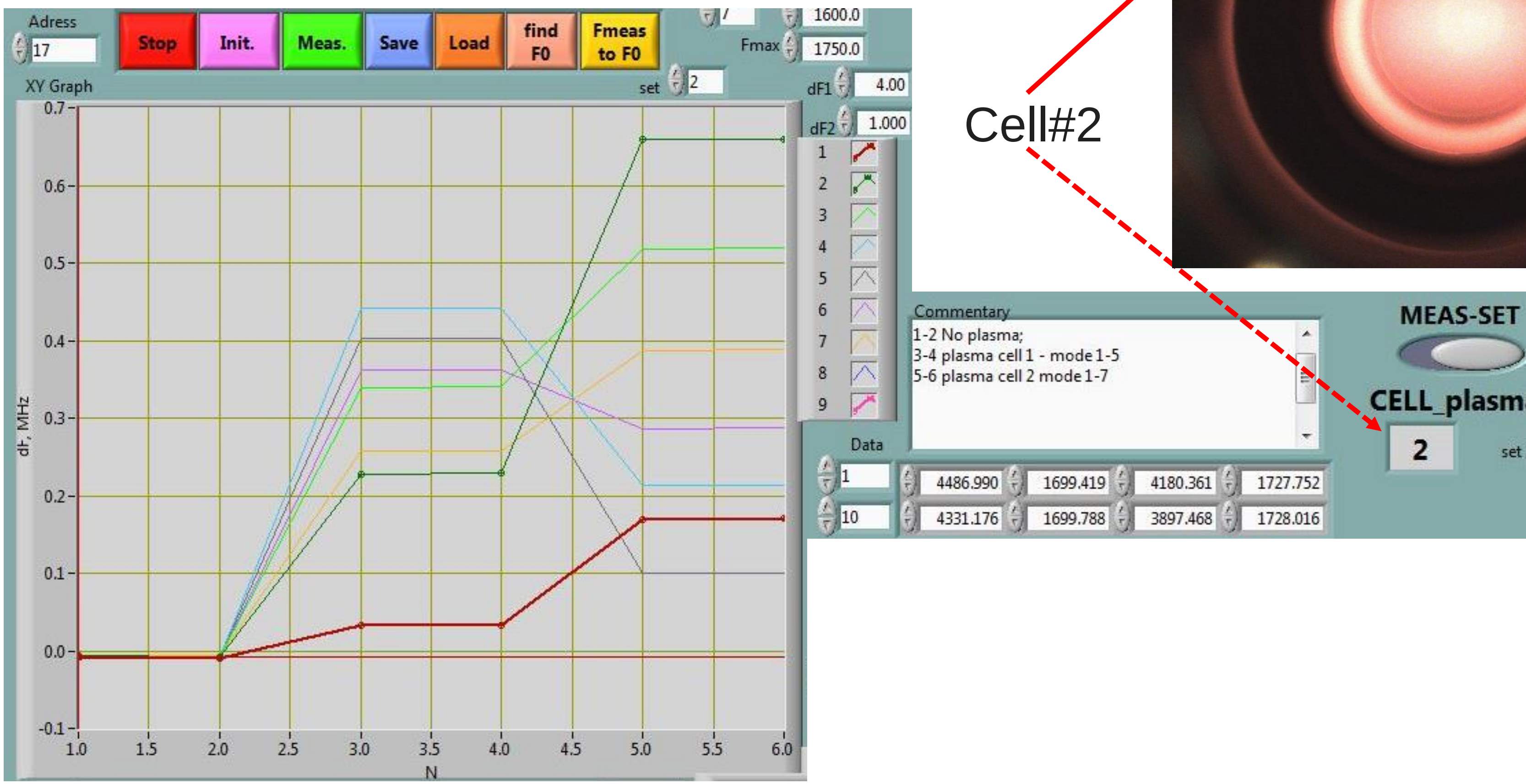
$$\frac{\delta\omega}{\omega} \approx \frac{1}{2}\frac{\iiint_{plasma} \eta E^2 dV}{\iiint_{cavity} E^2 dV}, \qquad \eta = \frac{\omega_{plasma}^2}{\omega_{RF}^2}$$

2. Measured $\delta\omega$ is compared with $\delta\omega$ calculated simulating the glow discharge in each cell of the cavity

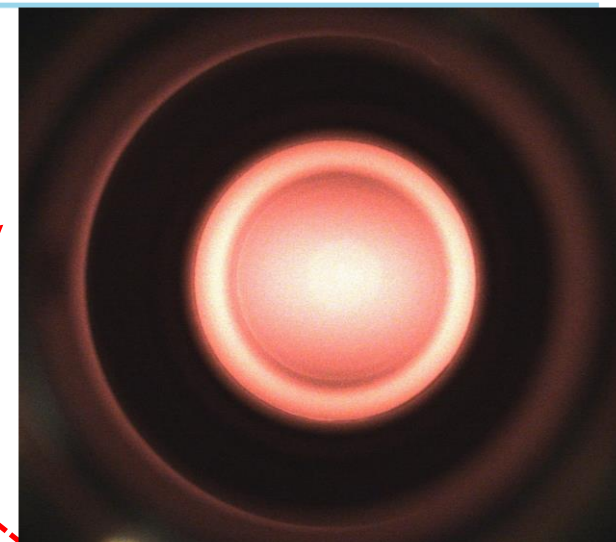
Fermilab

Plasma detection via RF measurements II

Developed a Labview program that measures $\delta\omega$ and compares it to simulated $\delta\omega$ and identifies cell of ignition



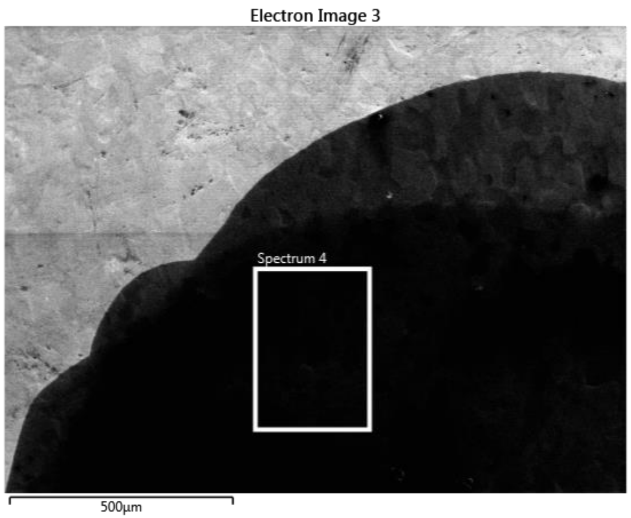
Cell#2



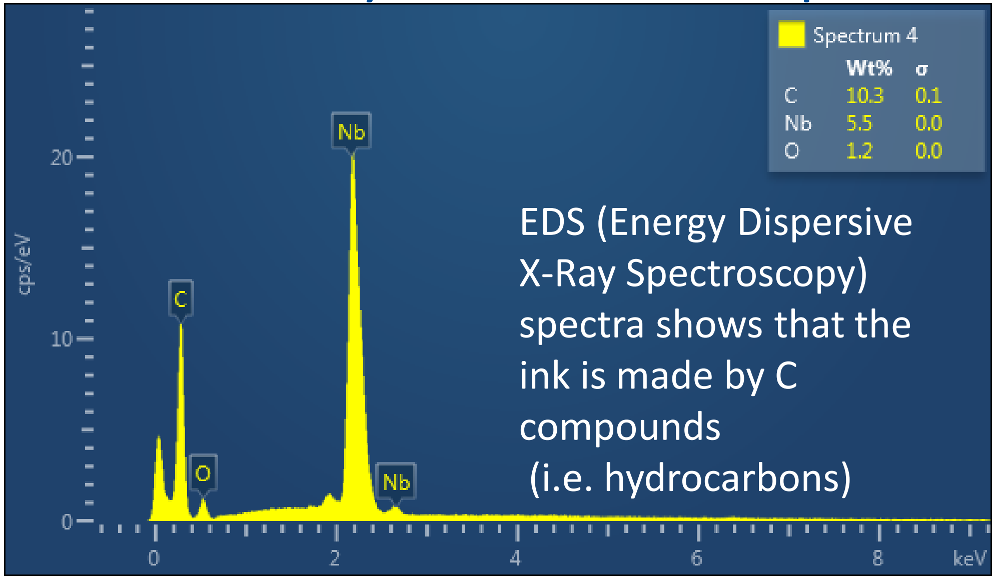
Fermilab

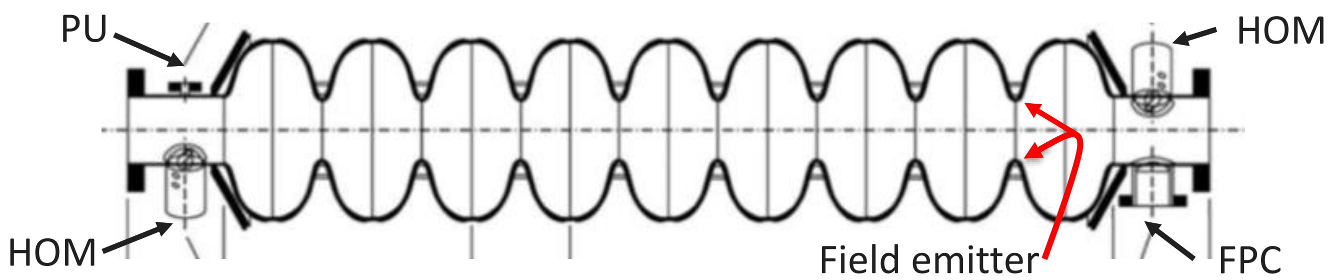
Plasma processing studies in artificially contaminated cavity

