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PDV for Electron Density Measurements

PRESENTED BY

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Photonic Doppler Velocimetry (PDV) for Electron Density

Developed to measure the motion of a surface at high velocities with good time resolution

- 1-10,000 m/s speeds
- 1ns to 1ms time scales
- Measuring apparent velocity v^*

$$v^*(t) = -\frac{d}{dt}\int n(x,t)\,dx$$

Use two lasers with similar wavelengths to set up a beat frequency, changes to that beat are related to apparent velocity.

Apply the apparent velocity measurement to phenomena other than motion.

- Measurement depends on a change of refractive index, n

D. Dolan, K. Bell, et. al., Journal of Applied Physics 123, 034502 (2018)

Signal Proportional to Density Change and Path Length

Electron Density N changes the refractive index according to below, with Nc the cutoff density.

- $N_c = 4.6 \times 10^{20}$ electrons/cm^3 using 1550nm light.

$$n = \sqrt{1 - \frac{N}{N_c}}, \quad N_c = \frac{m_e \epsilon_0}{e^2} \left(\frac{2\pi c}{\lambda} \right)^2$$

Measuring over a probing chord, the signal is proportional to the

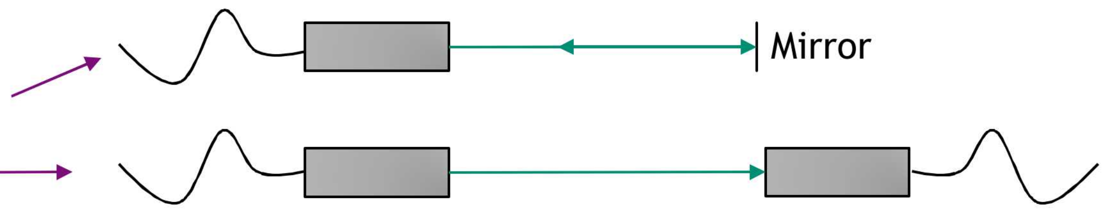
- the length of the plasma L, and
- the average change in density over that length

$$v^*(t) \approx -L \frac{d\hat{n}}{dt},$$

Measurement Practicalities

Density threshold depends on the

- Laser wavelength
- Size of the experiment -
  - Single Fiber Probe (SFP) or
  - Dual Fiber Probe (DFP)
- Timescales of the experiment
- Rate of change
- Background noise



Resolving the measurement requires scopes and detectors to be matched to requirements

- 10's MHz to 25GHz may be necessary depending on the experiment!

Background noise/signal has a large impact! May come from

- Laser instability – float of the wavelength
- X-ray radiation

Background Characterization

A single probe dedicated to background characterization is necessary for every measurement.

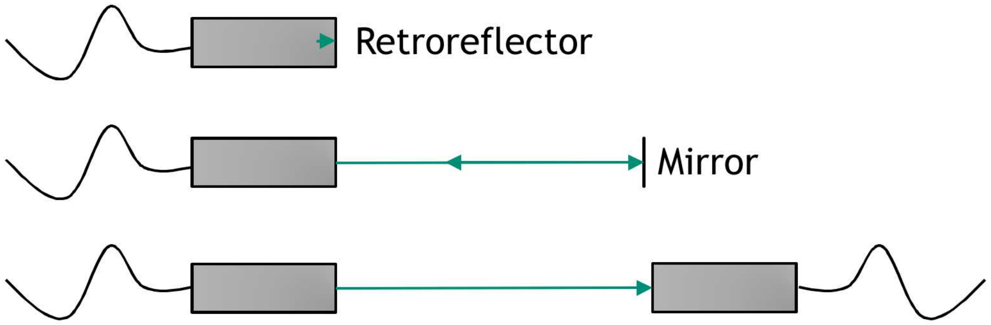
- Large background environments require signal subtractions to obtain measurement

If only have wavelength float:

- Use a retro reflector at the probe position to measure how the beat frequency changes with time.

If have both wavelength and radiation backgrounds:

- Use a probe beam that does not pass through any plasma but remains in the same radiation environment.
- Use the same configuration (SFP/DFP) as the other probes.



