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Optimizing an ***in-situ*** plasma discharge process for improving multi-MA accelerator performance

ICOPS 2023, Santa Fe, NM

O-4.4 – Generators and Compact PP Applications, **#152**

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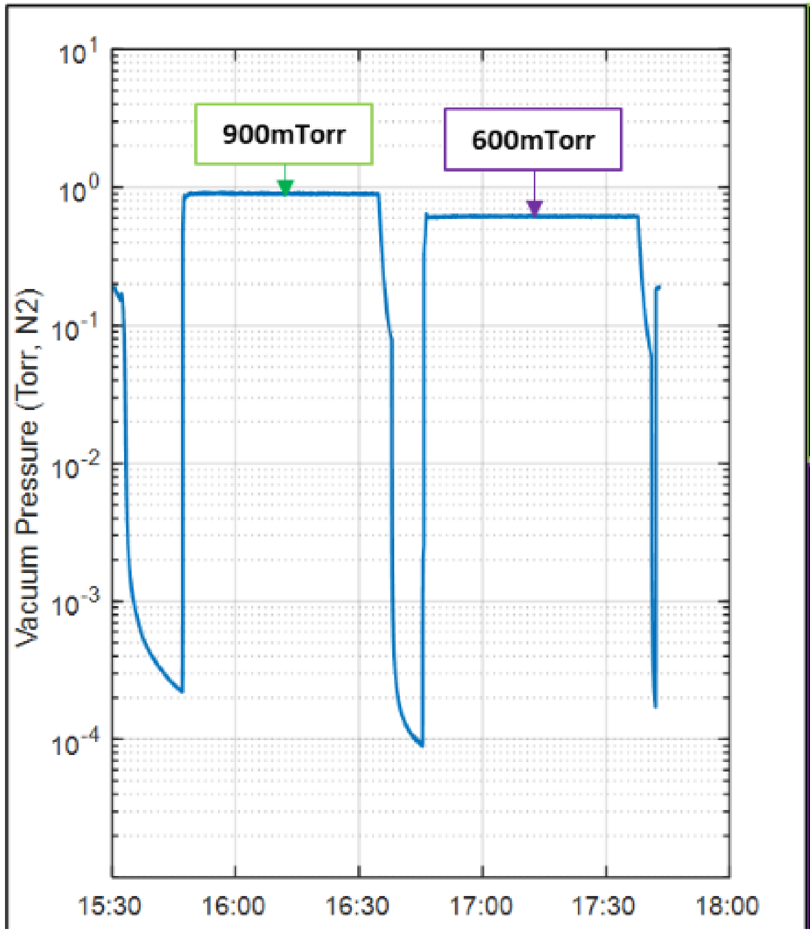
We are exploring ***in-situ*** plasma glow discharge to remove contamination from electrode surfaces

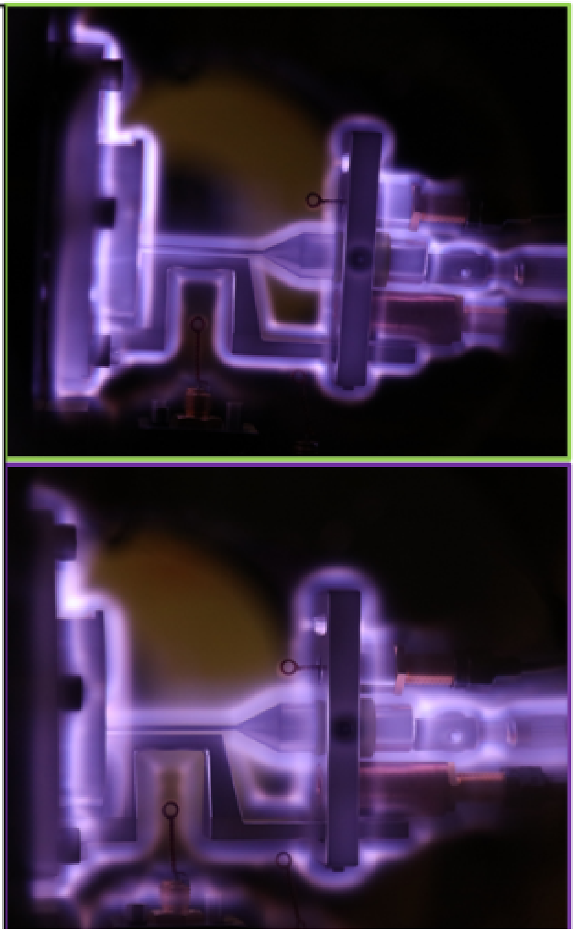
An 80% Argon, 20% oxygen process gas is used.

- Argon ions sputter lightly-bound contaminants into the gap (H_20, H_2, C_xH_y, etc.)
- Oxygen ions chemically react with sputtered contaminants and are pumped out

We have developed an audio-frequency square wave (ASW) excitation *on the accelerator electrodes themselves* to ignite glow discharge

- Switching frequency ~ 10-25 kHz
- Background gas pressures ~ 0.1 – 1 Torr
- Effective AK gap cleaning ~ 0.1 - 1 cm
- +/- 1kV, up to 600W switch potential of MITL cathode
- Electrical insulators are used to localize cleaning plasma in the MITL regions with highest power density
    - Only clean the surfaces where losses occur



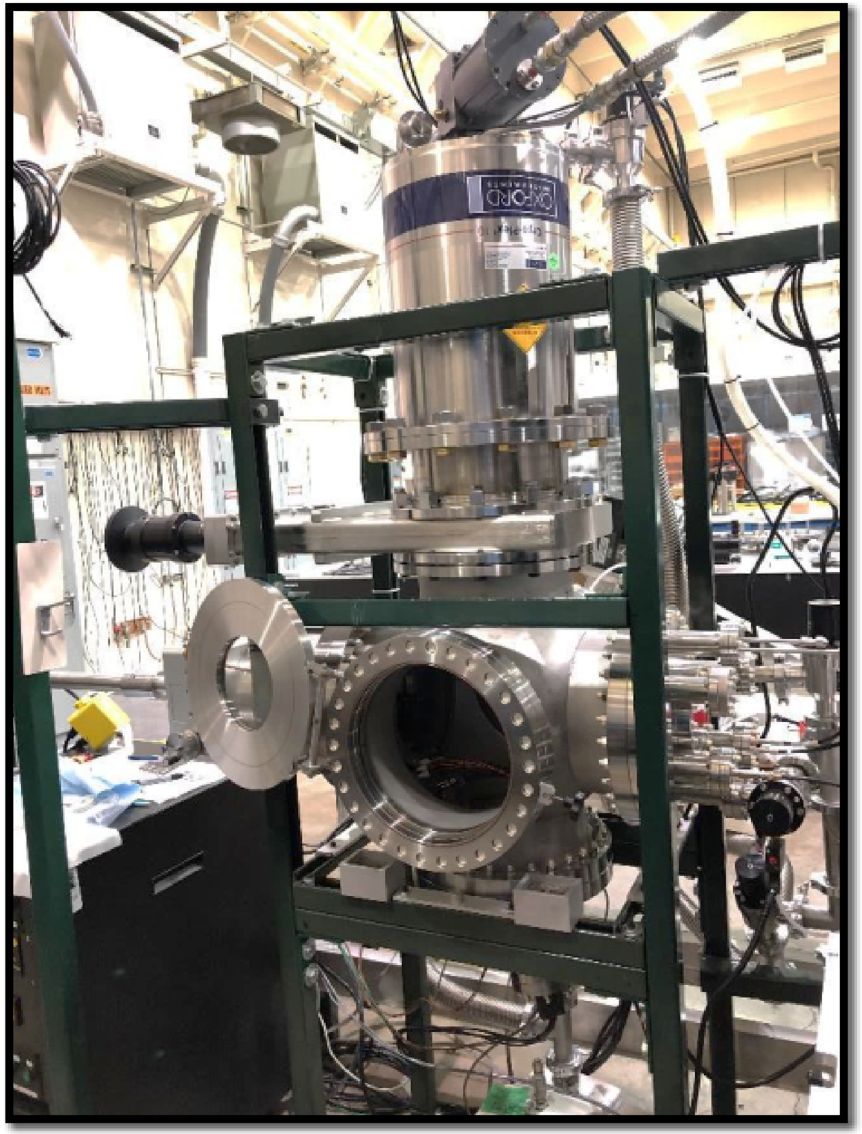


Example plasma glow discharges on parallel plate MITL experiment on Sandia's Mykonos Accelerator

Thanks to R. Tang, T. Ohlhausen, R. Sorensen, and many others at Sandia for work developing ASW and characterizing its effectiveness

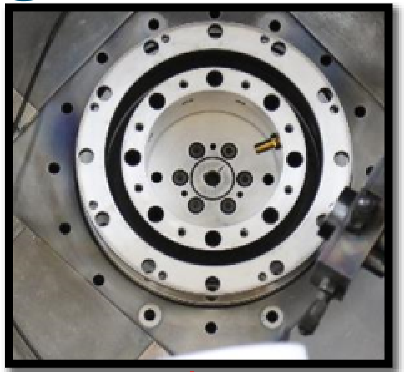
Testbed commissioned to study cleaning plasma characteristics tied to effective removal rates of contaminants

- **Best-guess cleaning protocols have been employed on accelerators to date**
  - Removal rates can be optimized for a given geometry via tuning excitation voltage, chamber pressure
  - Accelerators like Z and Mykonos have characteristic AK gaps from 1cm to 2-3mm that need to be efficiently cleaned
- **Designed experiment that allows diagnostic access to plasma glows in canonical geometries**
  - Study cleaning rates and glow characteristics for single-gap geometries
  - Differentially pumped RGA system in main chamber monitors reactant partial pressures
  - Diagnose the cleaning plasma with optical and electrical means
- **We have much work to do with the plasma discharge cleaning protocol**
  - Quantify, optimize contaminant removal rates as a function of canonical AK gap
  - Develop a protocol (varying backfill pressures, species, excitation power) that optimally cleans the Z Machine load hardware

