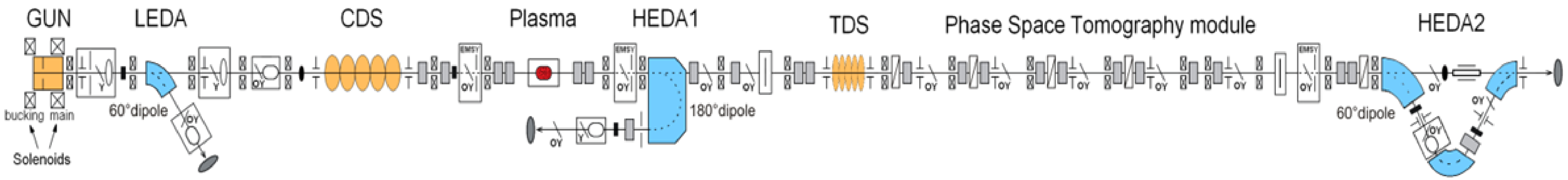
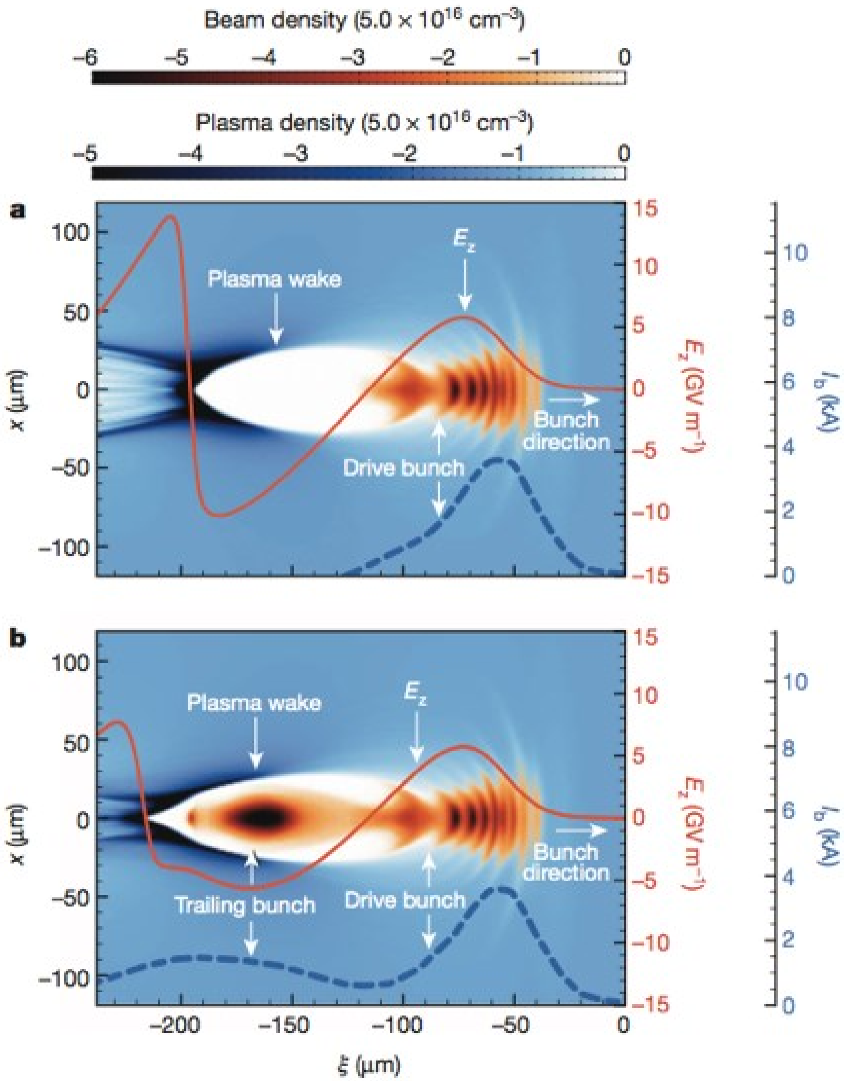
Diffusion of Plasma Density in PITZ Plasma Cells



Wakefield Acceleration

- Unlike RF cavities, plasma wakefields are not limited by electric breakdown/sparking.
- Can sustain accelerating gradient tens of TeV/m, a few orders of magnitude higher than RF cavities.
- Alternative to produce more compact accelerators or more energetic particle collider.
- Two main ways to generate wakefield – laser or particle beam.