Expanded Calculation of Electron Density

$$v^*(t) \approx -L\frac{d\hat{n}}{dt},$$

$$\tilde{n} = \frac{ck}{\omega},$$

$$\phi = \int k\, dl$$

$$\Delta\phi = \int \Delta k\, dl = \int (k_0 - k)\, dl = \int \frac{\omega}{c}(\tilde{n} - 1)\, dl.$$

$$\tilde{n}^2 = 1 - \frac{\omega_p^2}{\omega^2}$$

$$\omega_p = \sqrt{\frac{n_e e^2}{\epsilon_0 m_e}}$$

$$\Delta\phi = \int \frac{\omega}{c}\left(\sqrt{1 - \frac{\omega_p^2}{\omega^2}} - 1\right) dl$$

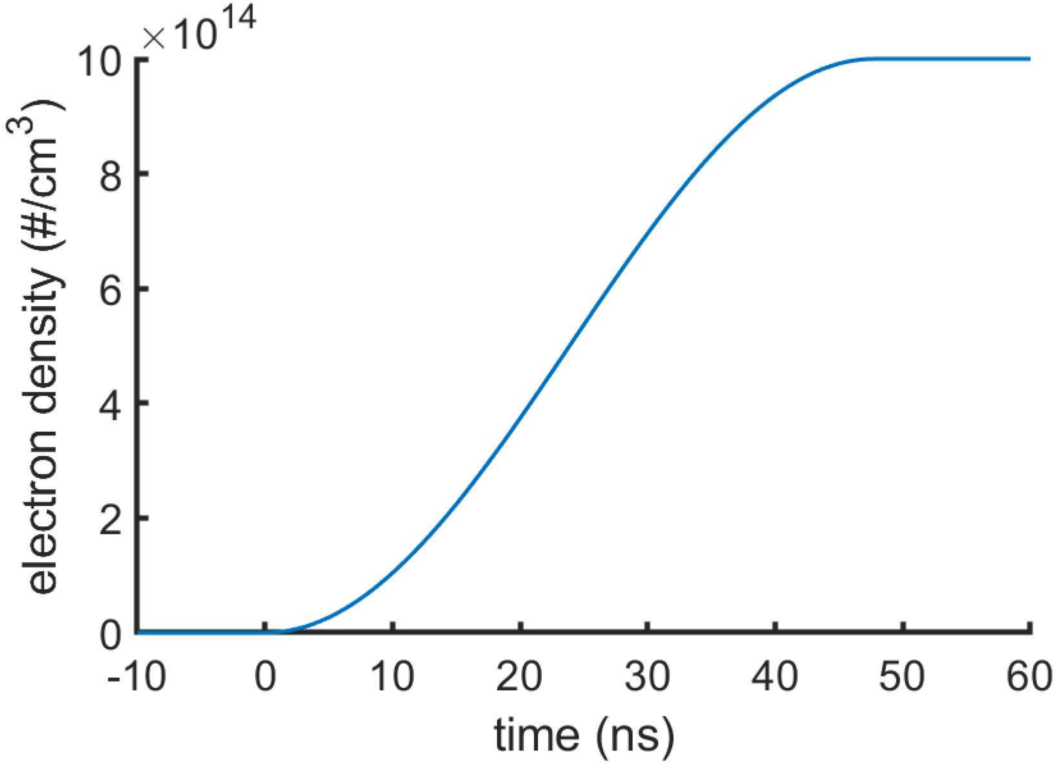
$$n_c = \frac{\omega^2 \epsilon_0 m_e}{e^2}$$