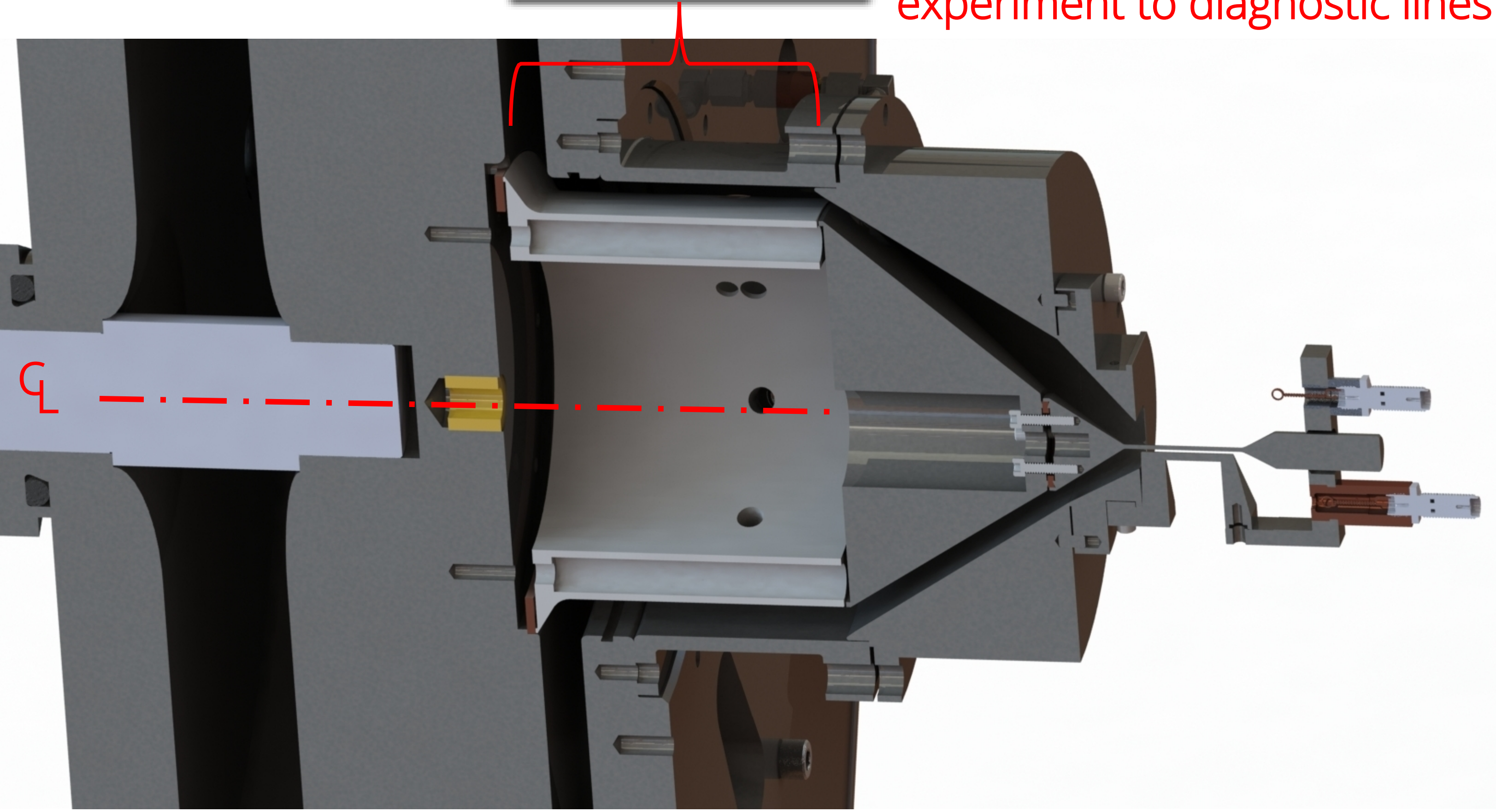


More work to be done in the coming months! ICOPS 2024…

We have developed a diagnostically accessible parallel plate load region for Sandia's 1 MA Mykonos accelerator



Axisymmetric standoff pieces bring experiment to diagnostic lines of sight



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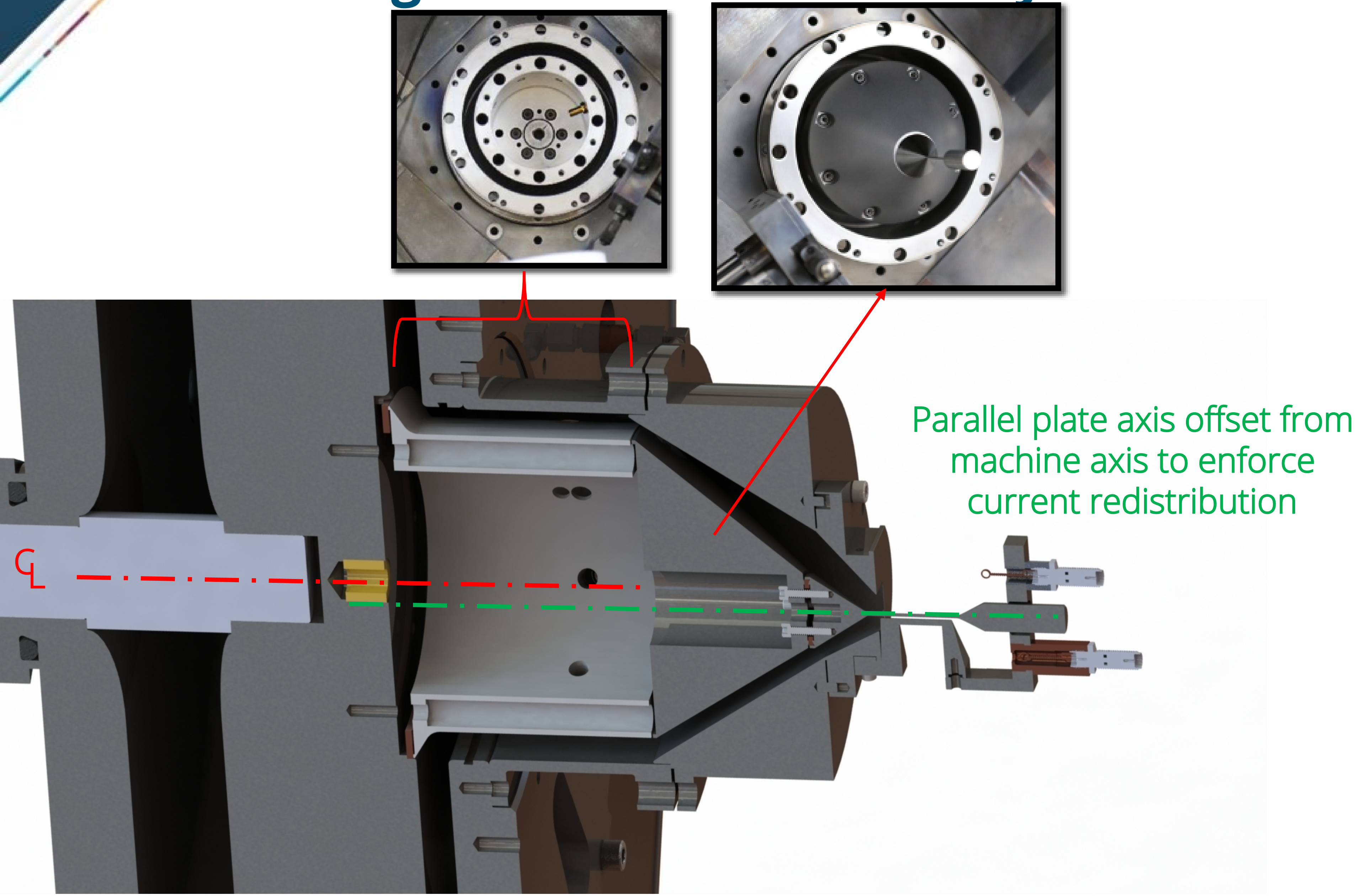

