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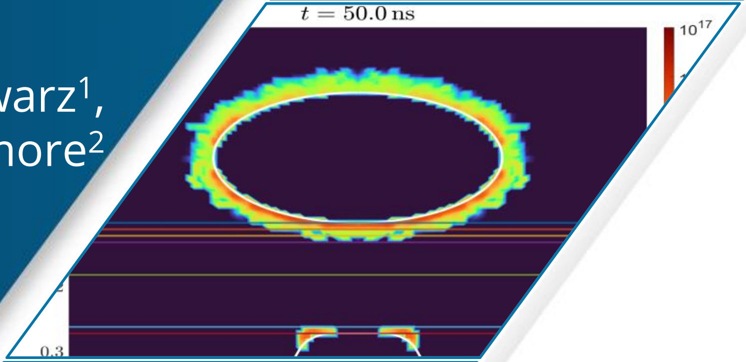
MITL ELECTRODE PLASMA FORMATION MEASUREMENTS

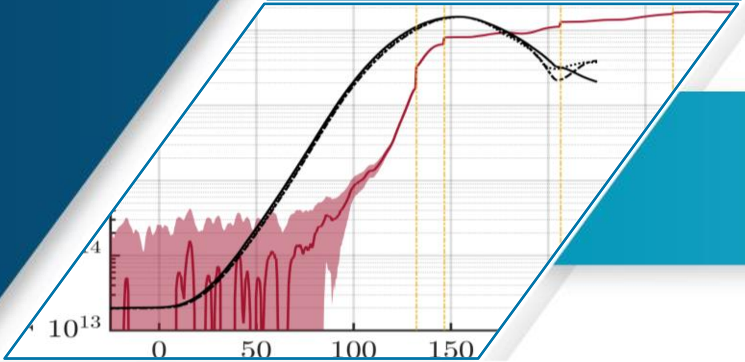
via a dispersion interferometer on the 1 MA Mykonos accelerator

Nathan R. Hines[1,2], Derek C. Lamppa[1], Jens Schwarz[1], Michael E. Cuneo[1], Thomas J. Awe[1], Mark A. Gilmore[2]

[1] *Sandia National Laboratories, Albuquerque, NM, USA*
[2] *University of New Mexico, Albuquerque, NM, USA*

Presented Friday August 9th, 2024 at:
2024 *Z* Fundamental Science Workshop,
Albuquerque, NM, USA