- 1^{st} test goal: remove hydrocarbon contamination with plasma cleaning
- 8 "dots" were drawn with both red and black permanent markers around the iris of the first cell of a 9-cell LCLS-II cavity



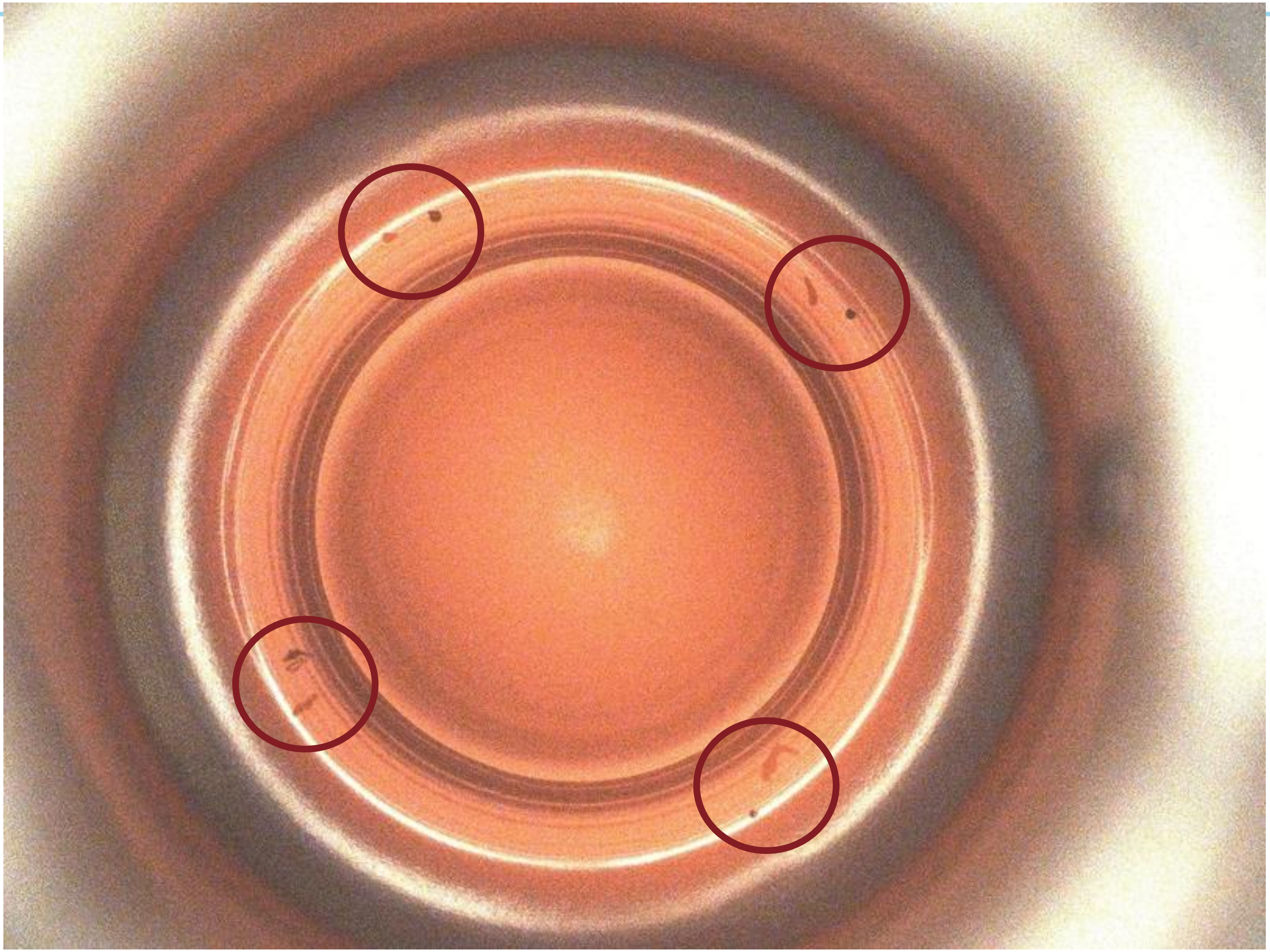
EDS analysis of black Sharpie ink





Fermilab

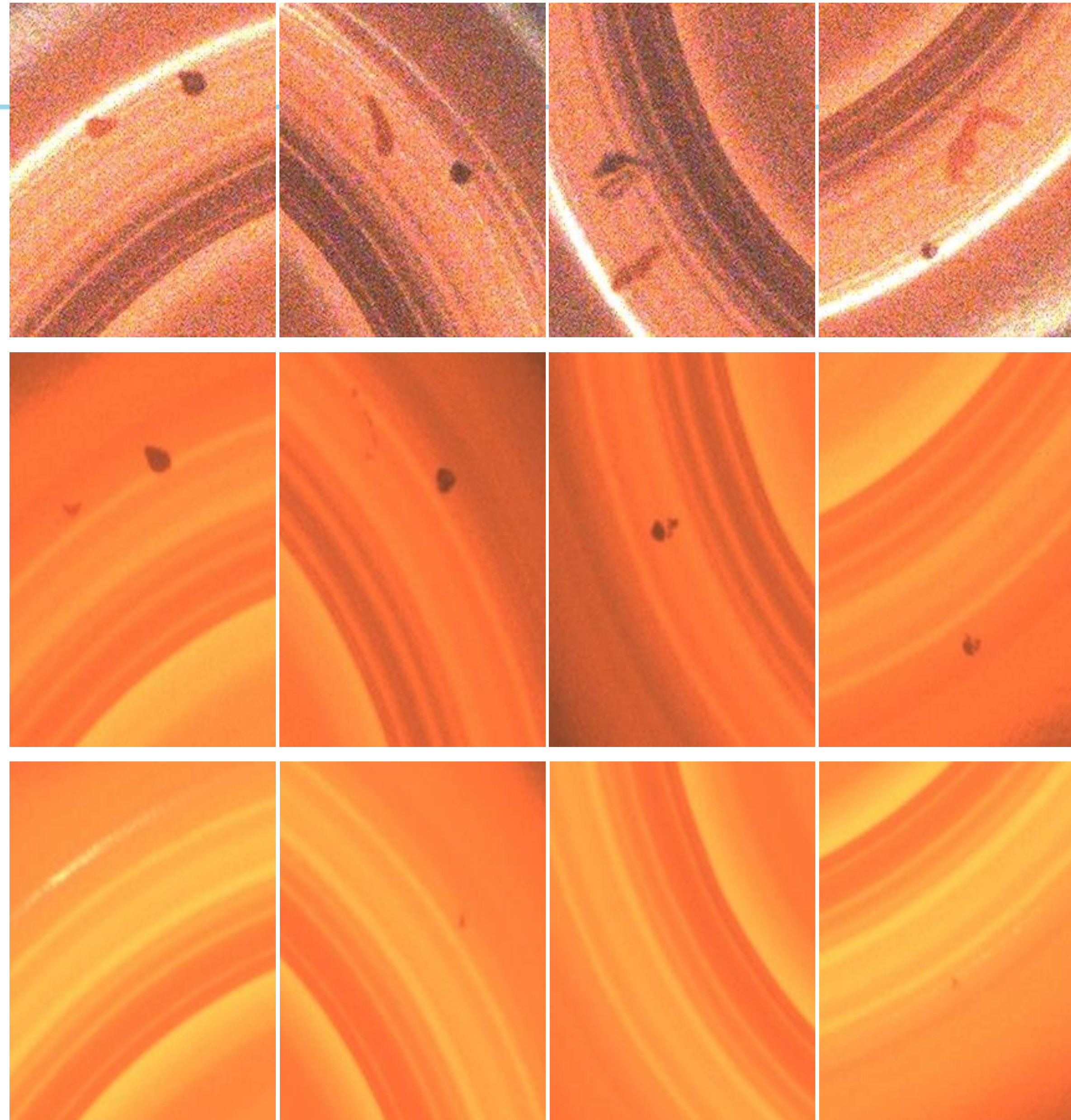
Contaminated cell (#1) has been processed for ≈ 19 hours total