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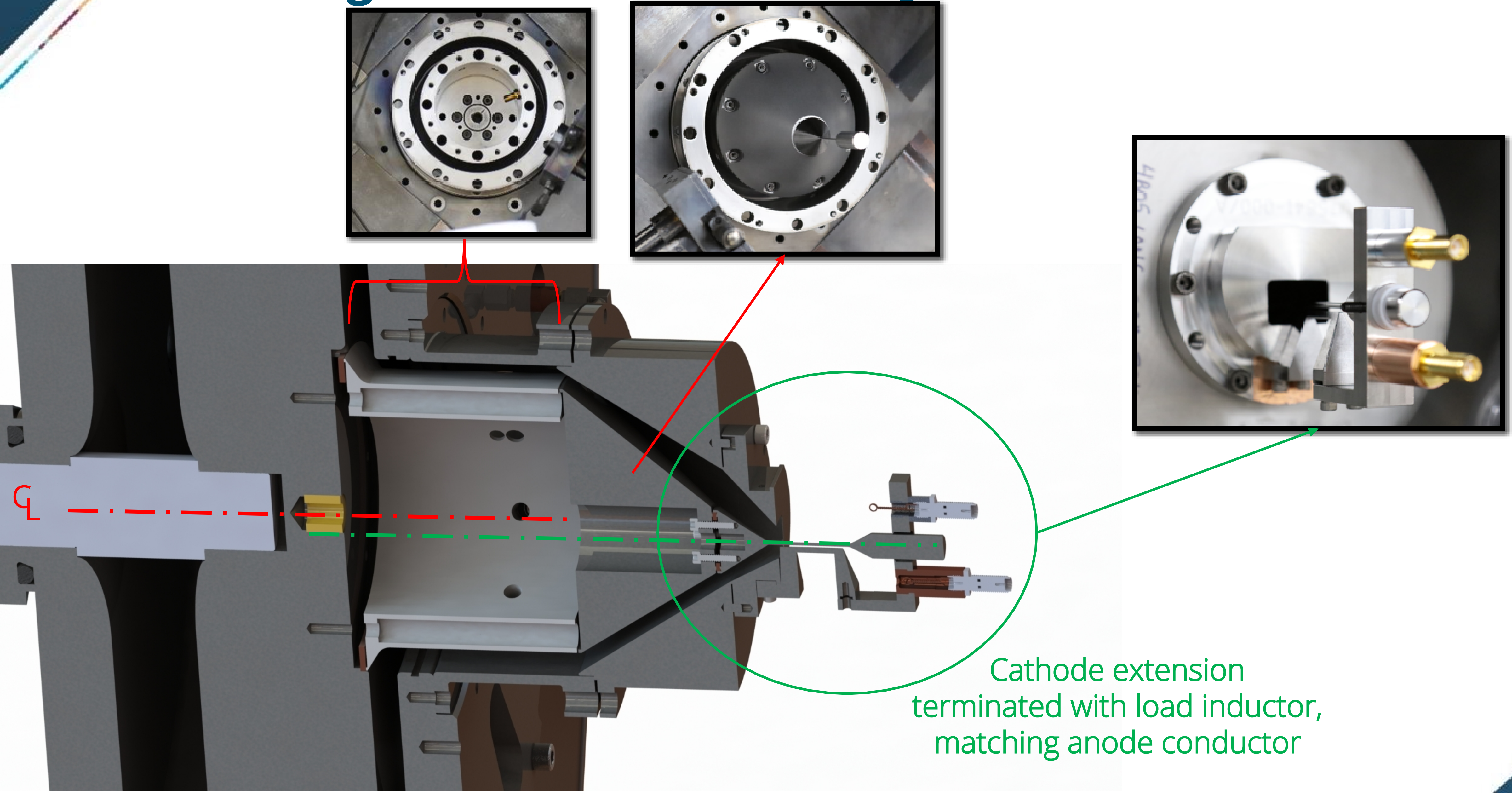

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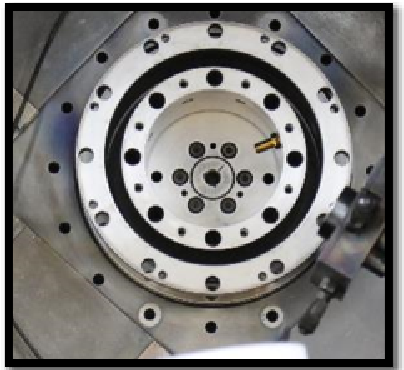
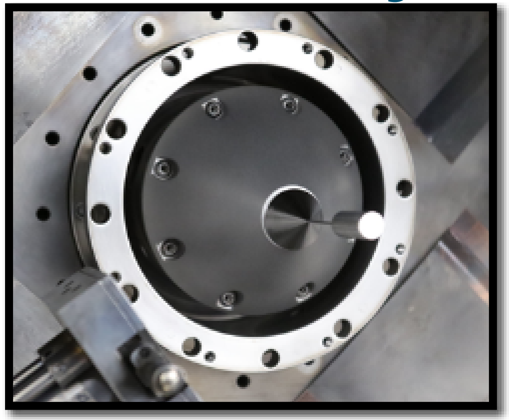
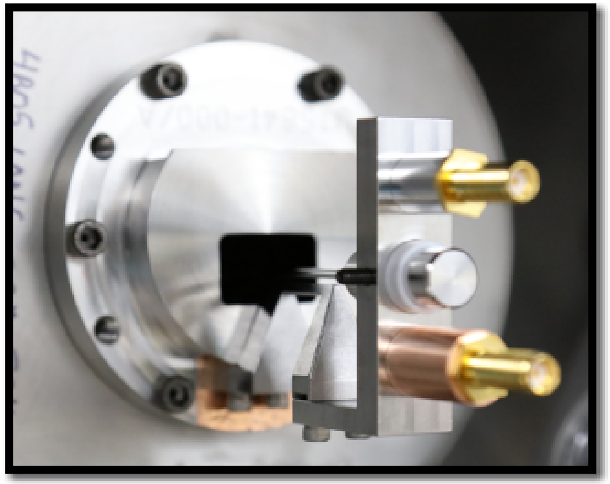
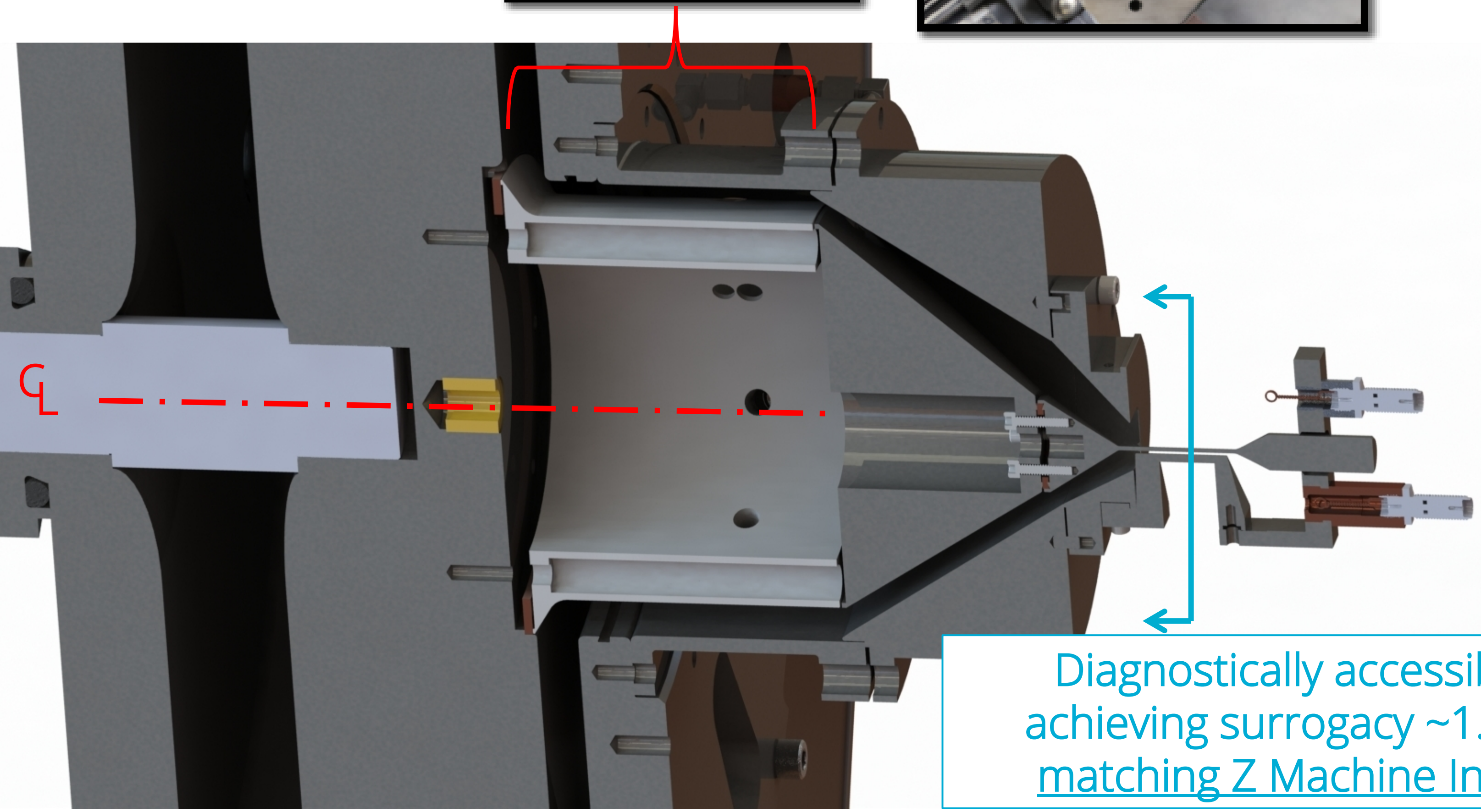
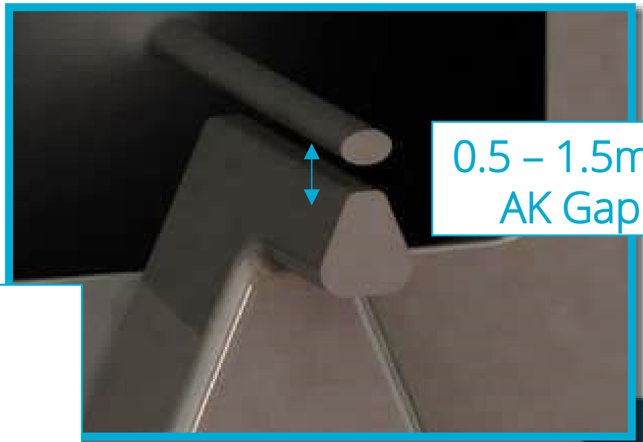