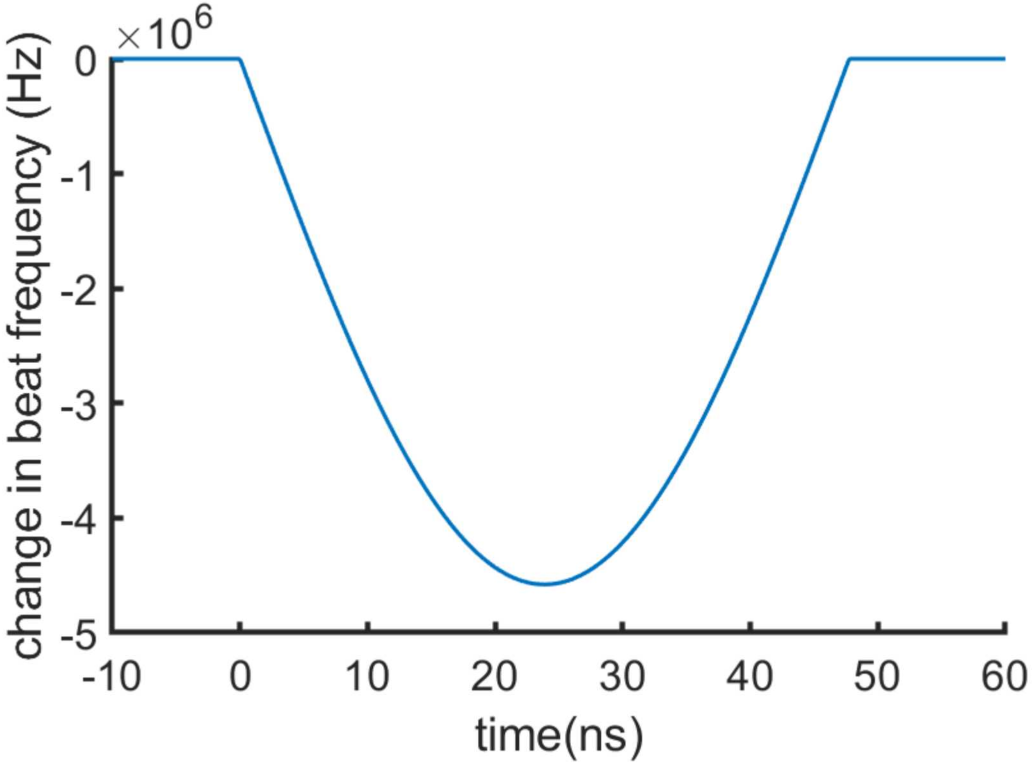
$$\Delta\phi = \int \frac{\omega}{c}\left(\sqrt{1 - \frac{n_e}{n_c}} - 1\right) dl$$

$$\boxed{\Delta\phi \approx -\frac{\omega}{2cn_c}\int n_e dl}$$

Idealize Application Example

Sine wave increase of average electron density from zero to **1e15 electrons/cc** (1e18#/m^3) over **50ns** with a plasma that is **200 mm diameter.**





*Assuming Dual Fiber Probes

Measuring a velocity of 3.5m/s!

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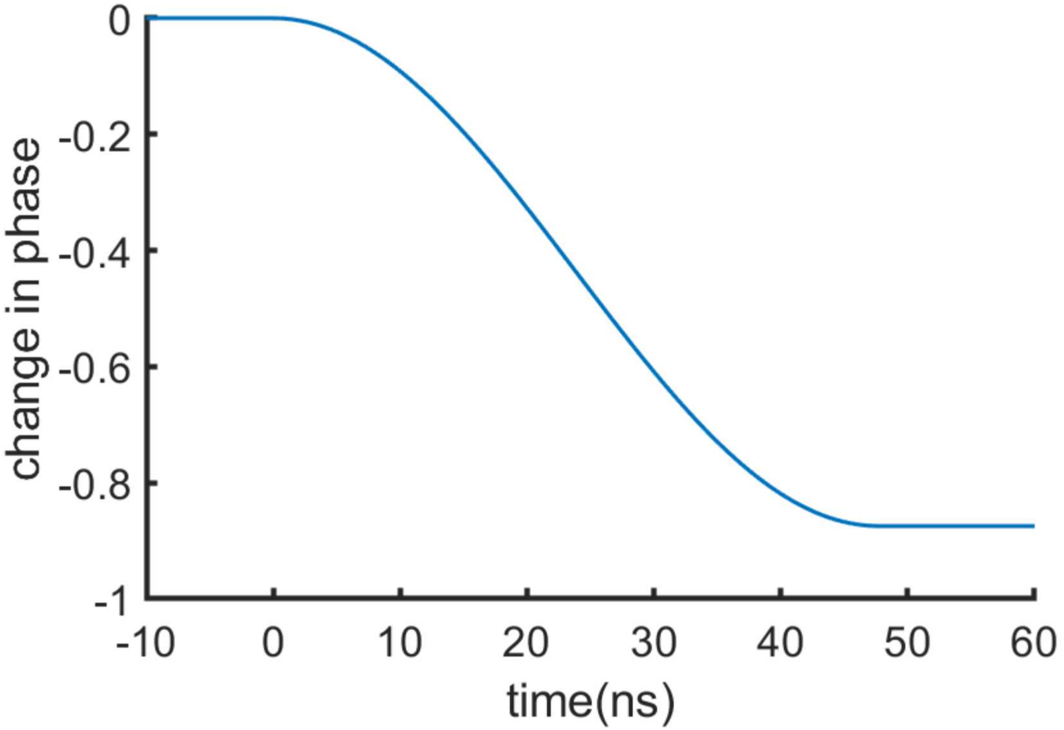