Initial state

After 5h of plasma cleaning

After 19h of plasma cleaning

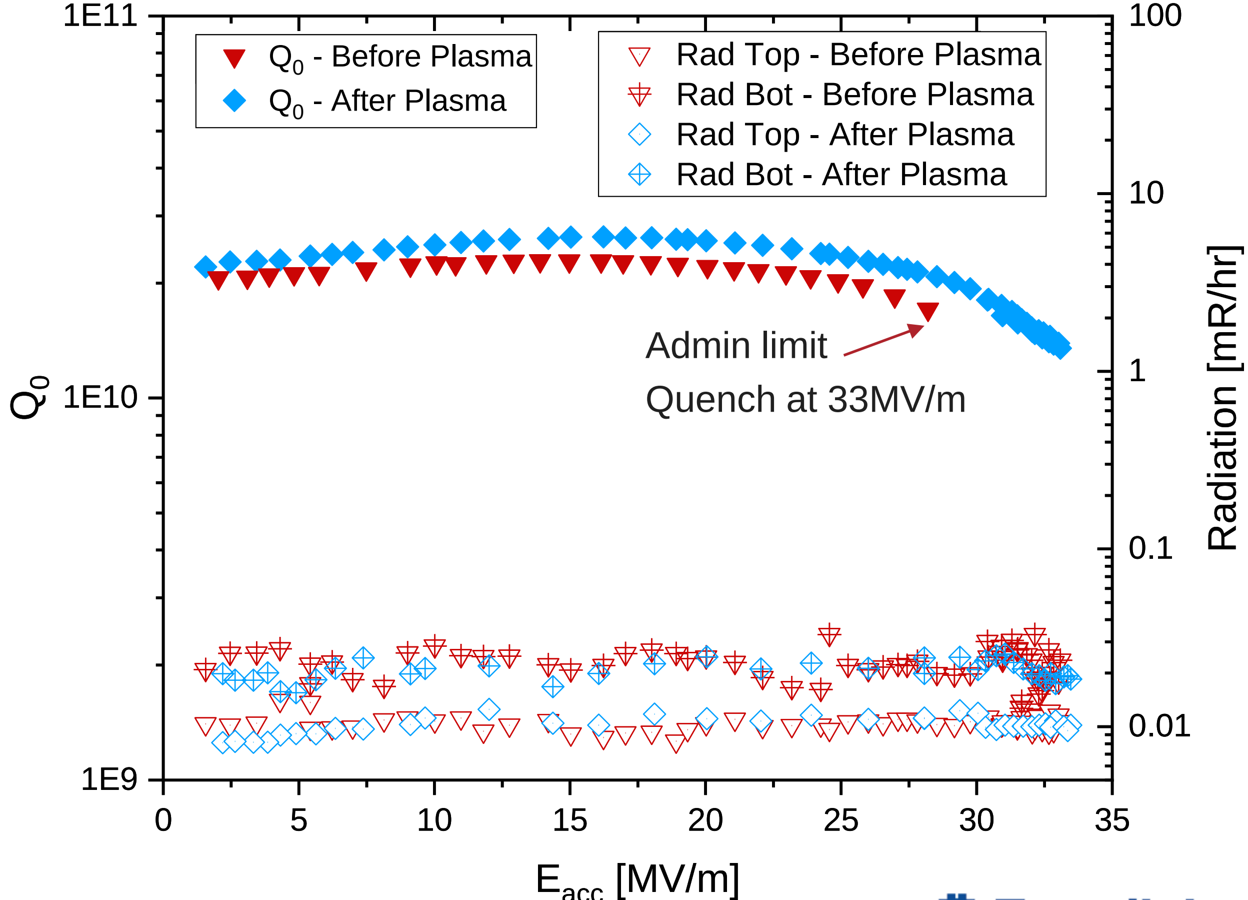


N-doped single cell: RF results before and after plasma processing

Scope: study effect of plasma processing on Q-factors on N-doped cavities

- N-doped cavity processed for 16h with Ne-O_2 plasma.

RF test proved that the **plasma preserves** the **high Q and E field** on N-doped cavity



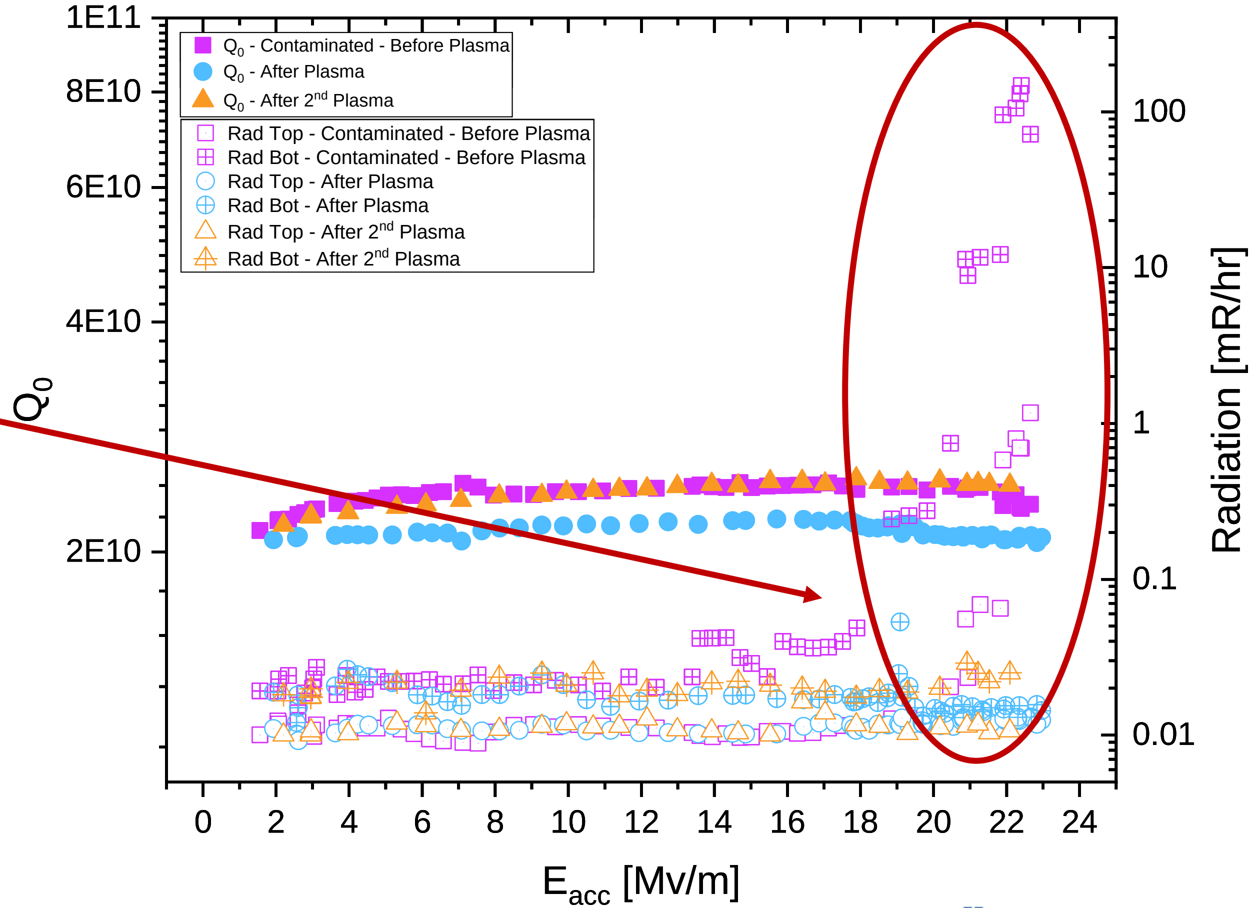
Simulated vacuum failure: RF results before and after plasma processing

Scope: study the removal of natural contamination

- 9-cell cavity: each cell processed for 1h 40min with $Ne\text{-}O_2$ plasma.