U.S. DEPARTMENT OF ENERGY
NNSA National Nuclear Security Administration

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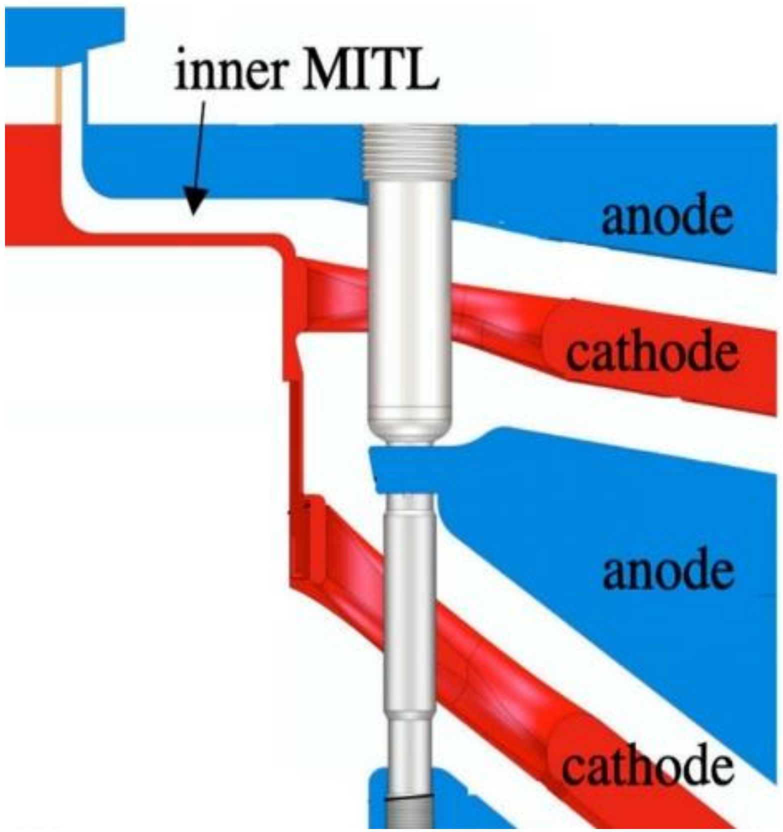
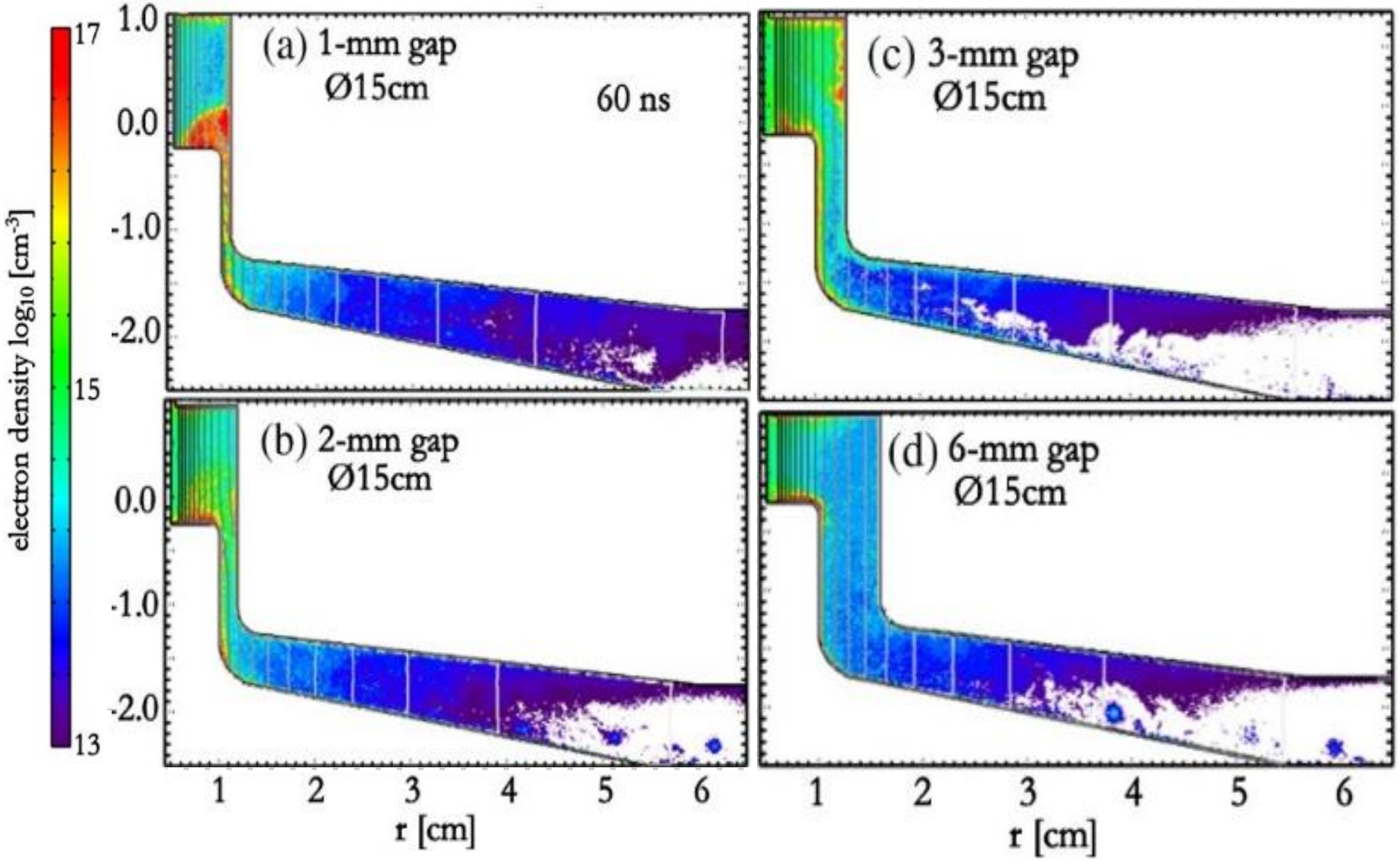
SAND2024-10383C

Z's inner MITL experiences current loss from charged particle cross-gap flow of expected e^- densities of 10^{13} - 10^{17} cm^{-3}