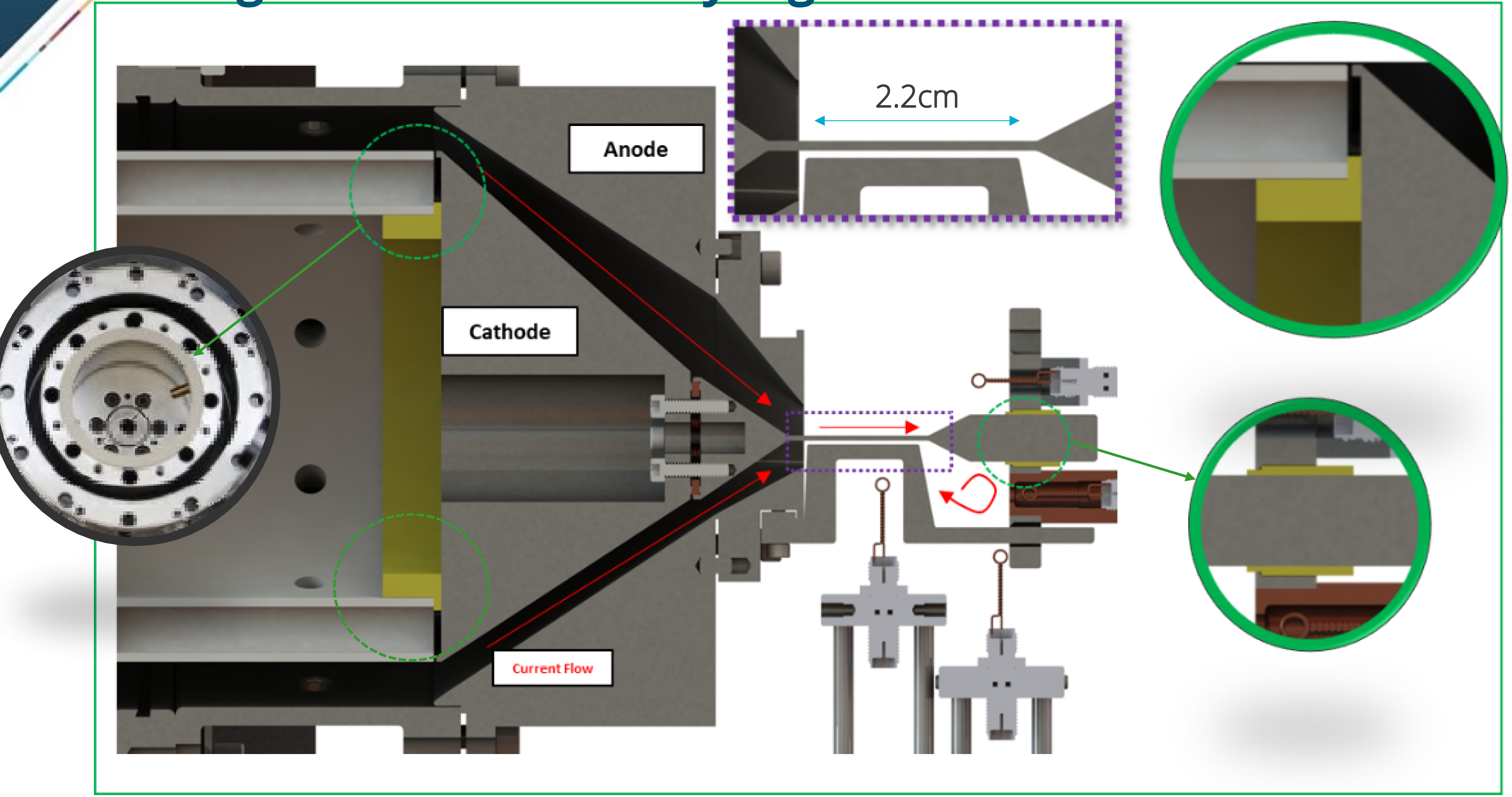




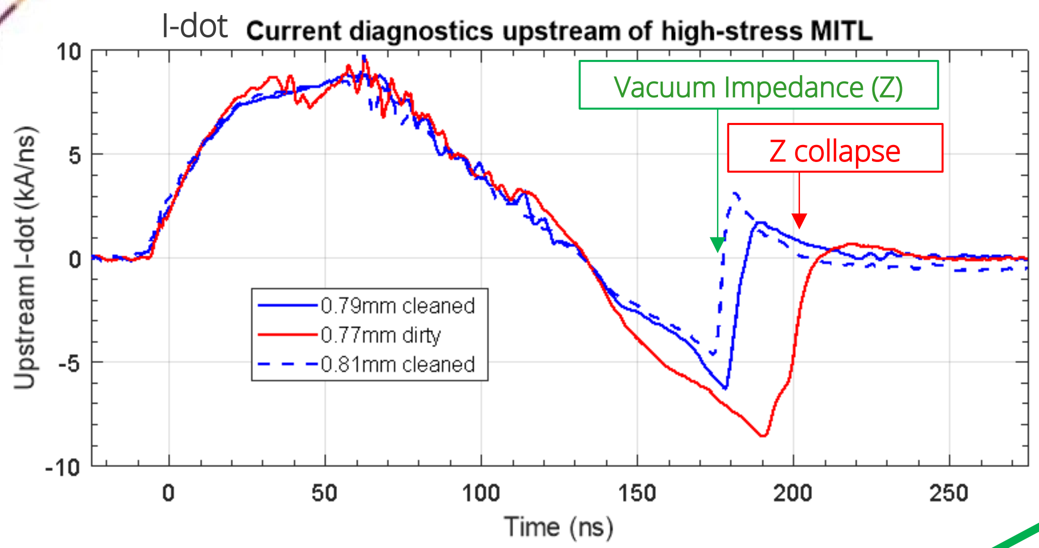


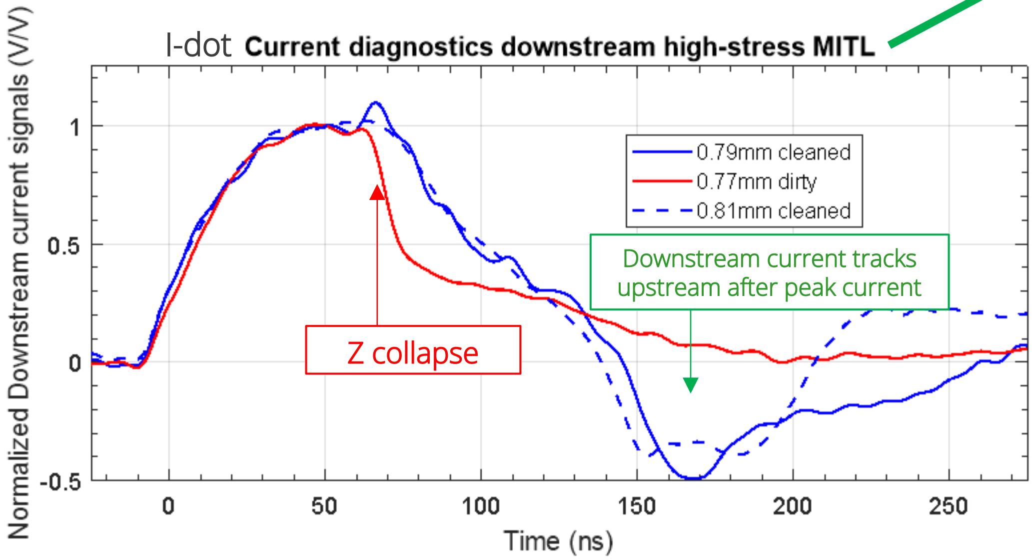
Diagnostically accessible MITL achieving surrogacy ~1.5 MA/cm, matching Z Machine Inner MITL

We introduce insulating breaks to localize plasma excitation in highest current density regions of accelerator

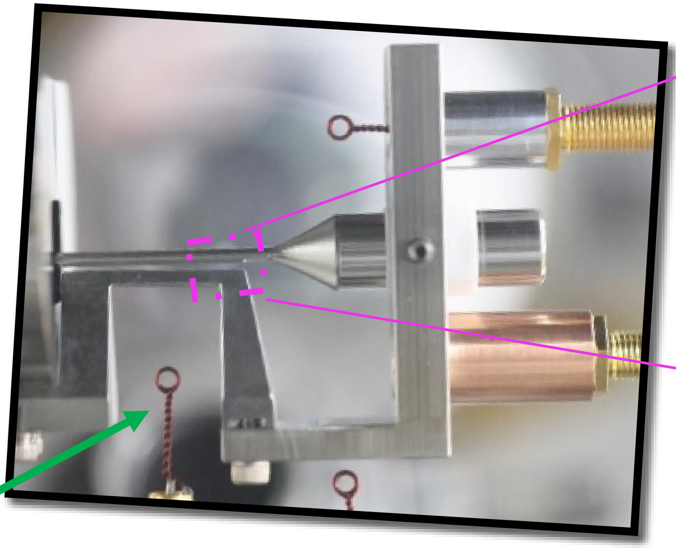


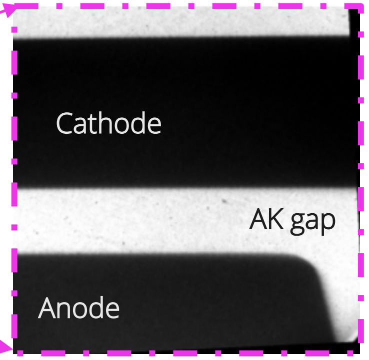
Cleaning process mitigates catastrophic loss in high-stress MITL region in recent experiments.