RF test showed that the **plasma removed** the **radiation** associated with field emission

Q_0 lowering due to trapped flux during cool down

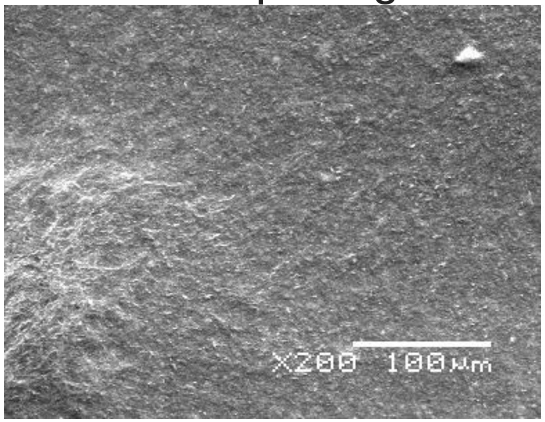


Fermilab

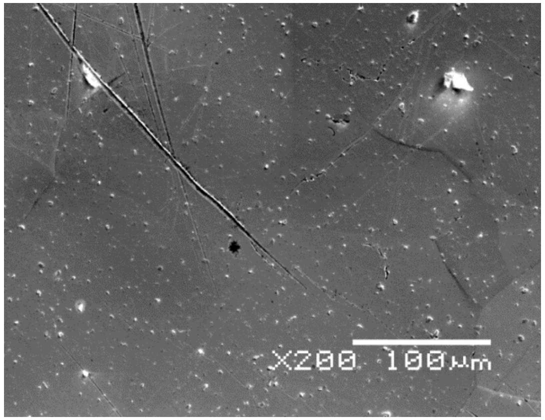
Controlled introduction of carbon contamination

- Small drop of Aquadag (carbon-based conductive paint) introduced using a clean Nb wire at the iris of a single-cell cavity

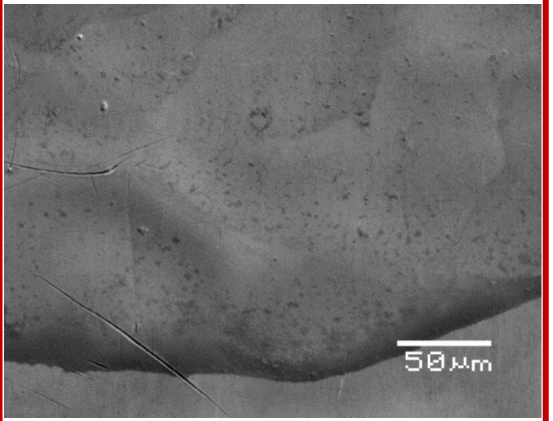
Pure Aquadag



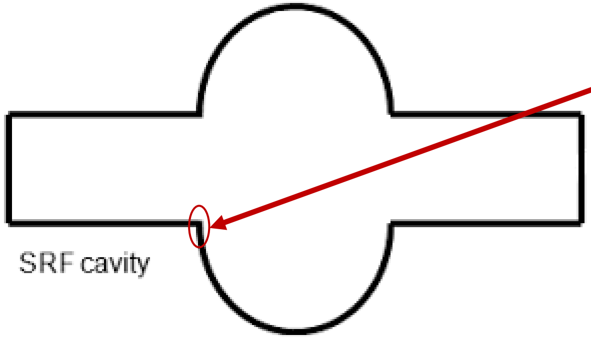
10^2 times diluted Aquadag



10^4 times diluted Aquadag



Chosen concentration

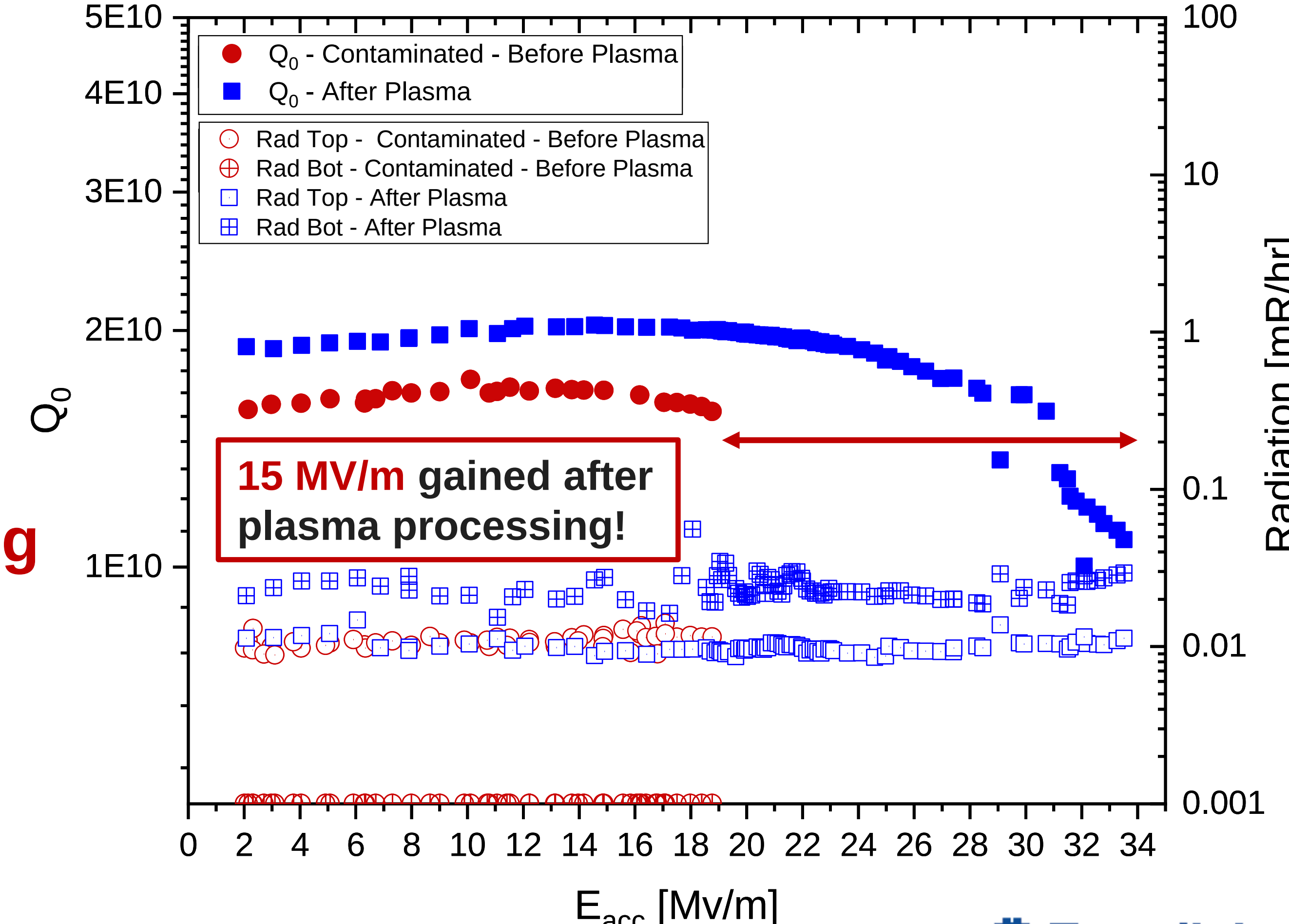


Carbon contamination: RF results before and after plasma processing

Scope: study the removal of Carbon contamination

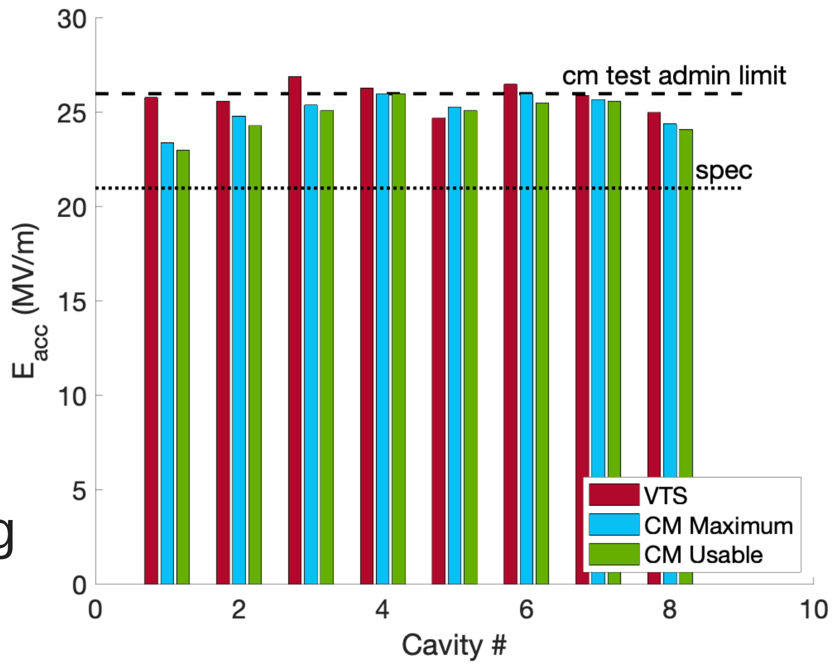
- Single cell cavity processed for 17h with Ne-O_2 plasma.