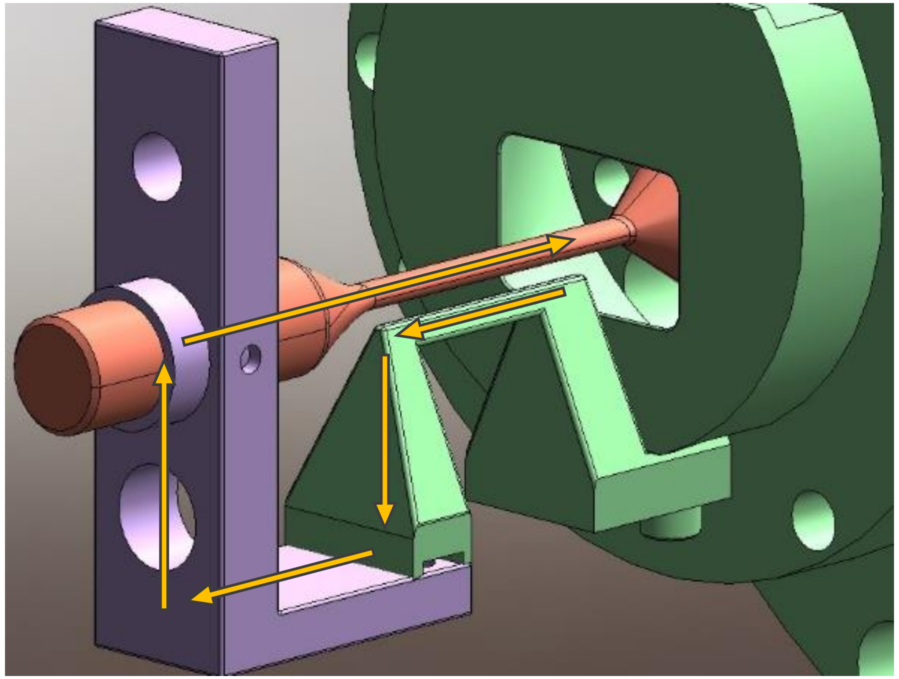


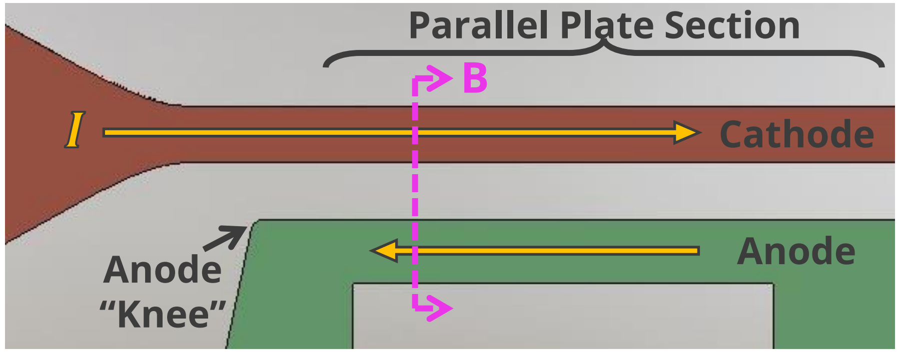


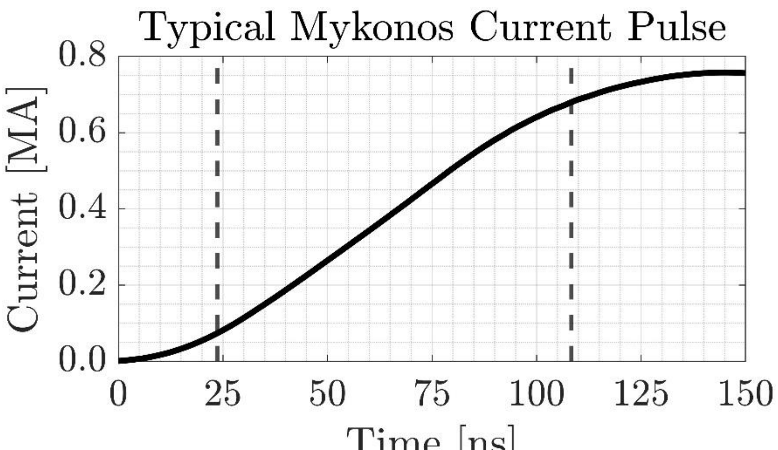
[1] W. A. Stygar et al., "55-TW magnetically insulated transmission-line system: Design, simulations, and performance," Phys. Rev. Accel. Beams, vol. 12, no. 12, p. 120401, 12/07/2009.

[2] N. Bennett, D. R. Welch, G. Laity, D. V. Rose, and M. E. Cuneo, "Magnetized particle transport in multi-MA accelerators," Physical Review Accelerators and Beams, vol. 24, no. 6, p. 060401, 06/23/2021.

An existing platform on Mykonos provides diagnostically accessible A-K gap geometry scaled to match Z's inner MITL field strengths







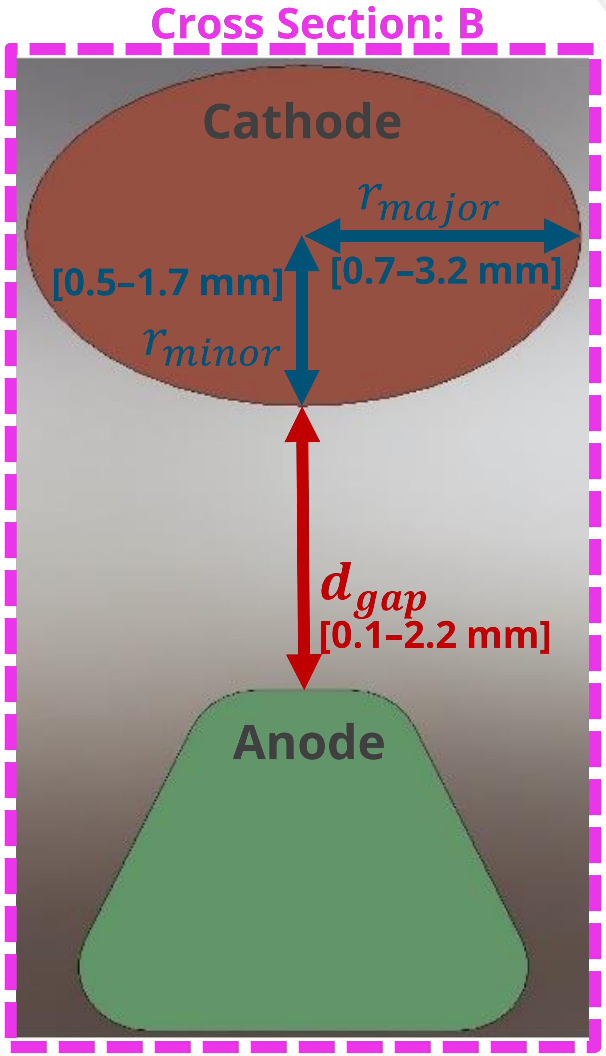
$t_{Rise} \approx 85$ ns

$1/d_{gap} \propto |\vec{E}|$ (electric field)