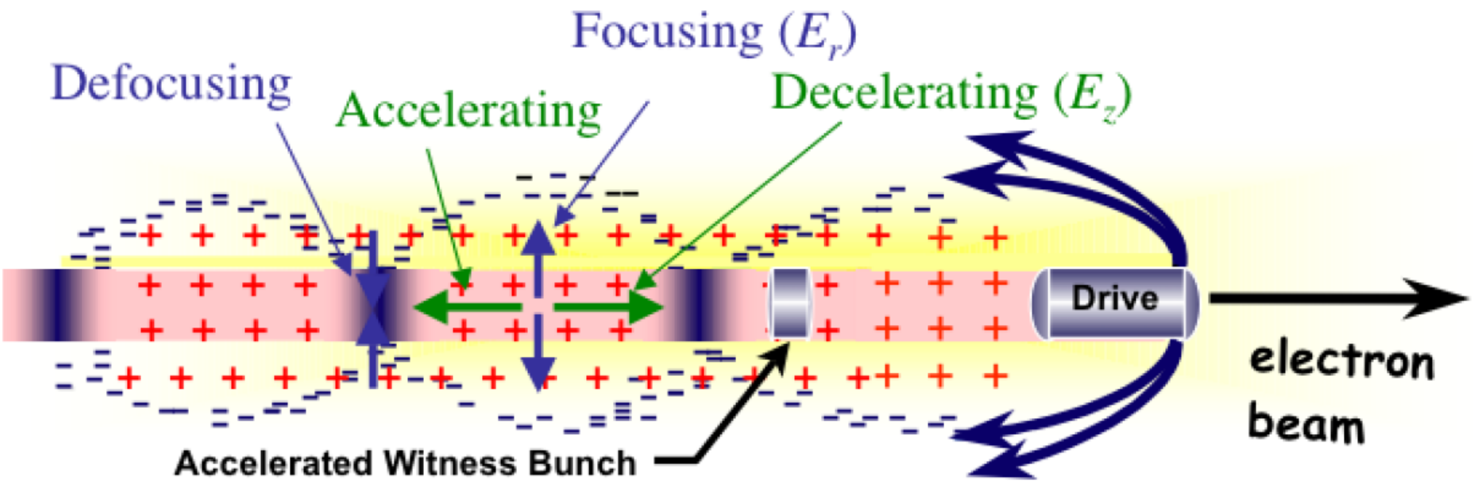
Beam-driven Plasma Wakefield Acceleration



- A drive bunch is first injected into a plasma to excite a wakefield.
- A trailing or witness bunch is inserted, which is accelerated by electric field.