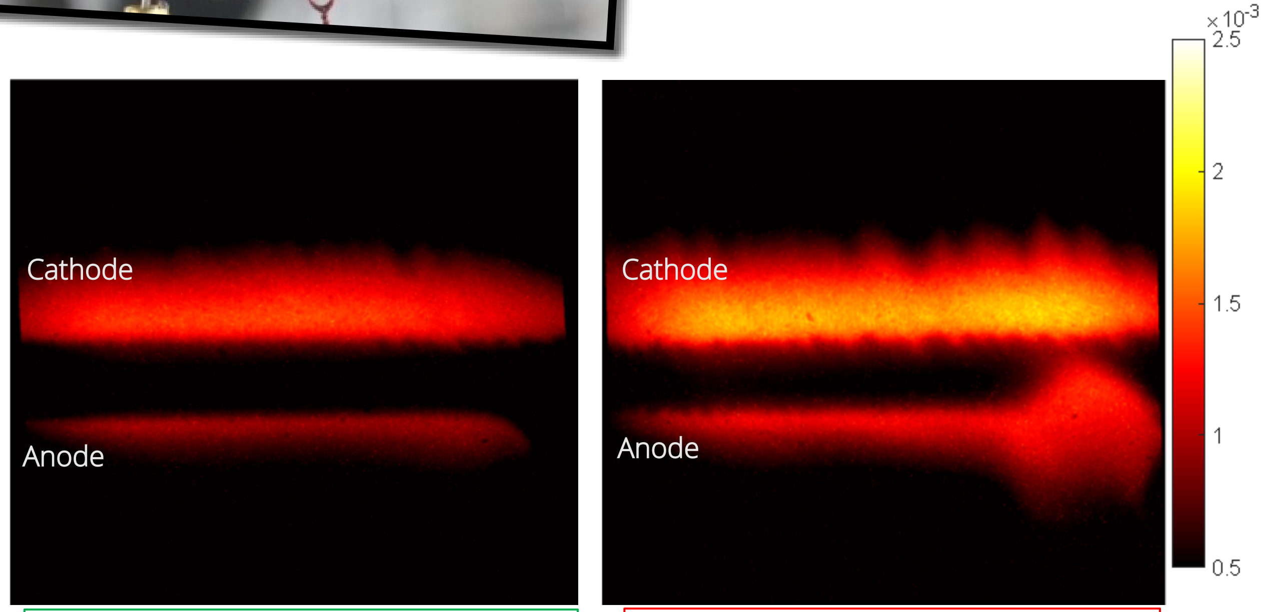


Significant MITL shorting observed in uncleaned experiment; this is mitigated by in-situ cleaning





Backlit anode-cathode gap

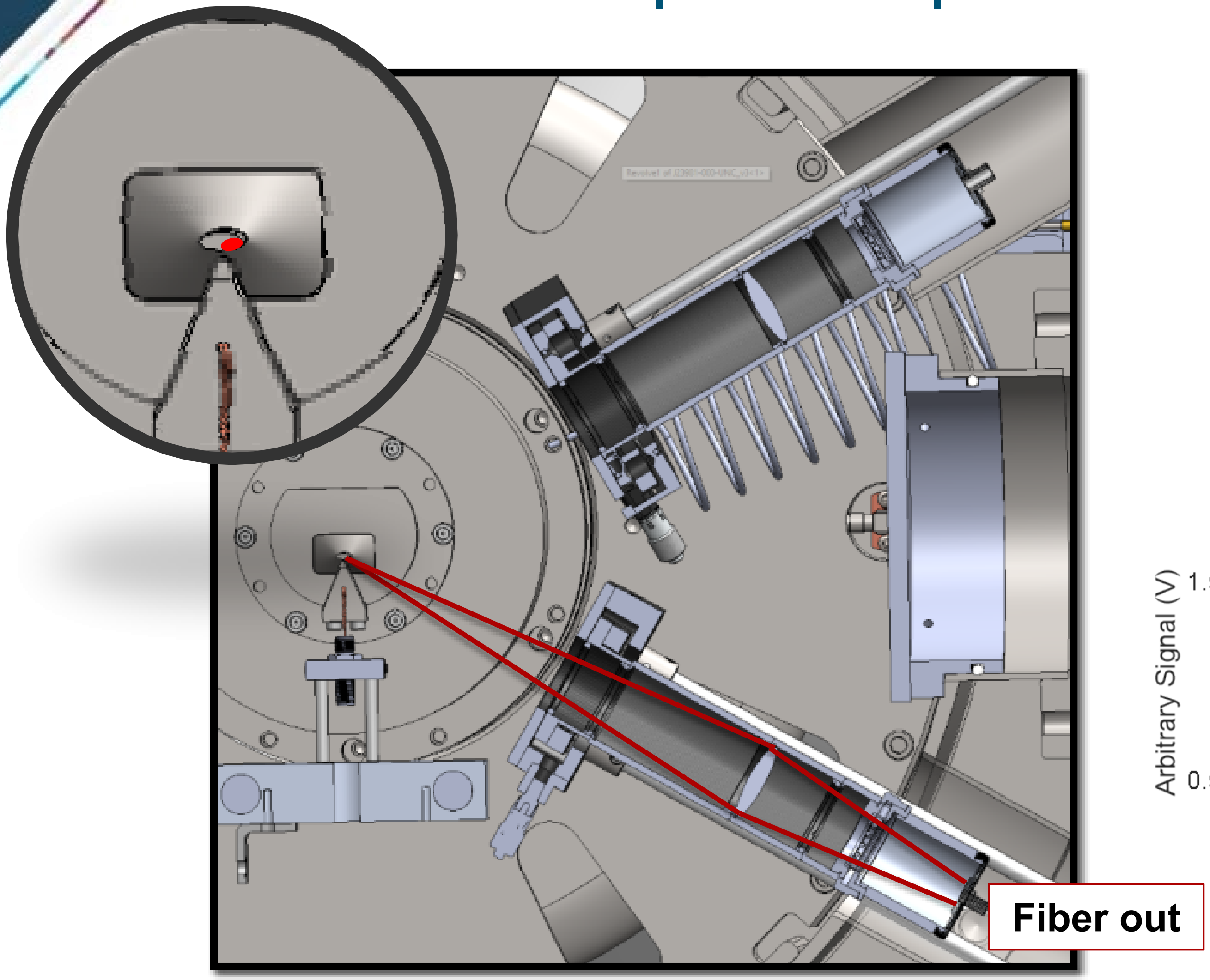


0.81mm cleaned, 5ns exposure at t=145ns

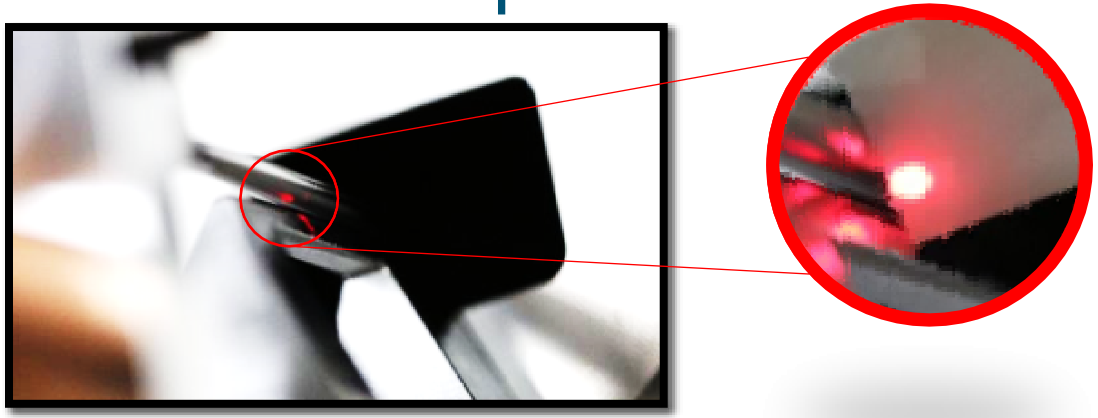
0.77mm dirty, 5ns exposure at t=145ns

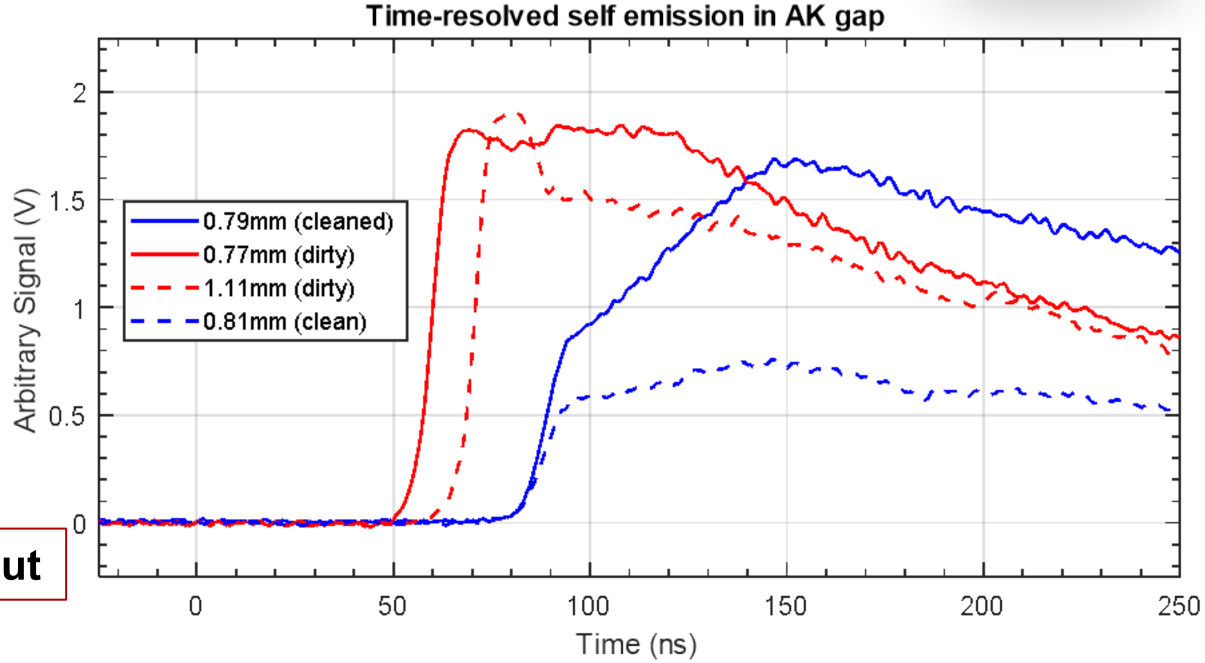
Electrode plasma self emission intensity significantly reduced, gap closure delayed by cleaning process.