RF test showed that the plasma removed the contamination **restoring** the **initial accelerating field**



LCLS-II-HE verification Cryomodule

- Verification CM for LCLS-II-HE: assembled and tested at Fermilab
- **Gradient and Q_0 in all 8 cavities exceeds the ambitious LCLS-II-HE specification**
- No field emission observed at any gradient in any cavities after processing



World record cryomodule!

	E_{acc} Spec	E_{acc} avg	Q_0 Spec	Q_0 avg
HE vCM (8 cavities)	**21 MV/m**	**25 MV/m**	**2.7×10^{10}**	**3.0×10^{10}**
LCLS-II prod'n (280 cavities)	16 MV/m	19 MV/m	2.7×10^{10}	2.9×10^{10}

S. Posen et al., Phys. Rev. Accel. Beams 25, 042001

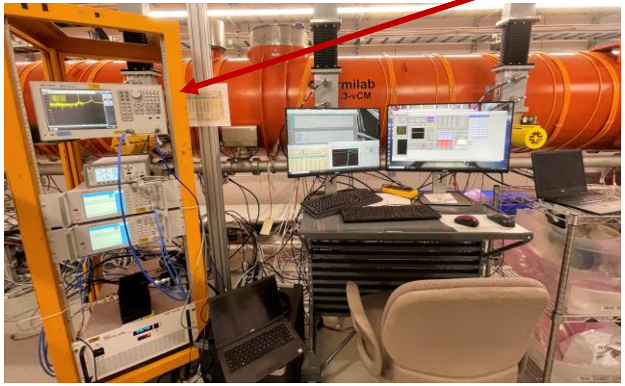
Fermilab

Experimental systems: gas injection, vacuum & RF

Gas cart – connected to Feedcap side

Vacuum cart – connected to Endcap side

RF system, computers

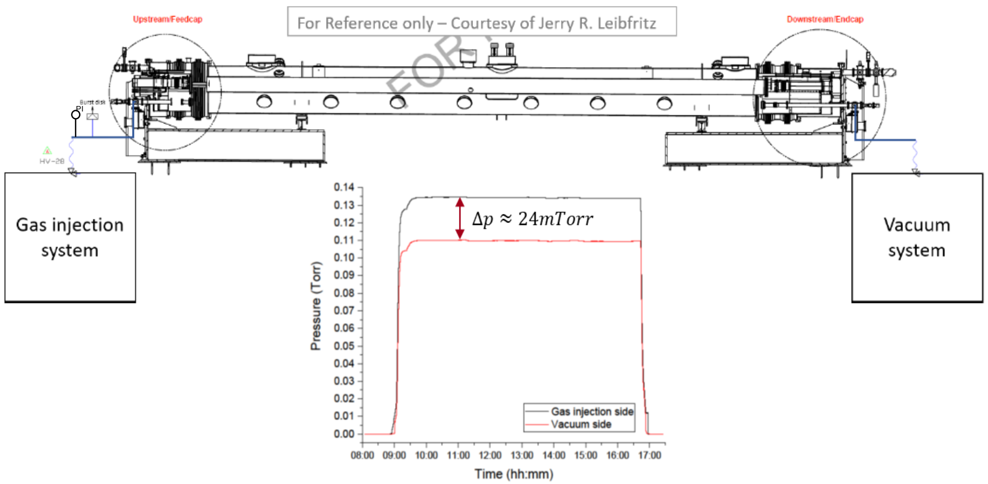


Fermilab

Connections between gas/vacuum systems and CM

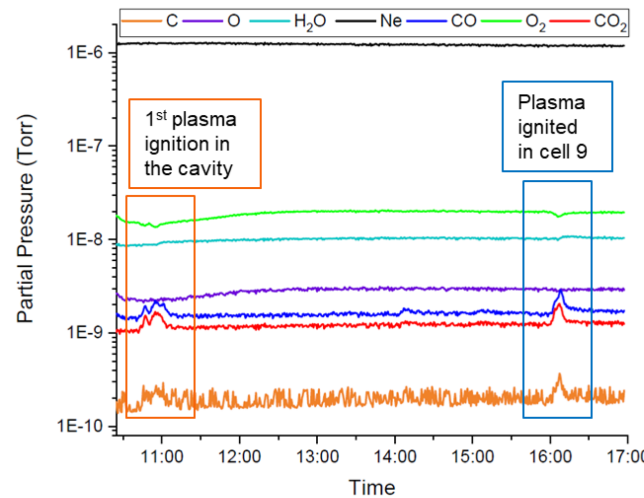
Connections between vacuum/gas systems and vCM: conducted in cleanroom to minimize risk of particle contamination

Plasma processing applied to LCLS-II HE vCM I



Each morning the gas flow was established through the vCM

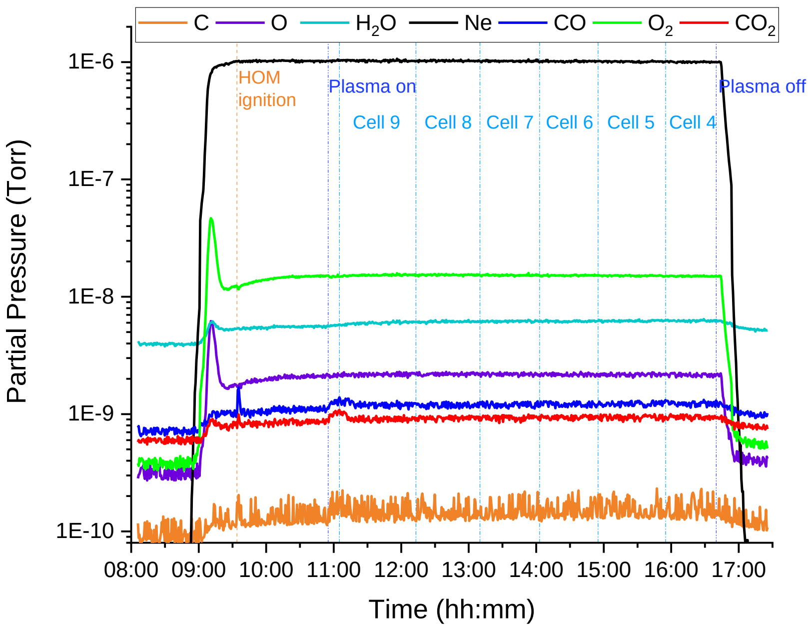
CAV1: 1st day of plasma processing

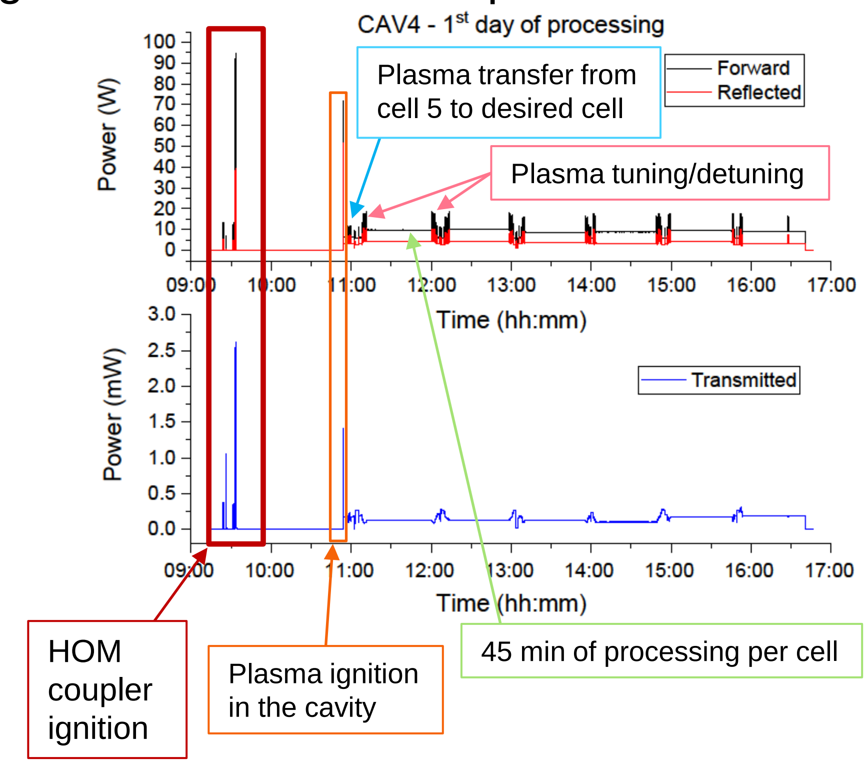


- Increase in CO,CO_2, C signals is observed along with decrease in O_2 signal
- Almost no by-products measured by RGA during 2nd day of plasma processing.