$|\vec{E}| \sim 0.5\text{-}5$ MV/cm

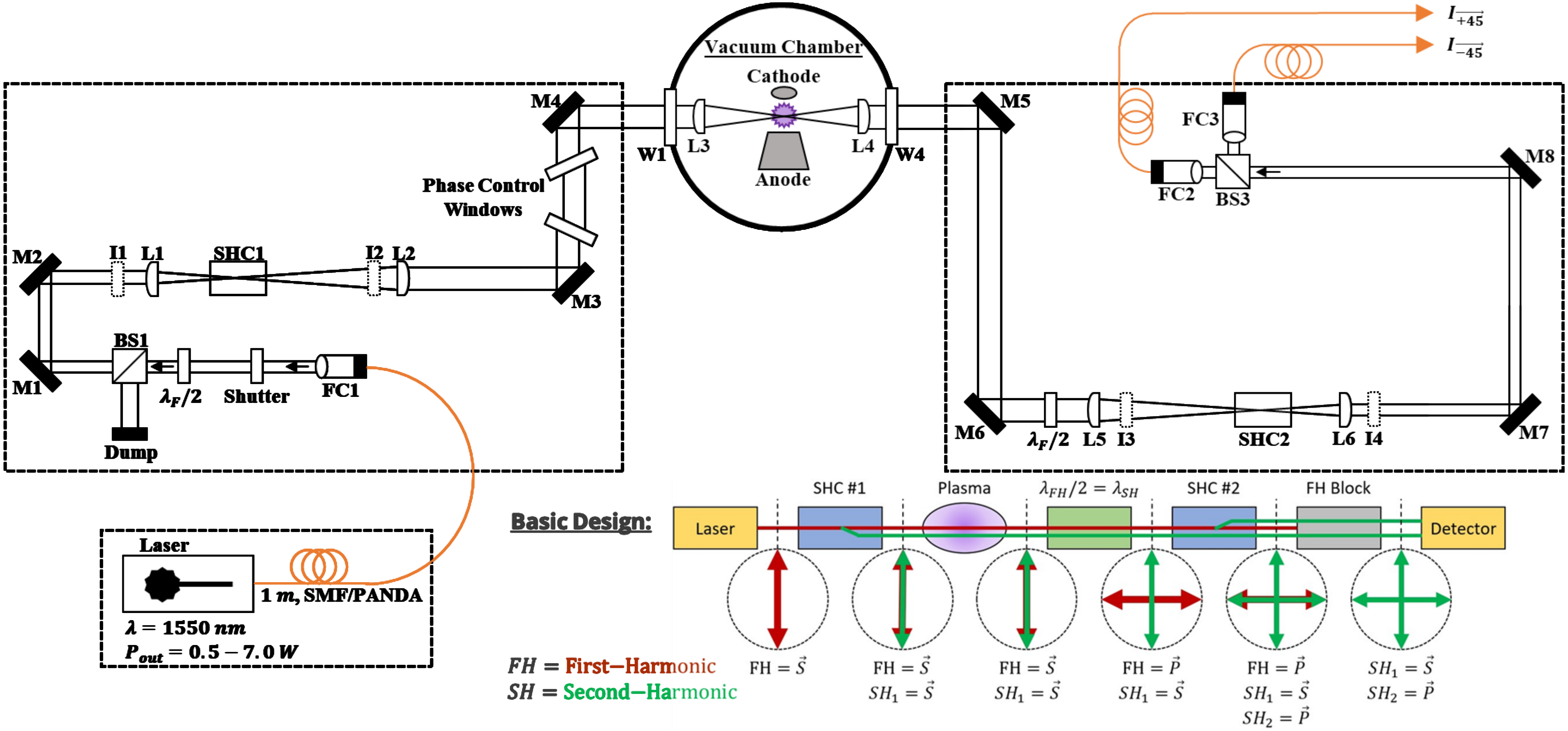
$1/r_{major}, 1/r_{minor} \propto |\vec{J}| \propto |\vec{B}|$