M. Litos *et al.*, Nature, **13882** (november 2014)

Beam Driven Plasma Acceleration

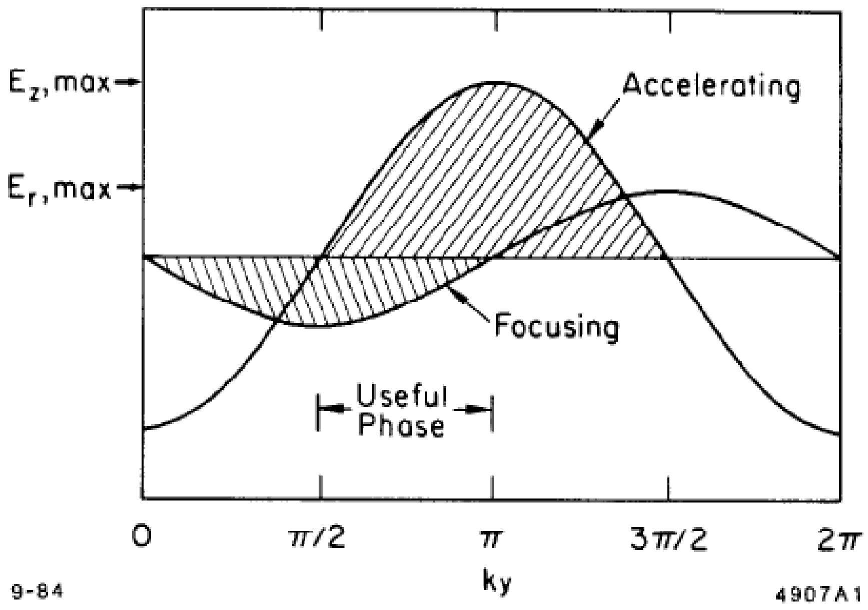


- Plasma Wavelength is determined by:

$$\lambda_p = 2\pi c \left(\frac{\varepsilon_0 m_e}{e^2 n_e}\right)^{1/2} = 3.34 \times 10^7 (n_e)^{-1/2}$$

- Density will affect the wavelength and acceleration of witness bunch →

Density variation and phase slippage



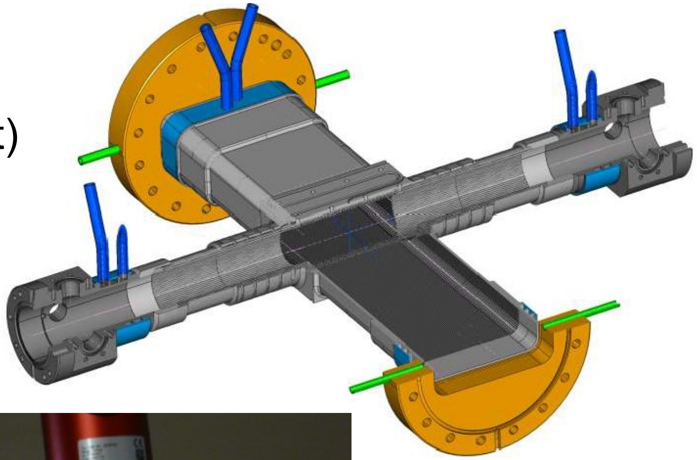
Ruth *et al.*, SLAC Publications, **3379** (July 1984)

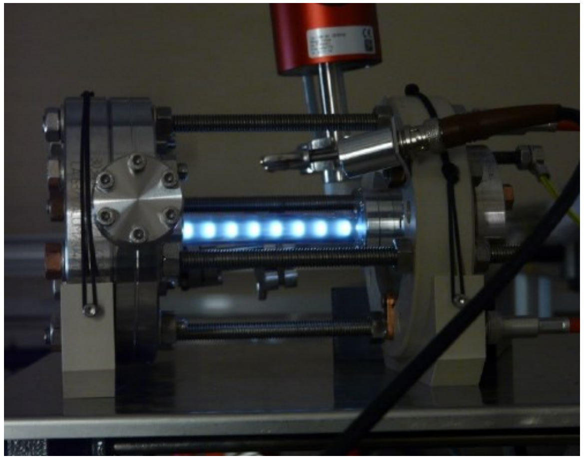
- Plasma wakes has accelerating/decelerating fields

  + focusing/defocusing fields
- → plasma wavelength effects acceleration as well as focusing
- Bunches at a fixed distance/delay slip in phase when plasma wavelength (i.e. density) varies