Plasma processing applied to LCLS-II HE vCM II

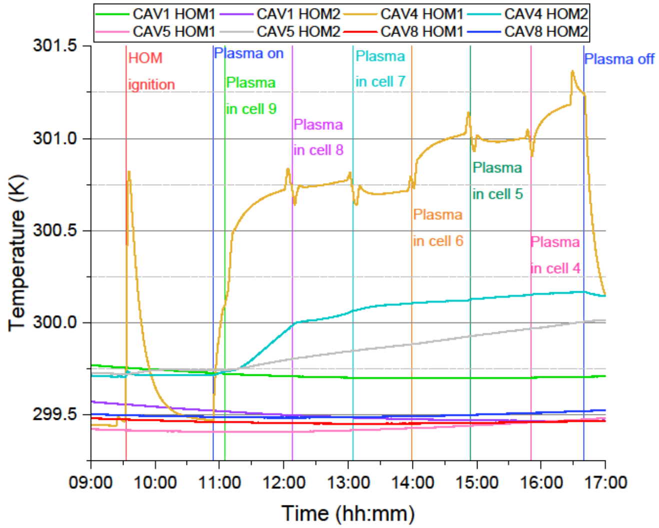
Example of experimental data collected during plasma processing of CAV4. This includes a rare case of plasma ignition at the HOM coupler

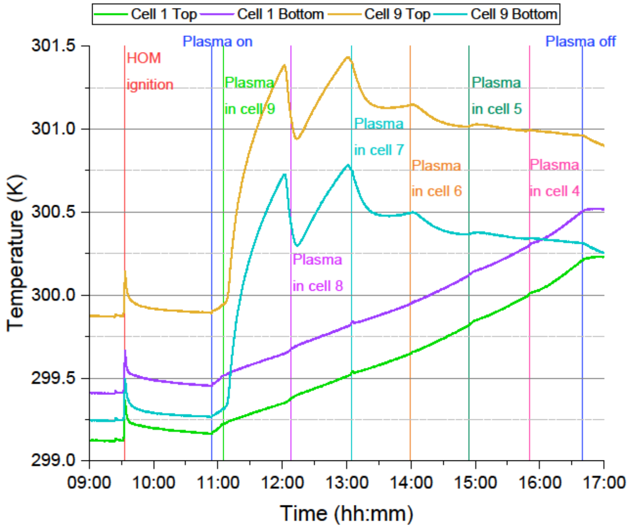




Plasma processing applied to LCLS-II HE vCM III

Example of experimental data collected during plasma processing of CAV4. This includes a rare case of plasma ignition at the HOM coupler





Temperature increase on:

- HOM1 cable < 2K
- HOM2 cable < 0.5K

During coupler ignition: 1.4K increase on HOM1 cable

Temperature increase on:

- Cell # 1 < 1.2K
- Cell # 9 < 1.6K
- During coupler ignition: 0.3K

vCM performance before and after plasma processing I

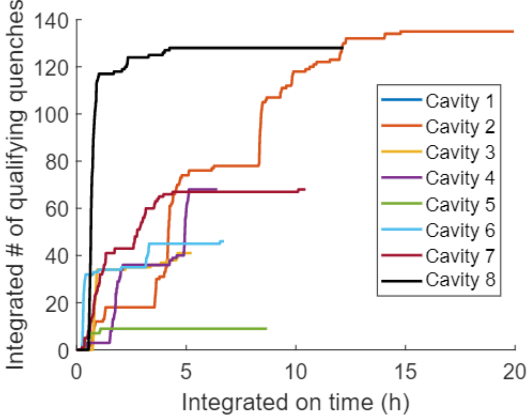
Cavity	Before Plasma Processing: Max E_{acc} (MV/m)	Usable E_{acc} (MV/m)	Q_0 at 21 MV/m $\times 10^{10}$	MP quenches	After Plasma Processing: Max E_{acc} (MV/m)	Usable E_{acc} (MV/m)	Q_0 at 21 MV/m $\times 10^{10}$	MP quenches
1	**23.4**	**22.9**	**3.0**	**Yes**	**23.8**	**23.3**	**3.4**	**No**
2	24.8	24.3	3.0	Yes	25.2	24.7	3.2	Yes
3	25.4	24.9	2.6	Yes	26.0	26.0	3.4	Yes
4	**26.0**	**26.0**	**3.2**	**Yes**	**26.0**	**26.0**	**3.2**	**No**
5	**25.3**	**24.8**	**2.9**	**Yes**	**25.5**	**25.0**	**2.8**	**No**
6	26.0	25.5	3.4	Yes	26.0	26.0	3.2	Yes
7	25.7	25.2	3.4	Yes	25.9	25.4	3.3	Yes
8	**24.4**	**23.9**	**2.7**	**Yes**	**24.7**	**24.2**	**2.6**	**No**
Average	25.1	24.7	3.0		25.3	25.1	3.1	
Total	209	205			210	208		

RF test after plasma processing demonstrated that:

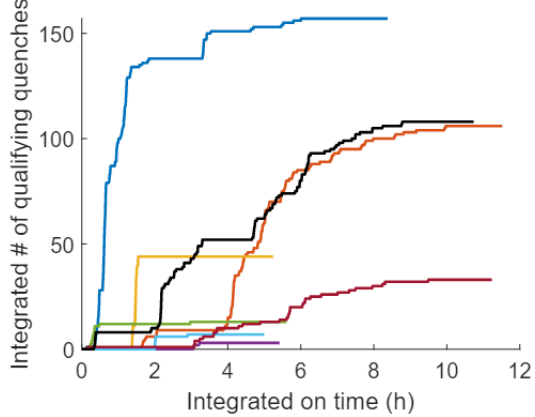
- **vCM performance** are **preserved**
- Plasma processing did not introduce any contamination: **vCM still FE-free**

vCM performance before and after plasma processing II

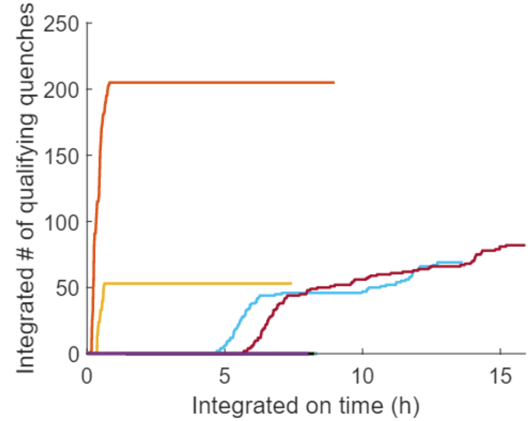
Before Plasma processing
1st cool down



Before Plasma processing
2nd cool down



After Plasma processing



Plasma processing **can eliminate multipacting:**

- **the 4 plasma processed cavities do no exhibit any MP quench**, contrary to the other 4 cavities

We could **address both FE and MP in situ at the same time**

Cavity	Multipacting Quenches		
	Before plasma Processing		After Plasma Processing
	1st cooldown	2nd cooldown	
1	/	**157**	**0**
2	135	106	205
3	41	44	53
4	**68**	**3**	**0**
5	**10**	**16**	**0**
6	46	7	69
7	68	33	82
8	**128**	**108**	**0**

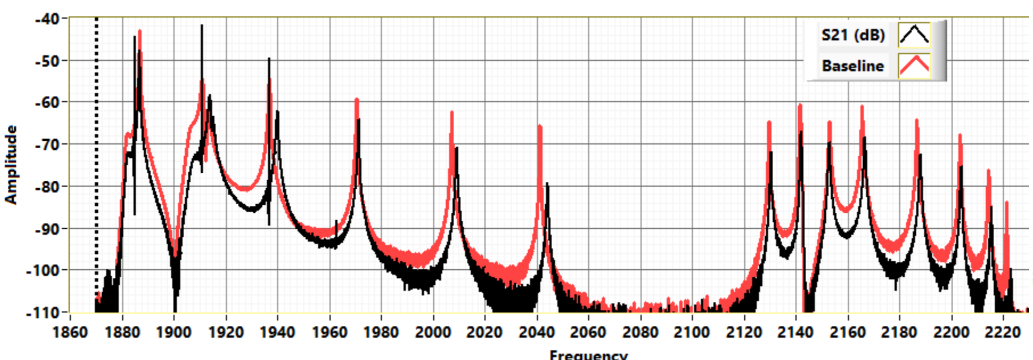
B. Giaccone, et al. arXiv:2201.09776 (2022)