$|\vec{B}| \sim 50\text{-}500$ T



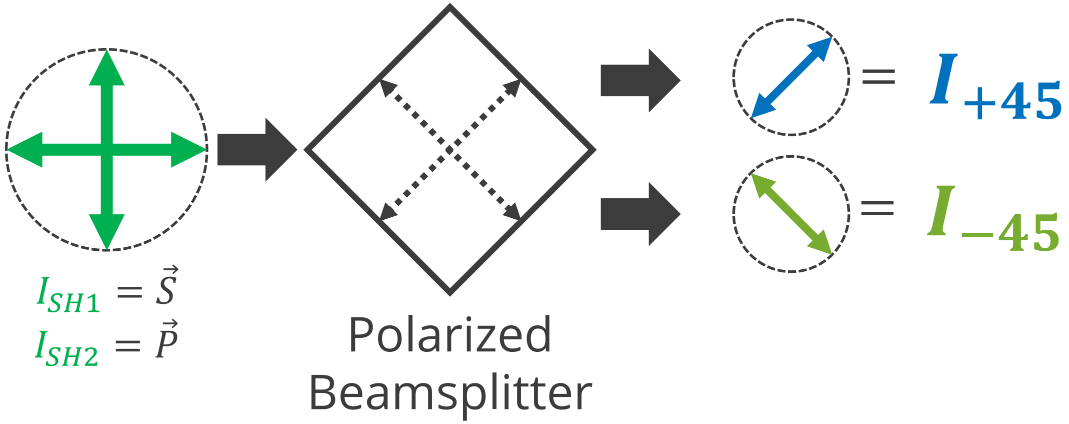
[6] D. Lamppa, S. Simpson, B. Hutsel, M. Cuneo, G. Laity, and D. Rose, "Assessment of Electrode Contamination Mitigation at 0.5 MA Scale," Sandia National Lab.(SNL-NM), Albuquerque, NM (United States), 2021.

Second-Harmonic Orthogonally Polarized Dispersion Interferometer (SHOP-DI) diagnostic design for Mykonos

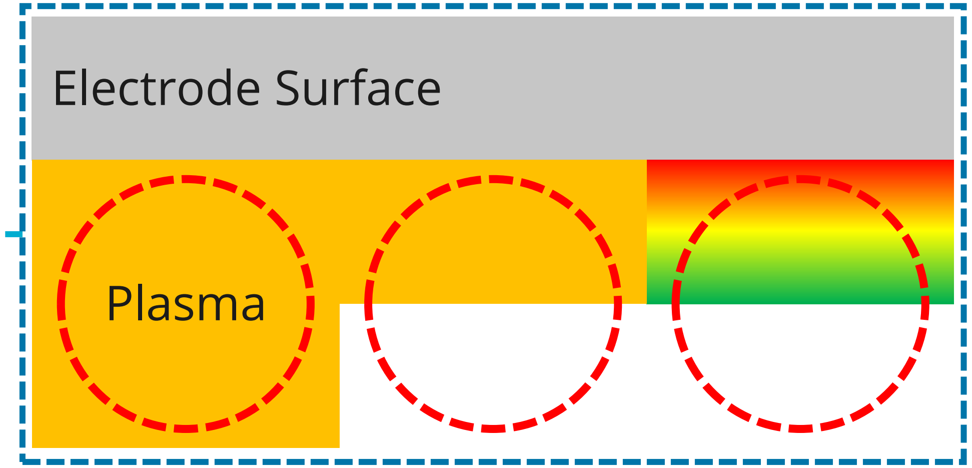


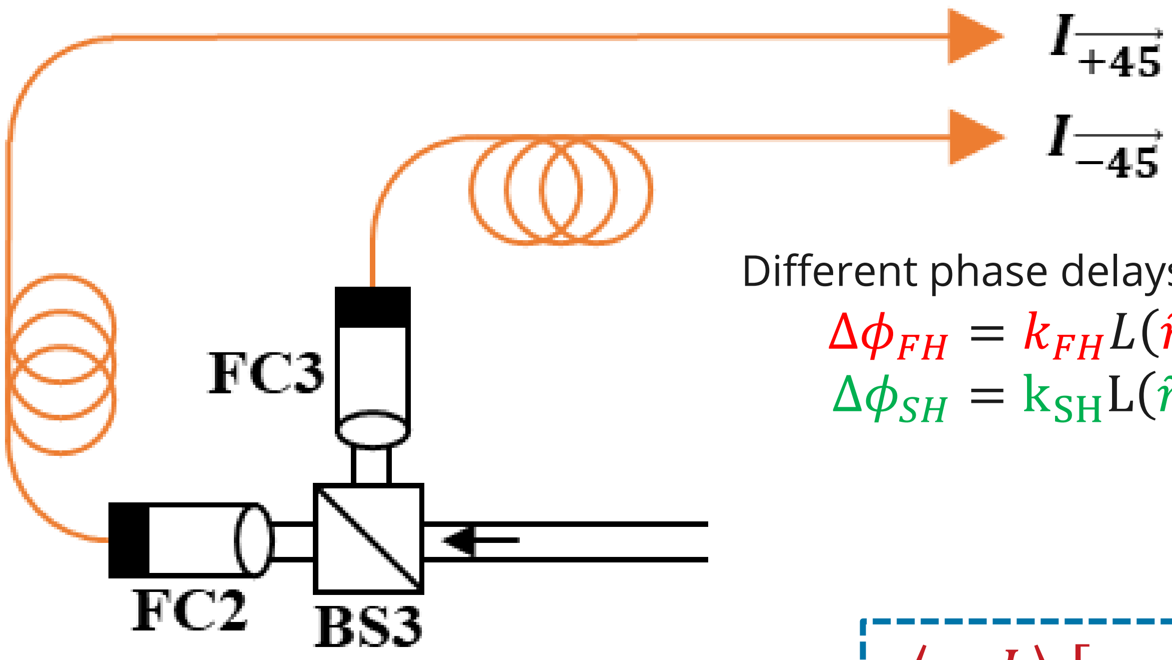
The SHOP-DI intensities I_{+45} and I_{-45} are sinusoidally related to the effective areal density $\langle n_e L \rangle$