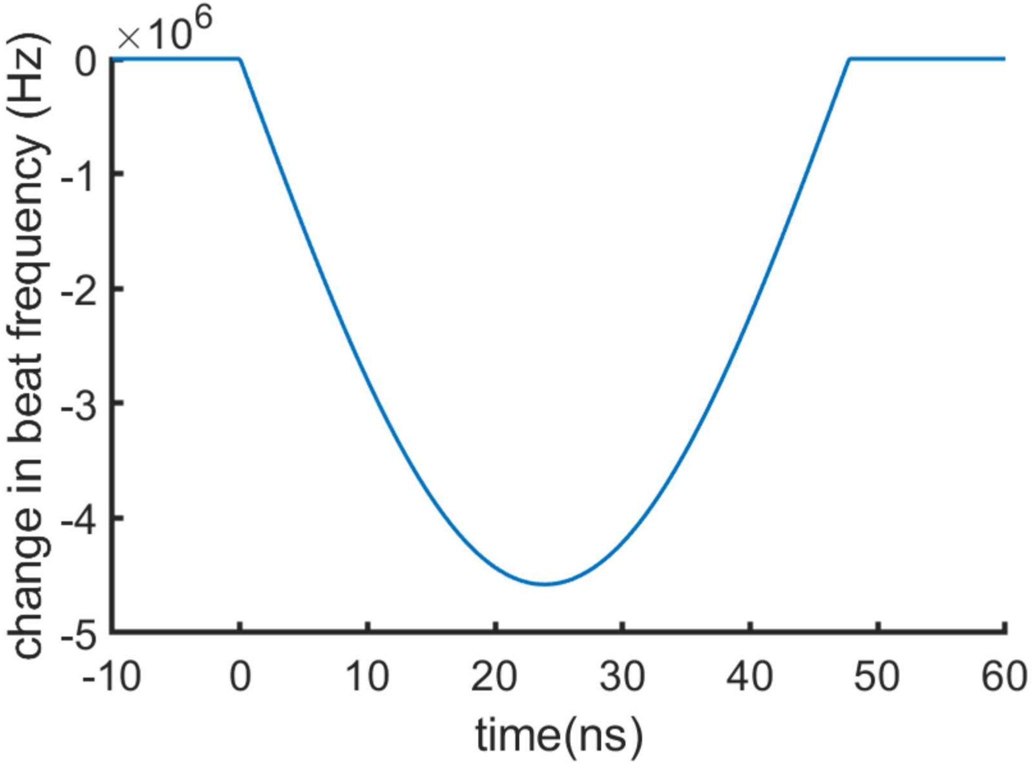

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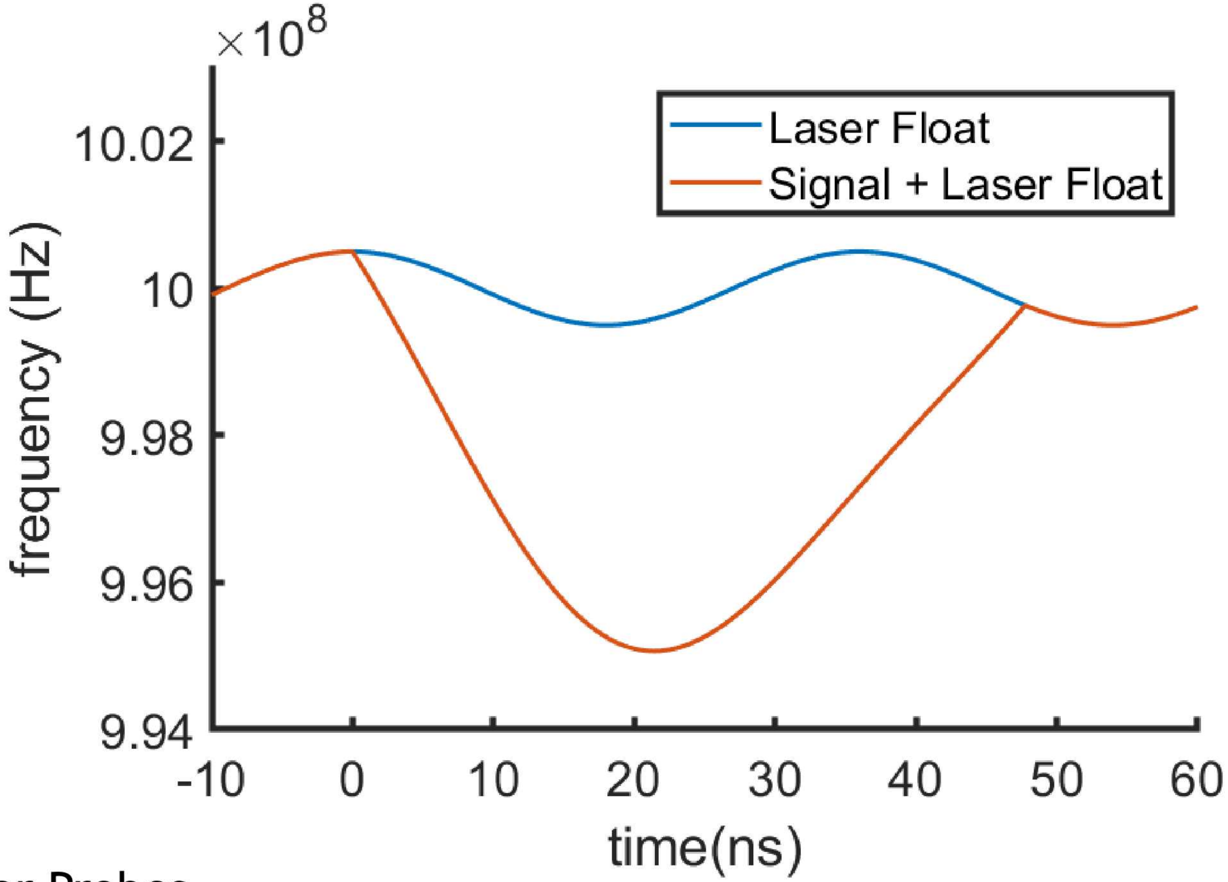
Less-Idealize Application Example

Sine wave increase of average electron density from zero to **1e15 electrons/cc** (1e18#/m^3) over **50ns** with a plasma that is **200 mm diameter** with **unstable lasers**.