Optical measurements show delays in electrode plasma turn on, absence of spectroscopic traces for contaminant species



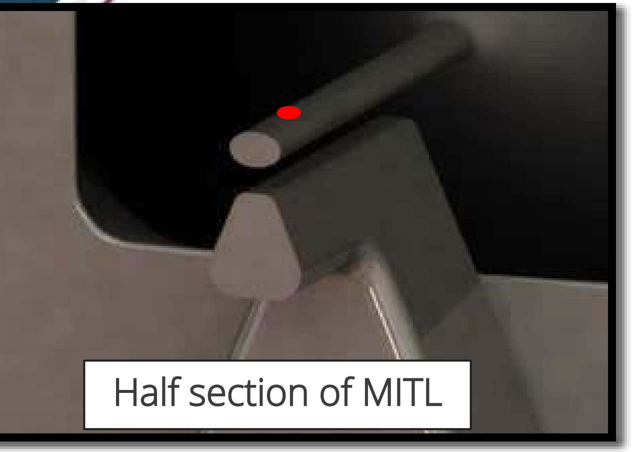
Lens tube assembly collects plasma self emission light from ~ϕ1mm spot size on cathode face

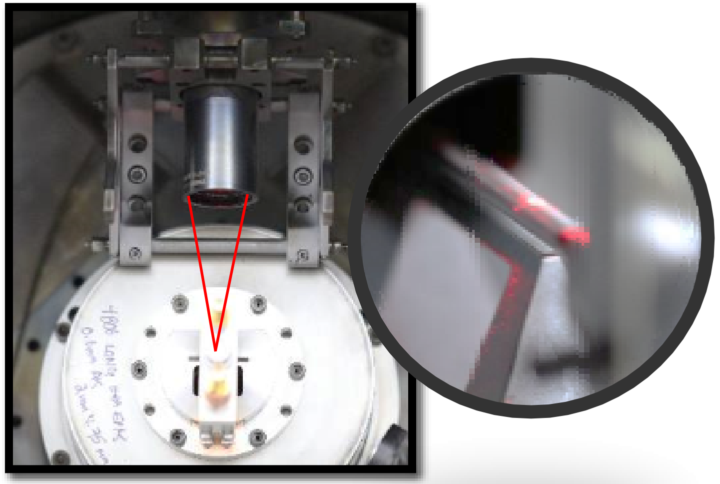


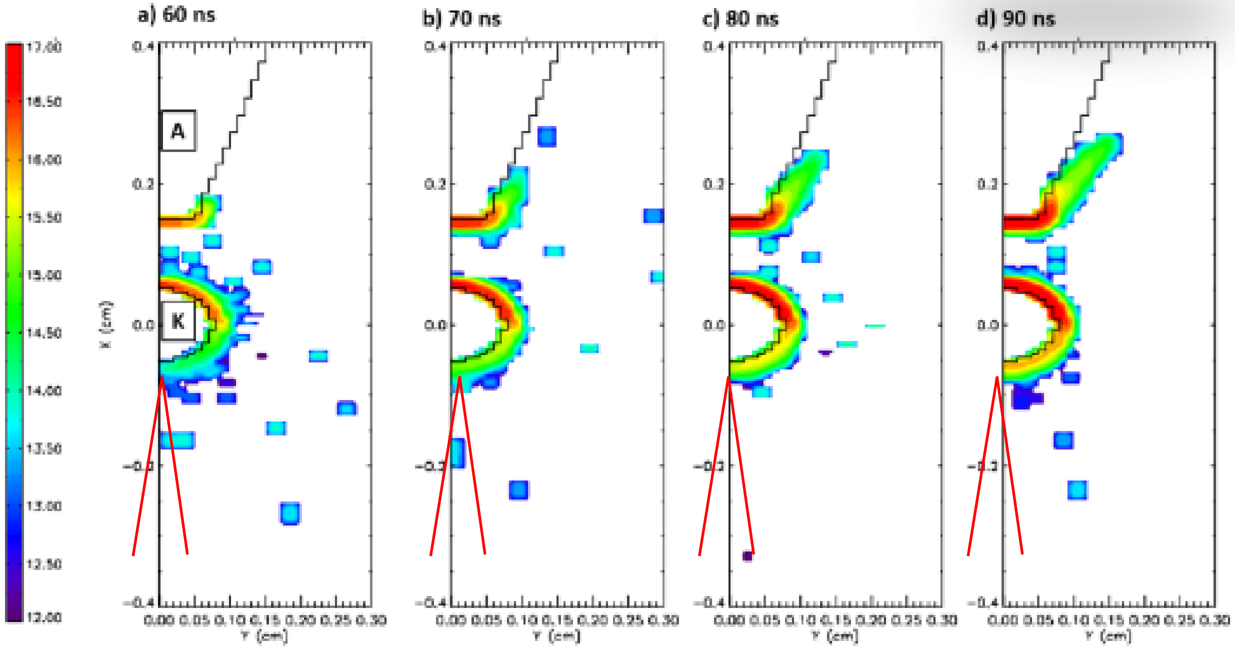


Cleaning process delays self emission by ~25 ns, reduces overall observed light. All traces above use <700nm shortpass filter except 0.79mm (cleaned)

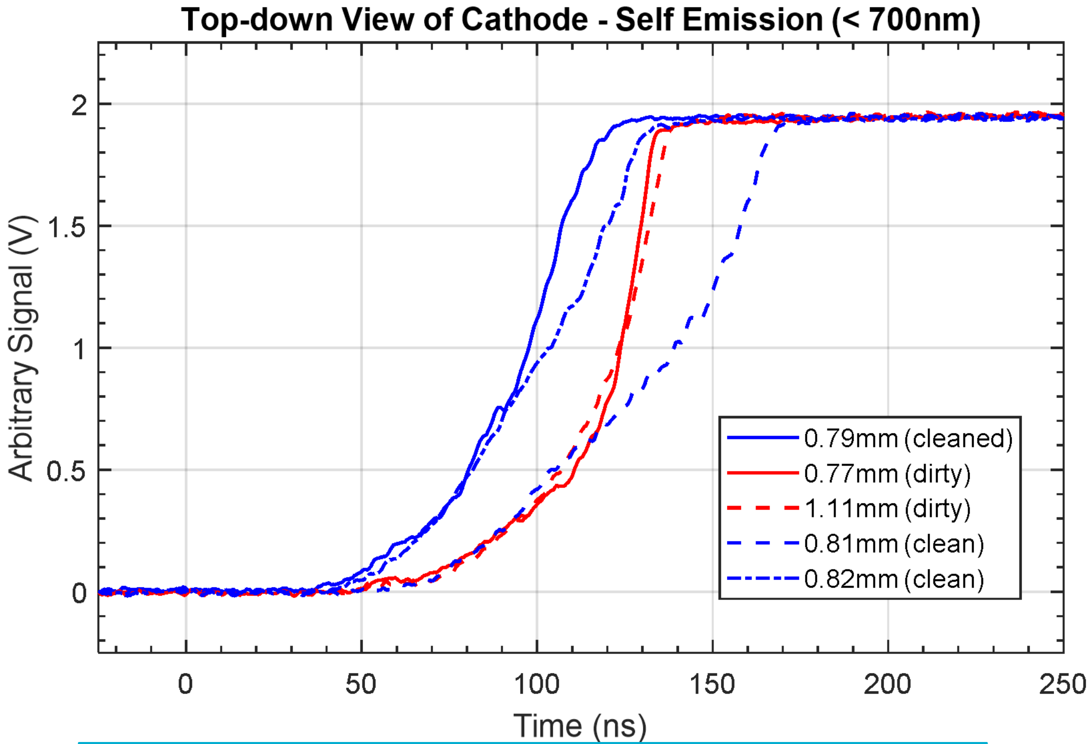
Optical measurements directed downward on cathode hope to observe plasma “dumping” from high temperature region