Detection:



$$I_{\pm 45} = \frac{I_{SH1}}{2} + \frac{I_{SH2}}{2} \pm \sqrt{I_{SH1} I_{SH2}} \cos(\Delta\Phi)$$





Different phase delays from plasma

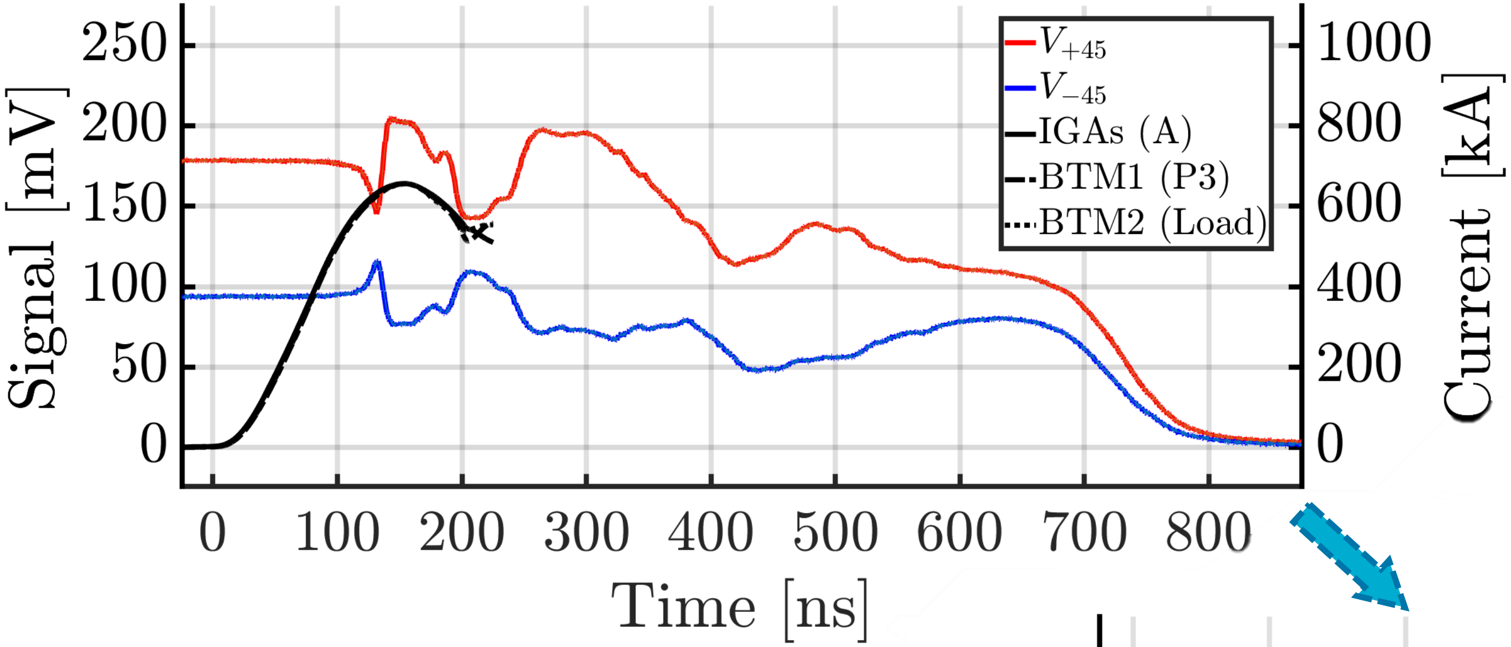
$$\Delta\phi_{FH} = k_{FH} L(\tilde{n}_{FH} - 1)$$
$$\Delta\phi_{SH} = \mathrm{k_{SH}} \mathrm{L}(\tilde{n}_{SH} - 1)$$

and the detected phase change is

$$\Delta\Phi = 2\Delta\phi_{FH} - \Delta\phi_{SH}$$
$$= 2k_{FH} L(\tilde{n}_{FH} - \tilde{n}_{SH})$$
$$\approx \left(\frac{-3(e^-)^2}{8\pi\epsilon_0 m_e c^2}\right) \lambda_{FH} \langle n_e L \rangle$$

$$\langle n_e L \rangle\ [\mathrm{cm}^{-2}] \approx -1.527 \times 10^{+16} (\Delta\Phi\ [\mathrm{rad}])$$

SHOP-DI data analysis (intensity fluctuations)



There are two distinct patterns:

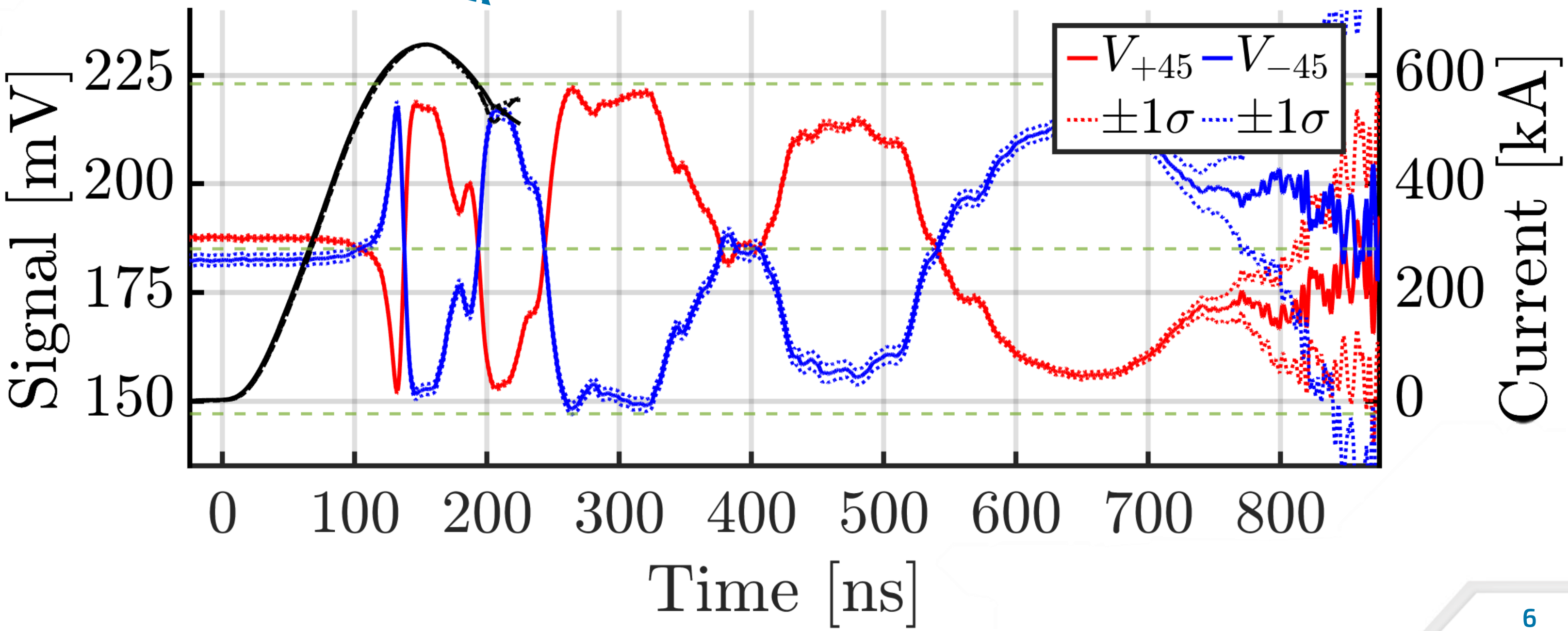
1. Similar signal reduction in both V_{+45} and V_{-45} corresponding to absorption and beam steering.
2. Opposite phase oscillations of the signals representing the plasma density measurement.

Power adjusted signals can be calculated by dividing out:

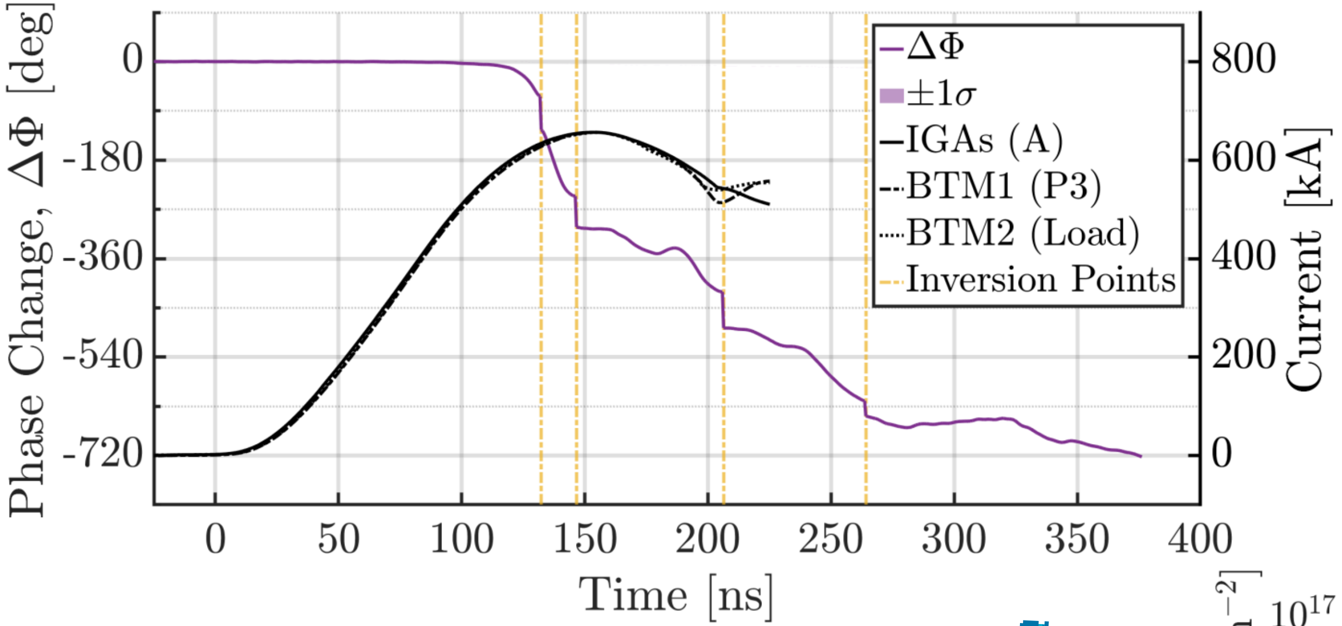
$$F_{\text{power},i} = \frac{\overline{V_i}}{(\overline{\overline{V_0}})}$$