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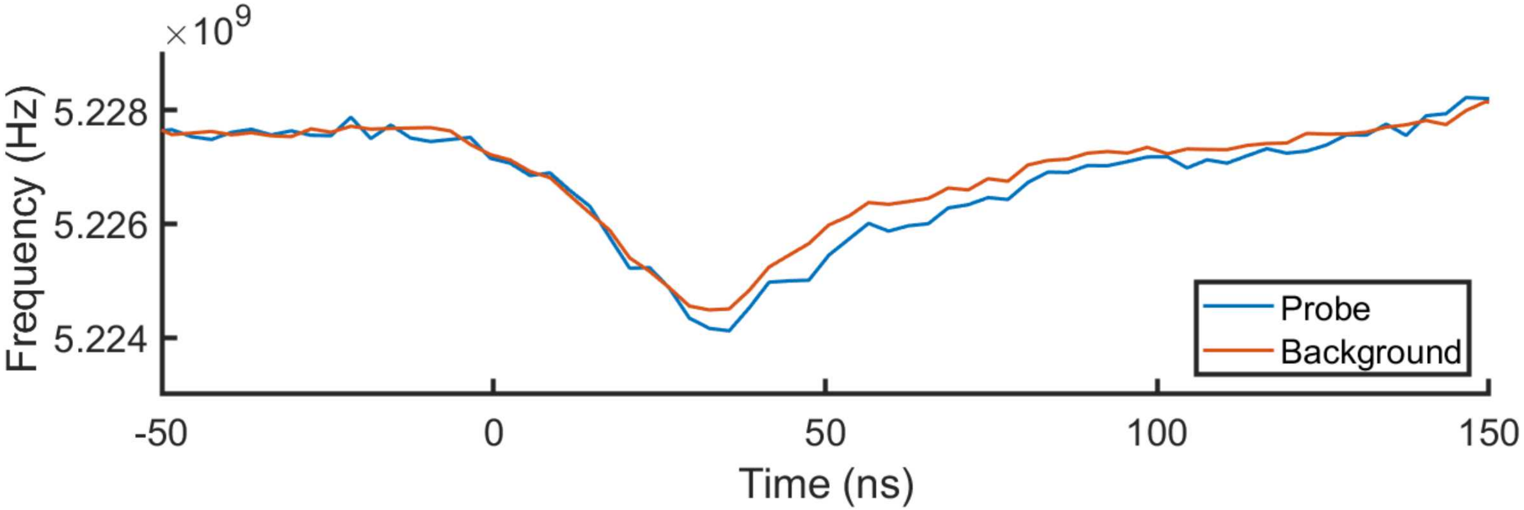
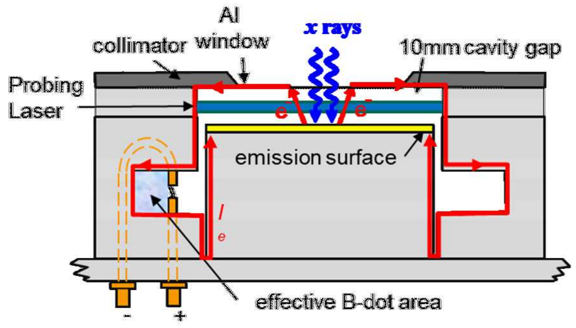
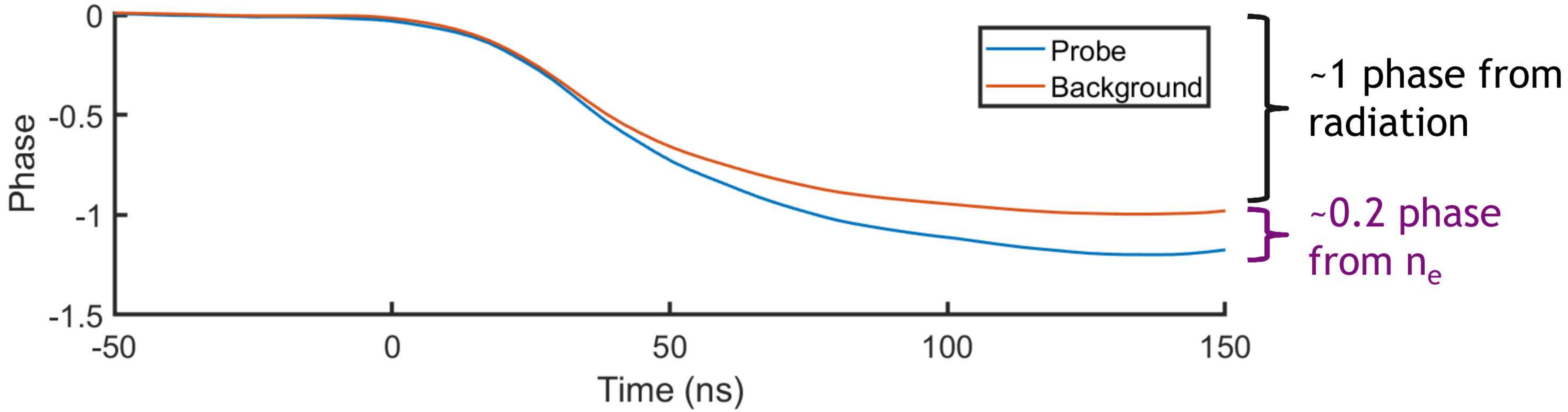
Application in High Radiation Environment

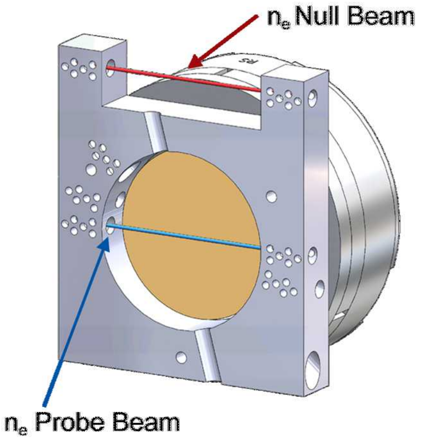
Background radiation can dominate signal by changing the index of refraction of lens and fiber optics.

- Can still measure electron density data (with larger error) if characterize background.









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