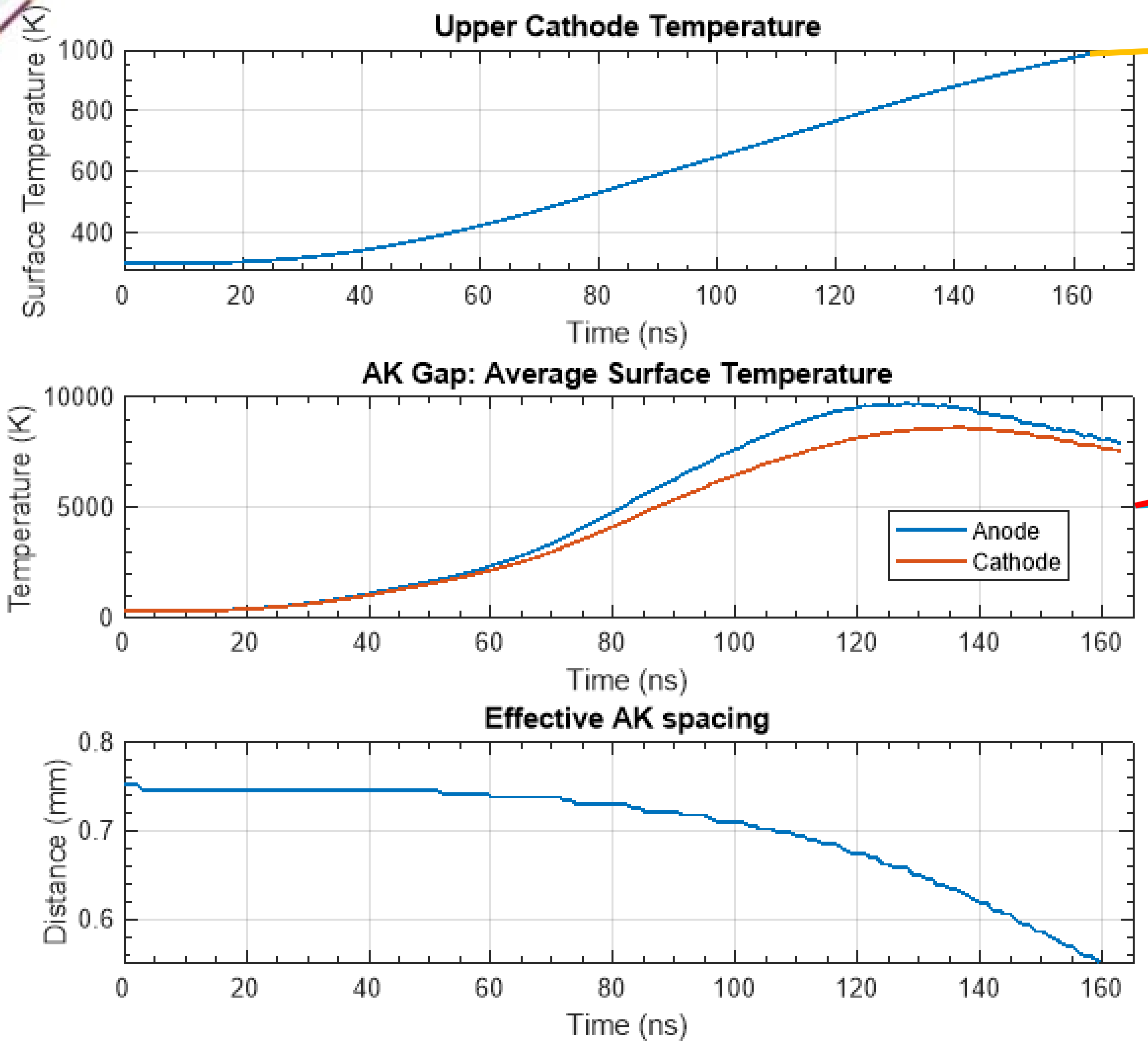
PIC simulations show plasma generated in AK gap streaming along field lines and collecting “above” the cathode

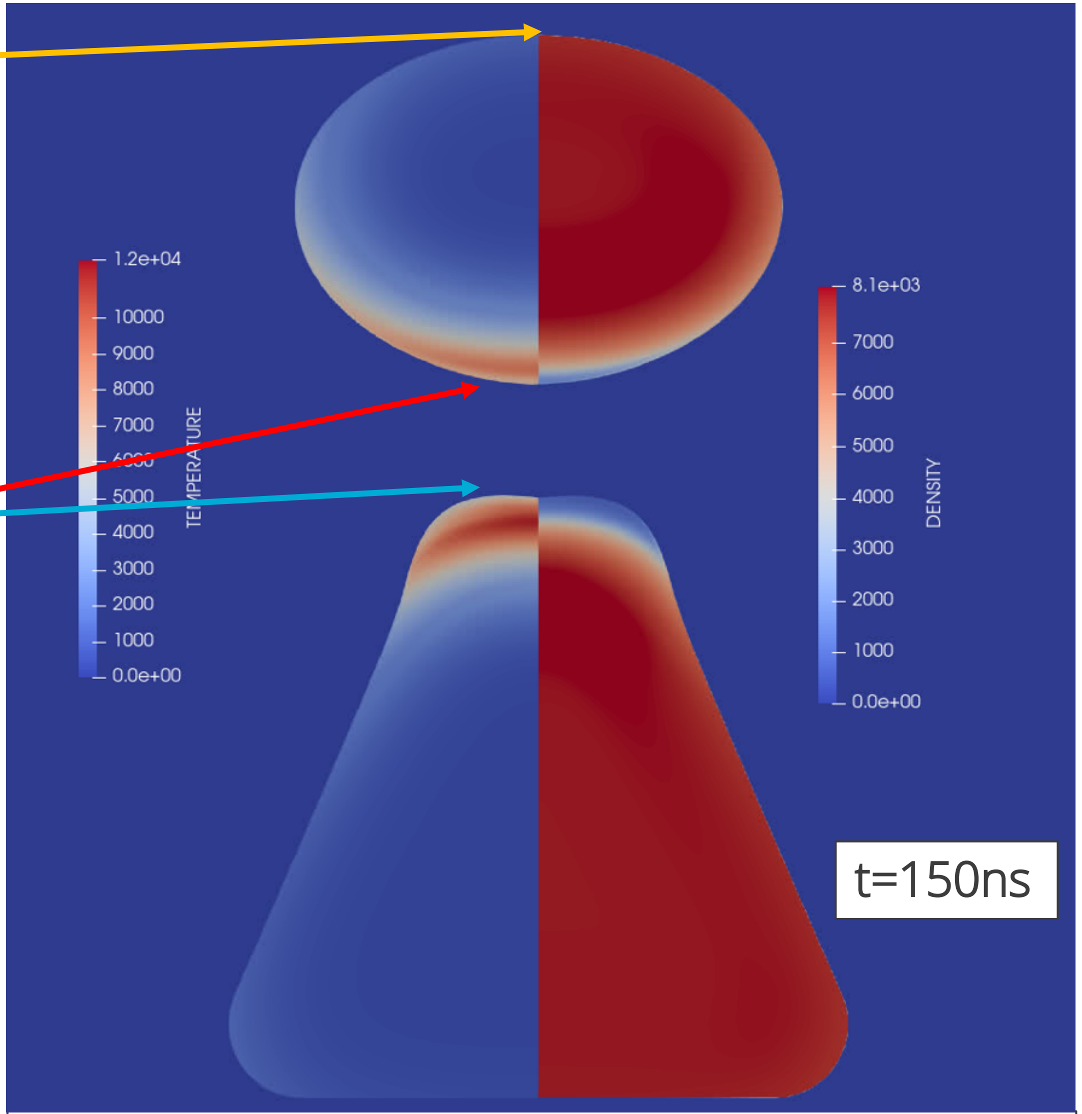


All APD measurements had short pass <700nm filter except *0.79mm (cleaned).* Peak accelerator current ~ 150ns

- Wideband APD results above cathode did not produce consistent trend, though caveats for 0.79mm and 0.82mm cleaned experiments exist.
- Speculate that periodic MRT-like structure produces striated intensity
- Plasma cleaned experiments also start $+\Delta T \sim 150°C$

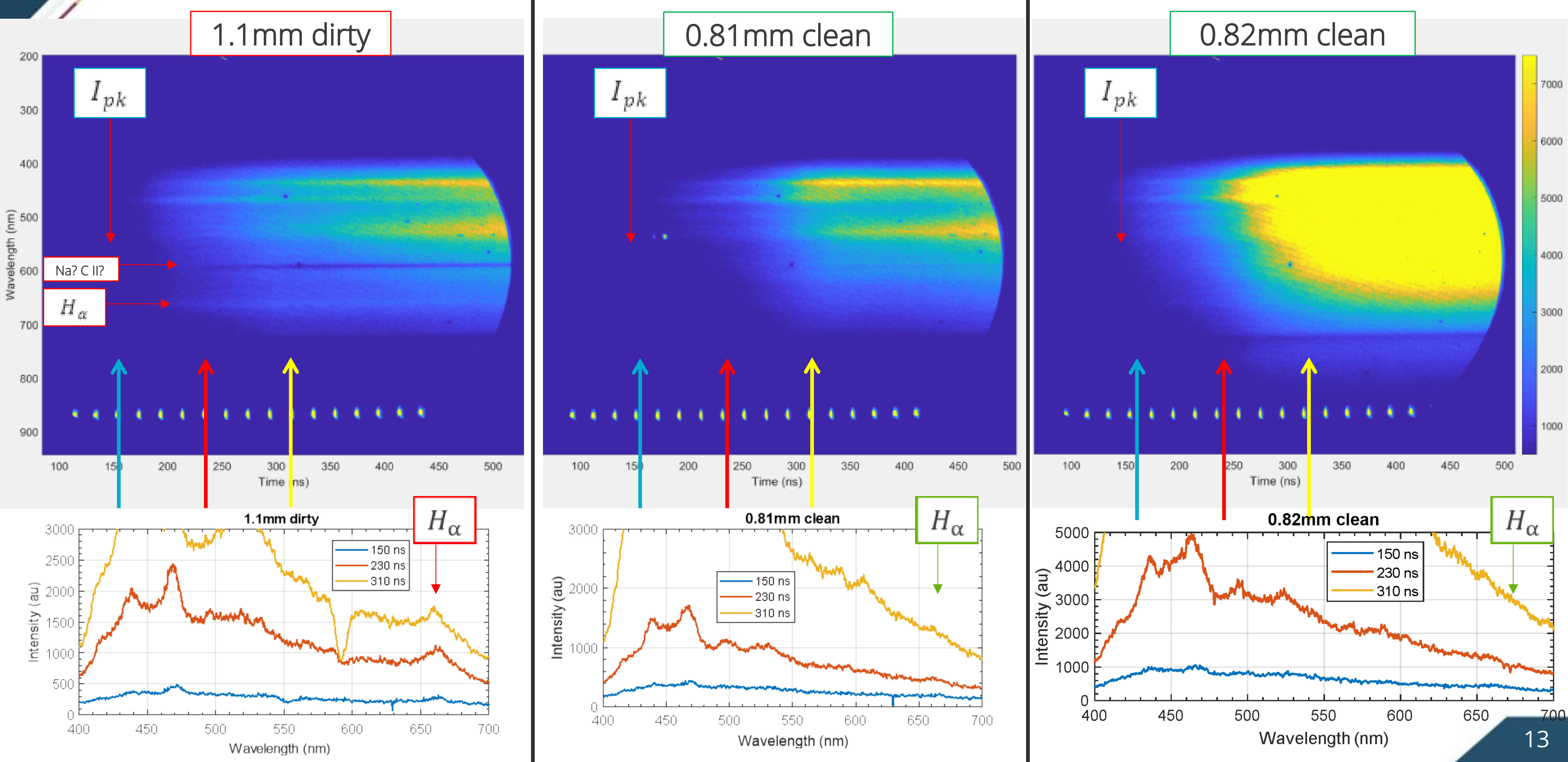
MHD simulations: top side of cathode lags electrodes in AK gap in electrode melt, ionization





ALEGRA MHD 2.5D geometry at t=150ns (peak current). AK electrode surfaces melted and ~1eV. Upper cathode face has not yet melted.