Motivation for Summer Project

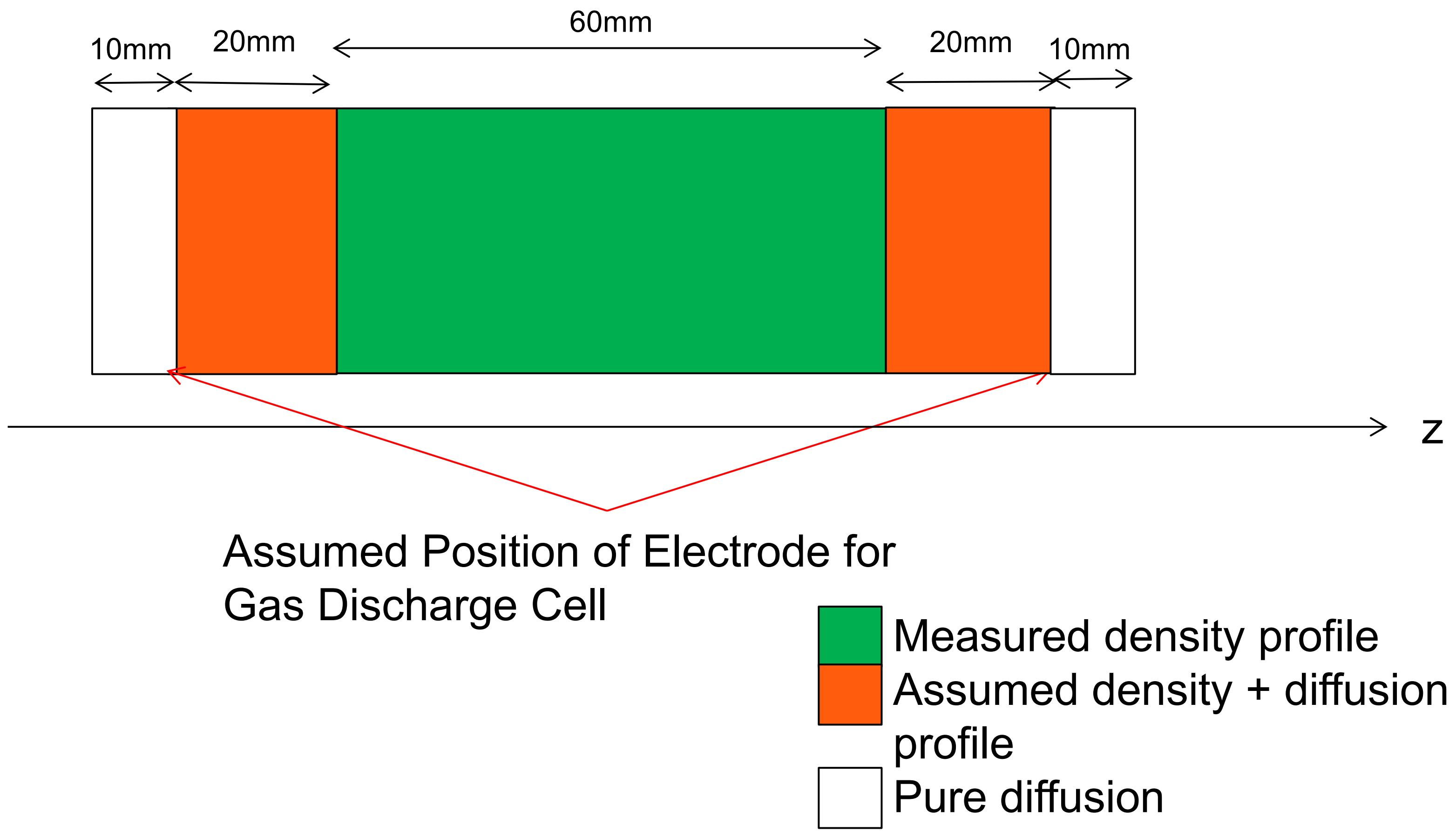
- Create a script that reads measured density profiles, adds assumptions on edge region development (diffusion..) and delivers profile in normalised units for simulation
- Features:
  - 2 types of plasma cells (different profile treatment)
  - Adjustable diffusion time
  - Adjustable nominal density