and

$$F_{\text{optic}} = \frac{\overline{V_0}}{\text{DC}_{\text{cal}}}$$



SHOP-DI data analysis (effective areal density)



The phase change can be tracked via:

$$\Phi_t = \cos^{-1}\left(\frac{V_t - DC_{cal}}{A_{cal}}\right)$$

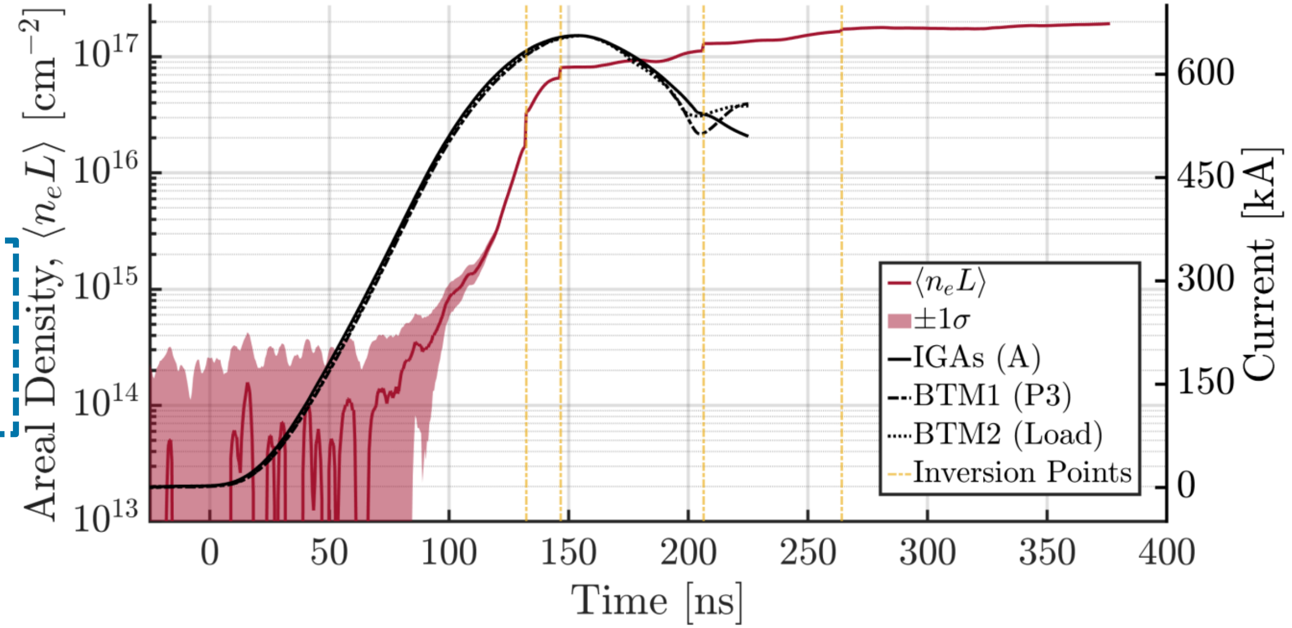
and

$$\Delta\Phi\ [\mathrm{rad}] = \Phi_t - \Phi_0$$

Need to account phase wrapping.

The effective areal density is then calculated via:

$$\langle n_e L\rangle\ [\mathrm{cm}^{-2}] \approx -1.527 \times 10^{+16}(\Delta\Phi\ [\mathrm{rad}])$$



Conclusion

- The SHOP-DI diagnostic at SNL has been upgraded, allowing it to measure electrode plasma free electron effective areal densities that are expected to form in the inner MITL and convolute regions of TW-class accelerators like the Z machine.
  - ❖ $\langle n_e L \rangle_{\text{min}} = 6.3 \times 10^{13}$ [cm^{-2}] (4.11 [rad] sensitivity)
  - ❖ $\Delta \langle n_e L \rangle_{\text{max}} = 4.8 \times 10^{16}$ [cm^{-2}/ns] (2 [GHz] bandwidth)
- The areal density is considered “free electron effective” since it’s calculated assuming the plasma’s **refractive index** is solely affected by free electrons.
  - There may in fact be substantial bound electrons that are affecting (positively) the detected phase change, thus affecting (negatively) the calculated electron areal density below reality. So, this is really a minimum free electron areal density measurement.