Streaked visible spectroscopy shows nearly undetectable hydrogen following cleaning process

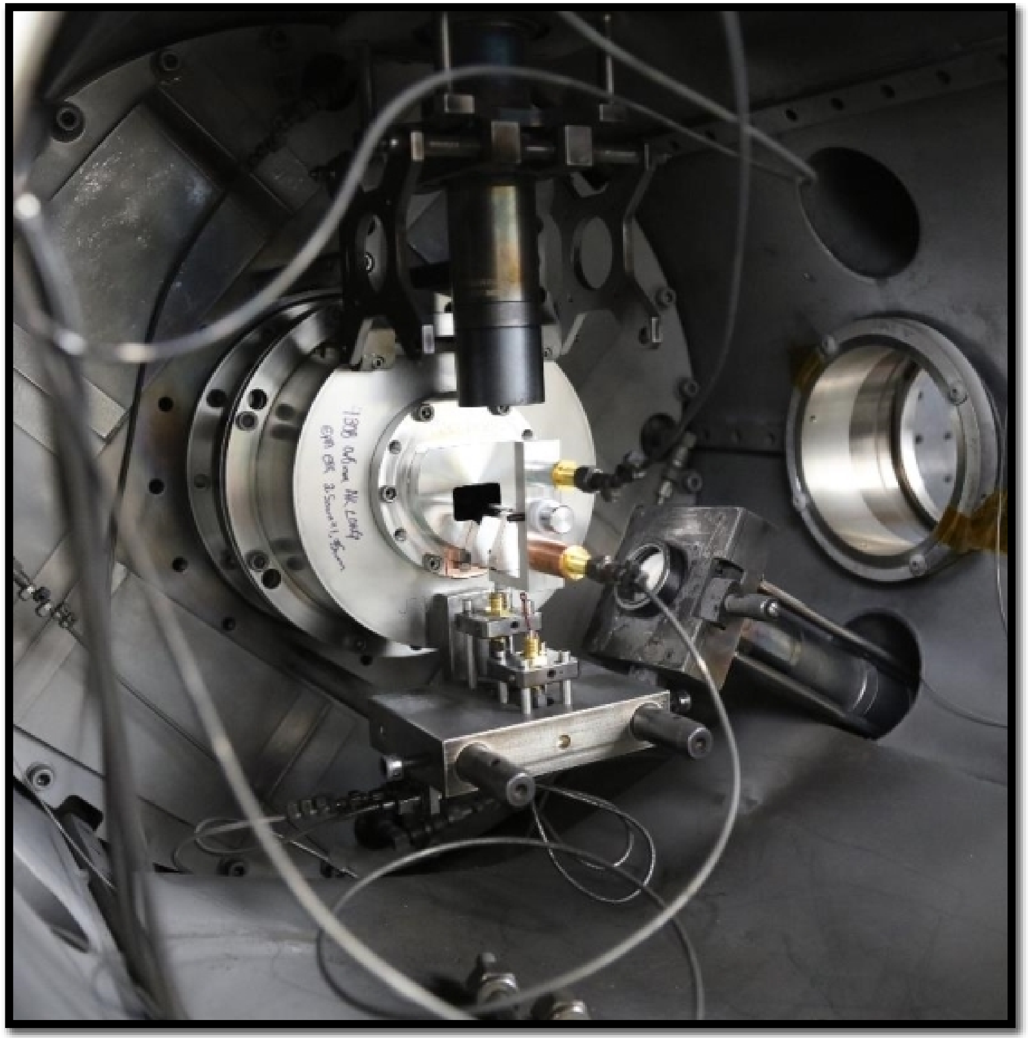


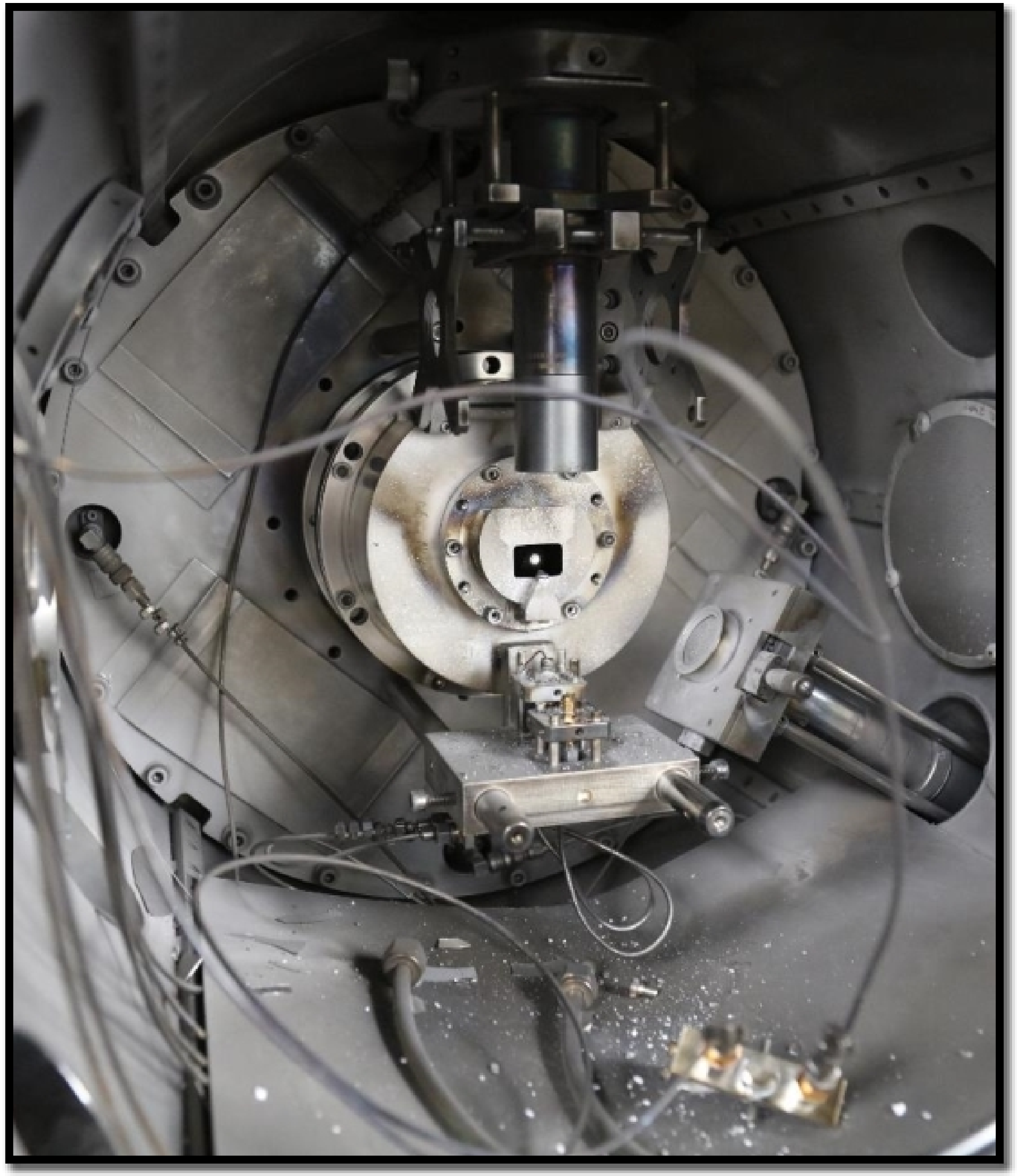
Summary and Next Steps

- **We (still) have much work to do to understand efficient cleaning protocol**
  - For a nominal electrode gap spacing, sweep backfill pressure and excitation potential to produce most effective cleaning rate
  - Characterize plasma densities, ionization states in these conditions
  - Verify same conditions are achieved in accelerator facilities to infer cleaning comparable cleaning rate

- **We have much work to do with this experimental platform**
  - Quantify delays in electrode turn on, load dynamic impedance, apparent closure velocities
  - Explore effect of delay between cleaning plasma extinguishment and downline shot
  - Explore transition into electrode melt and determine if bulk material and/or contaminants contribute to observed electrode plasma

Questions?





Like the Z Machine, Mykonos experimental hardware has a lifetime of one shot.

Backup

Light ion species desorbed from electrode surface contribute to Z Machine current loss

Lossy Magnetically Insulated Transmission Line (MITL)