Idealised geometry for Gas discharge cell

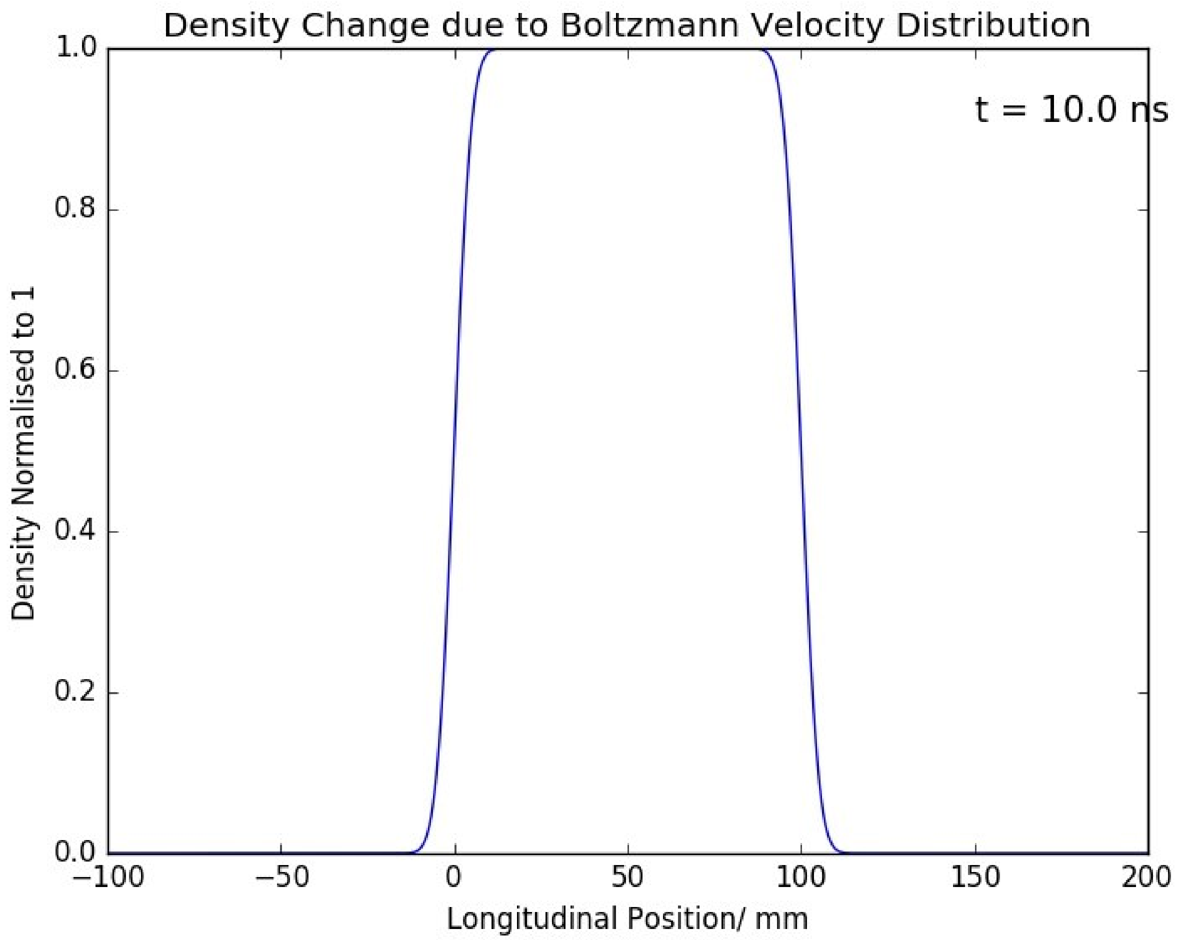
- Used a geometry assuming transverse symmetry:



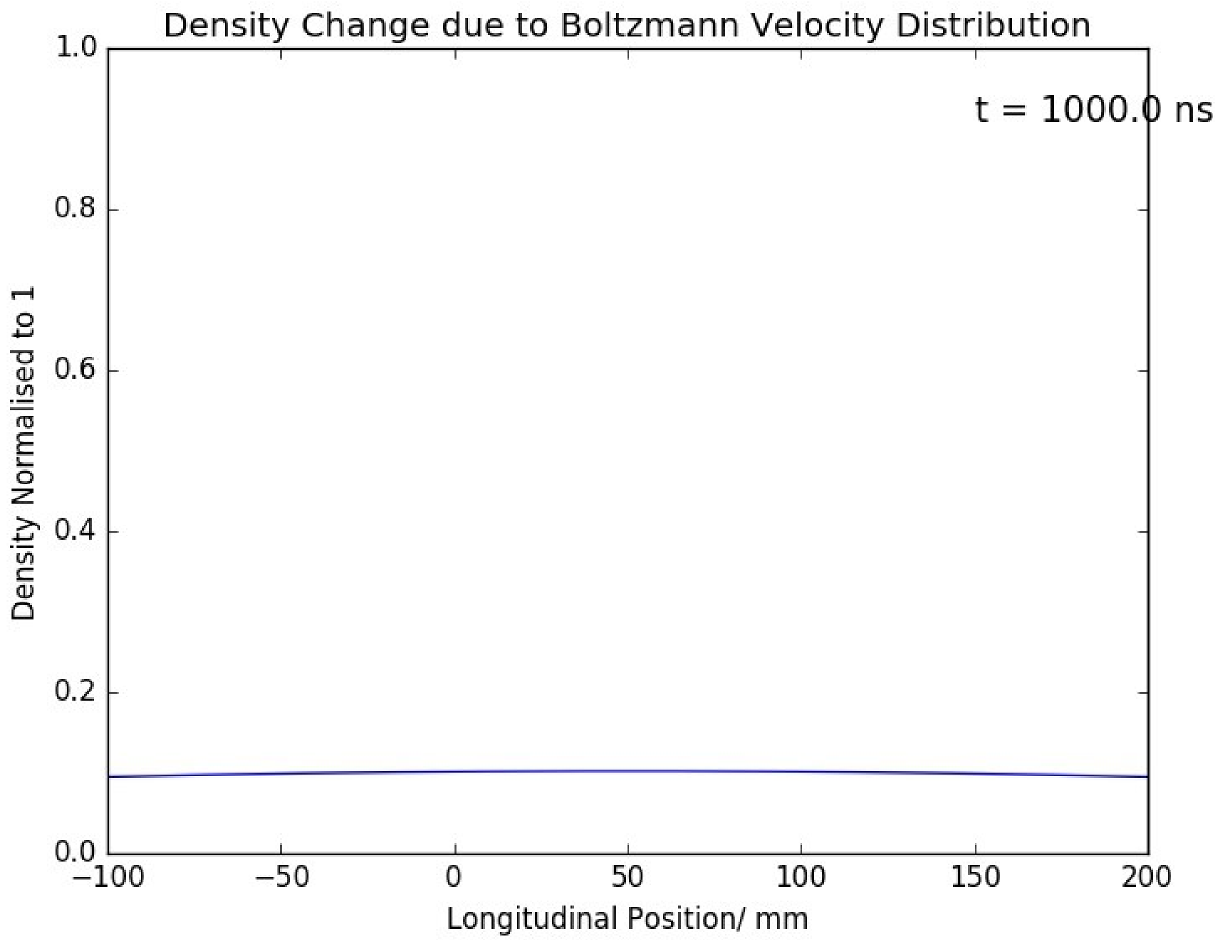
Edge Diffusion

- Attempted with Boltzmann distribution, assuming no collisions.
- After time t, the density at z is:
- $n(z,t) = \int_{50mm}^{-50mm} \sqrt{\frac{m}{2\pi kT}}\, e^{-\frac{m}{2kT}\left(\frac{z'-z}{t}\right)^2} dz'$

Boltzmann Diffusion distribution



Boltzmann Distribution Diffusion



Problems with Boltzmann Velocity Distribution Model

- Diffuses 3-4 orders of magnitude too fast.
- Due to mean free path (~60microns)<< plasma cell dimensions.
- Hence, need diffusion model with particle interaction.