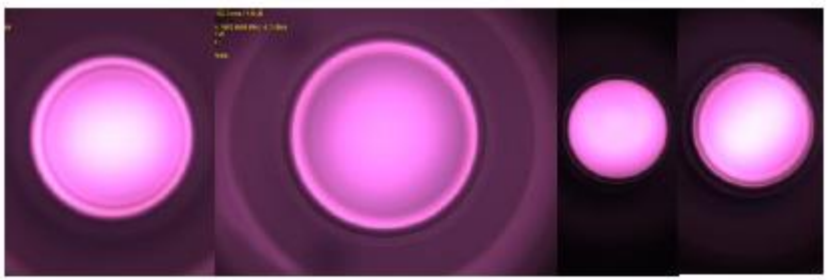
HOMs plasma ignition at JLAB for CEBAF I

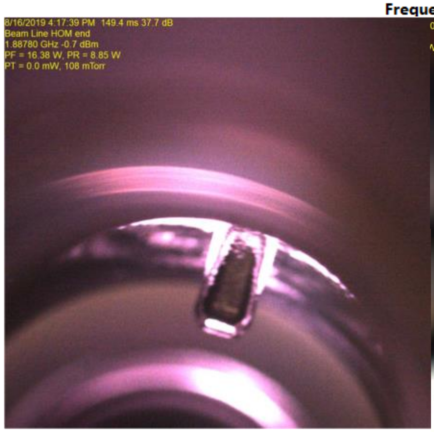
- JLAB has adapted the HOMS plasma ignition for C100 cavities for in situ plasma processing to help mitigate CEBAF linac energy degradation for just over 2 years.
- They built up to 5 channels of RF systems, 2 gas supply systems and 2 pumping systems.
- Initial effort focuses on C100 cryomodules with follow on effort towards processing the other cryomodule types used in CEBAF.
- Their “standard” technique for C100 cavities is to process 2 cells at the same time by applying
- They have processed a cavity several times in the vertical staging area and a C100 cryomodule in the cryomodule test facility.

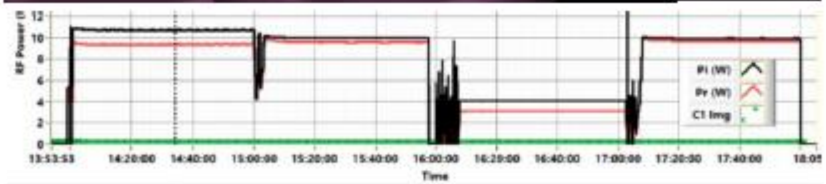
HOMs plasma ignition at JLAB for CEBAF II

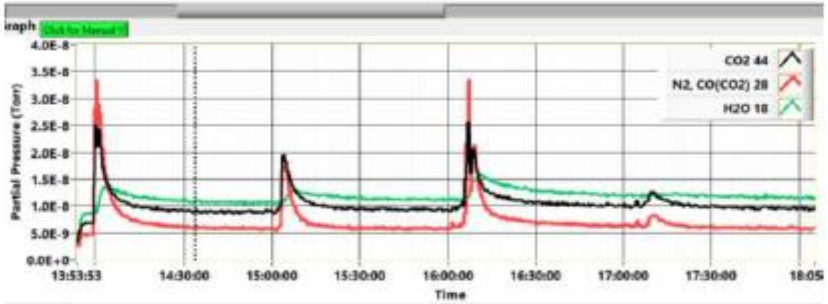
- Processing done in the vertical staging area with the cavity is mounted on a vertical test stand in order to reduce cleanroom labor and improve throughput.
- Argon with 1% to 3% oxygen at a pressure between 80 mTorr and 250 mTorr
- Exhaust gas monitored using an RGA, RF power and frequencies are monitored and plasma is detected with RF similarly to LCLS-II
- Recent tests conducted with He to ignite the plasma and Oxygen as a reactive gas





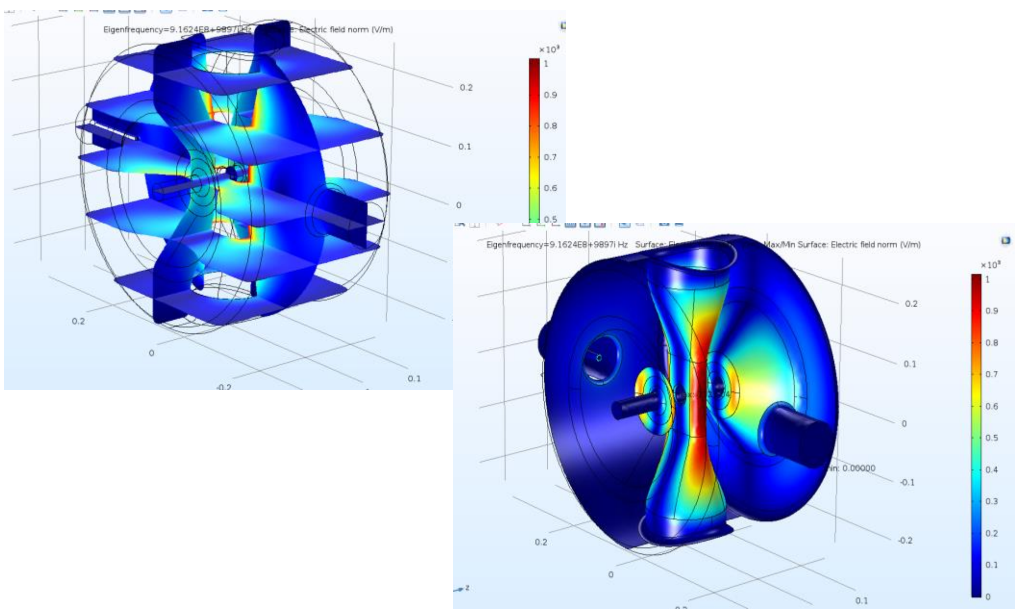




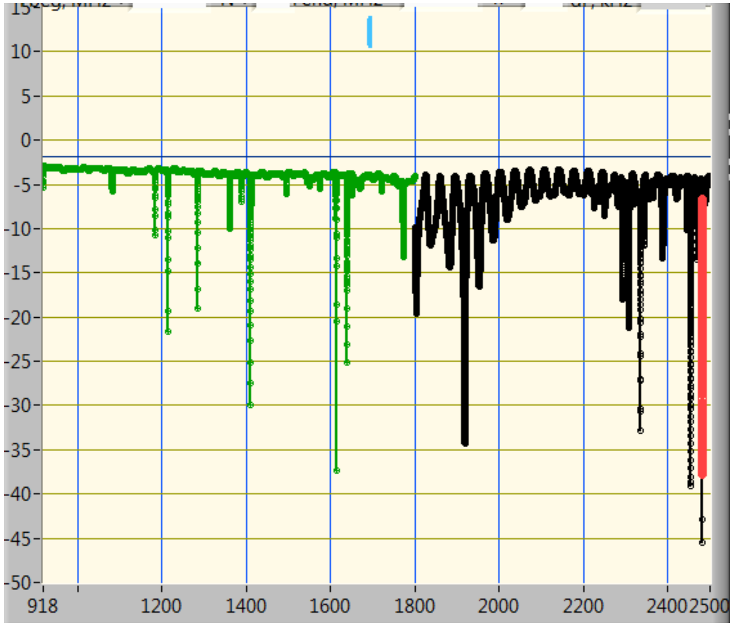


HOMs plasma ignition for coaxial resonators SSR

- Coaxial resonators may benefit from plasma cleaning (MP processing, FE), usually Q_0 at RT is ≈5E3: lower than multi-cell structure → coupler-cavity mismatch very high at RT.
- HOMs can couple to FPC better than fundamental mode at RT!
- Drawback: HOMs in spoke cavities have complicated field distribution…



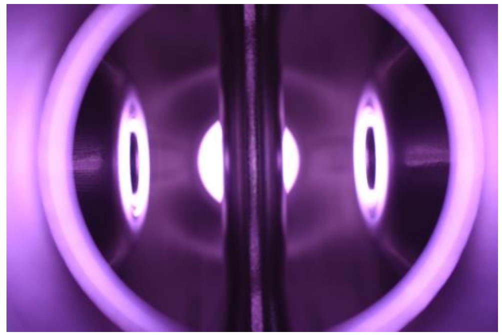
Example of Volume and Surface field distribution of HOM in SSR1 (FNAL)



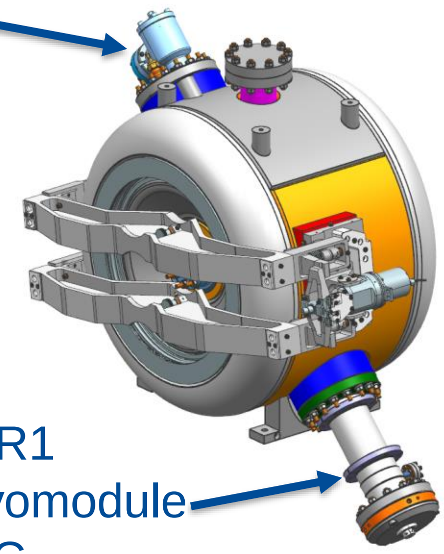
S11 measurements of SSR1 FPC

Plasma ignition SSR1 spoke cavity at FNAL I

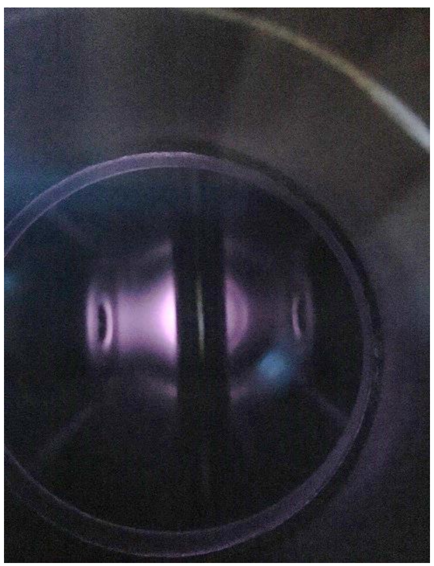
- Ar at 250-20 mTorr requires RF power ranging from ≈0.3W to ≈50W to ignite glow discharge depending on pressure and frequency.
- Correct mix of modes to ignite areas of interest:
  - accelerating gaps
  - spoke base
  - spoke side
  - cylindrical shell

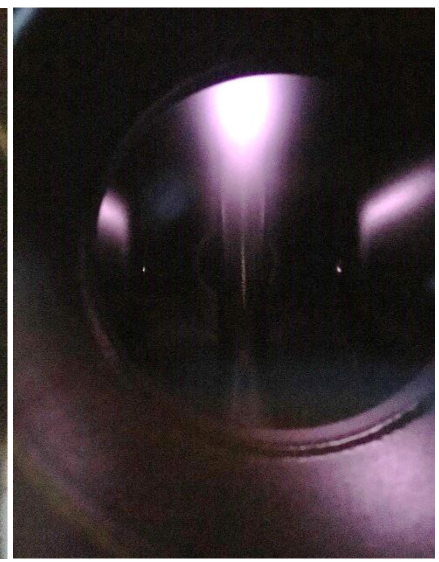


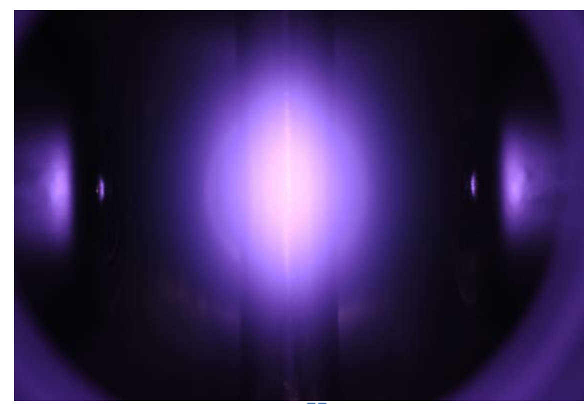
PU flange needs to be replaced with view-port



SSR1 Cryomodule FPC

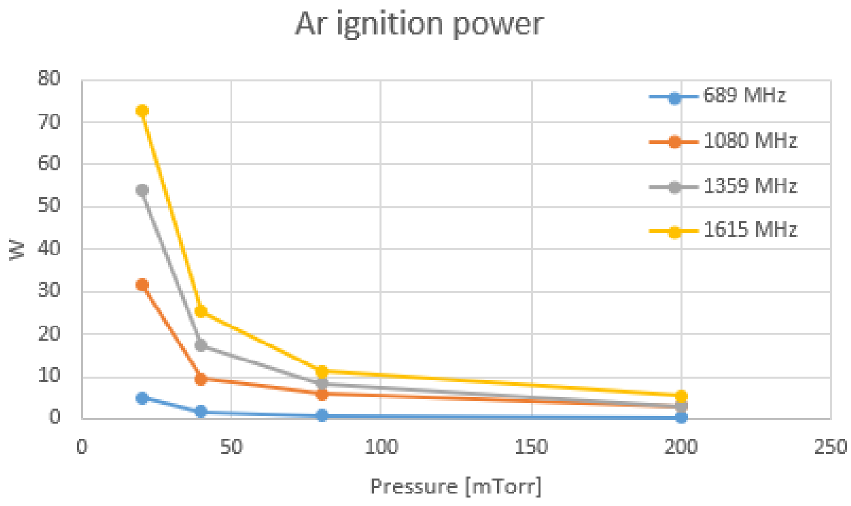


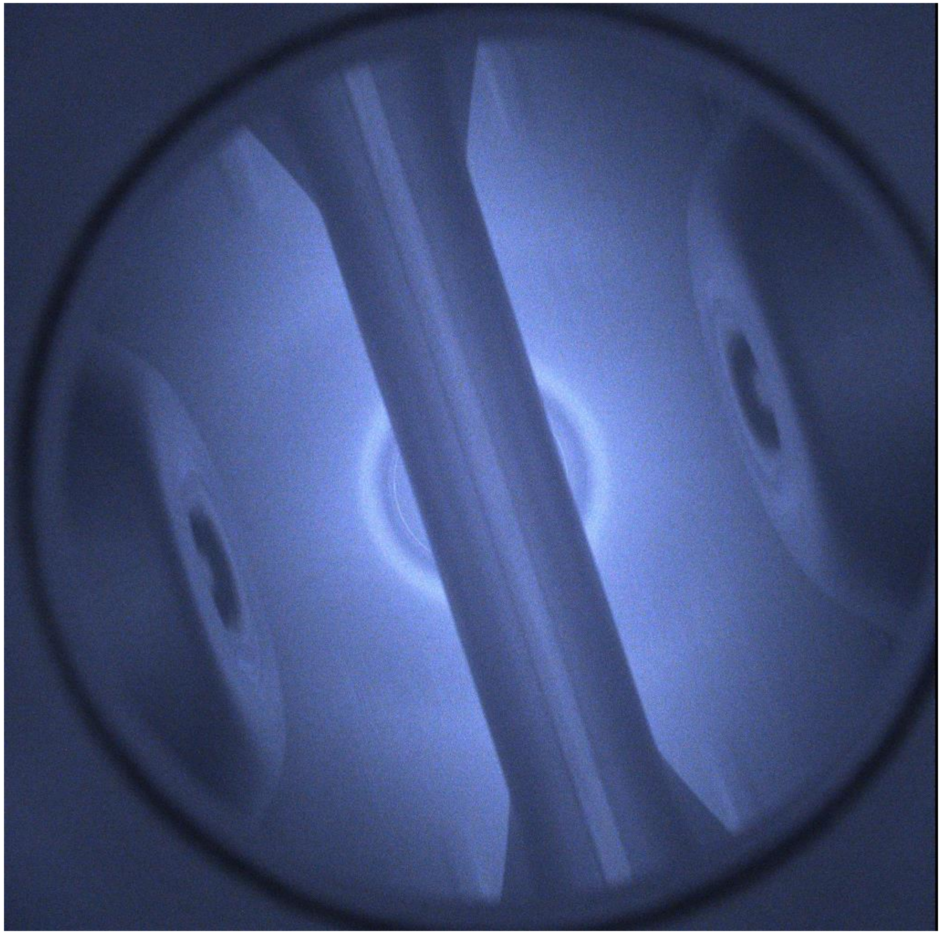




Plasma ignition SSR1 spoke cavity at FNAL II

- Ar pressure can be lowered as much as 20 mTorr without affecting easiness of plasma ignition.
- Less than 6W of forward RF power are enough to ignite the whole SSR1 cavity at 40 mTorr
- Higher frequency is usually related with higher plasma ignition power.





Future applications of Plasma Cleaning in SRF

- HOMs plasma ignition can be potentially applied to any cavity geometry, it has been proven successful for LCLS-II, CEBAF and for single spoke resonators
- Unusual cavity designs will be able to benefit from plasma cleaning using HOMs or other ignition techniques
- The Ne-Oxygen plasma recipe is being tweaked and perfected: Ar-Oxygen and He-Oxygen are being used in the community already
- Different plasma recipes could be investigated to include etching, deposition or surface properties changes for the RF surface of the SRF cavities
- Future plasma application for SRF cavities could merge with material science technologies for other industries like semiconductors and their material preparation…

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- F ... te ... preparation…

Thank you for your attention!