Linear Plasma Diffusion Equation

- Full discussion can be found in FF.Chen plasma book.
- Assuming no recombination of plasma.
- Plasma recombines at the ends (windows) of the plasma cell (boundary conditions).
- Only considered diffusion across longitudinal(z-axis) position (1D-model).
- Solved the following equation using separation of variables:

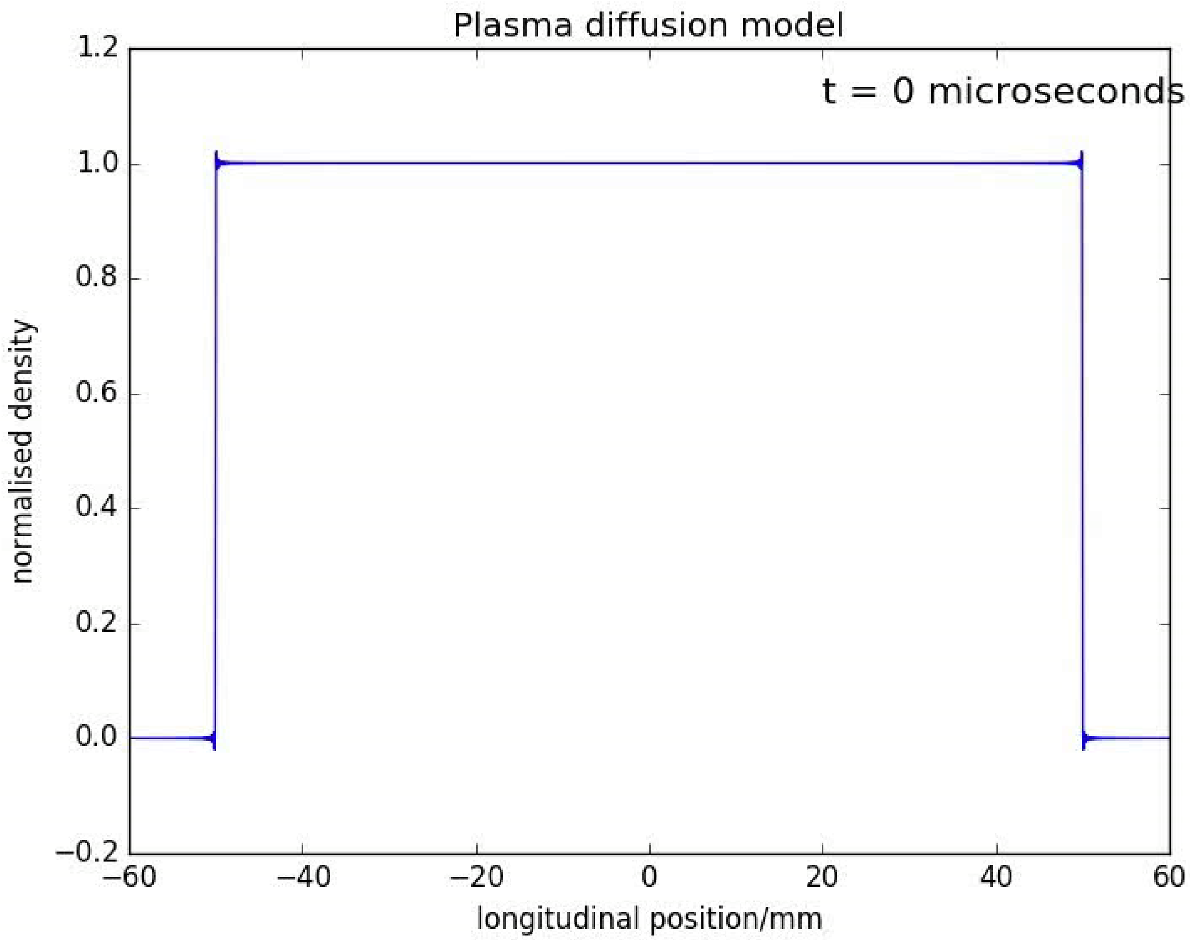
$$\frac{\partial n}{\partial t} = D\nabla^2 n$$

$$D = \frac{2}{n_p \sigma}\sqrt{\frac{kT}{3m}}$$

- With the solution:

$$n(z,t) = \sum_{n=1}^{\infty} a_n e^{-t/\tau_n} \cos(k_n z)$$

Plasma Evolution due to Diffusion



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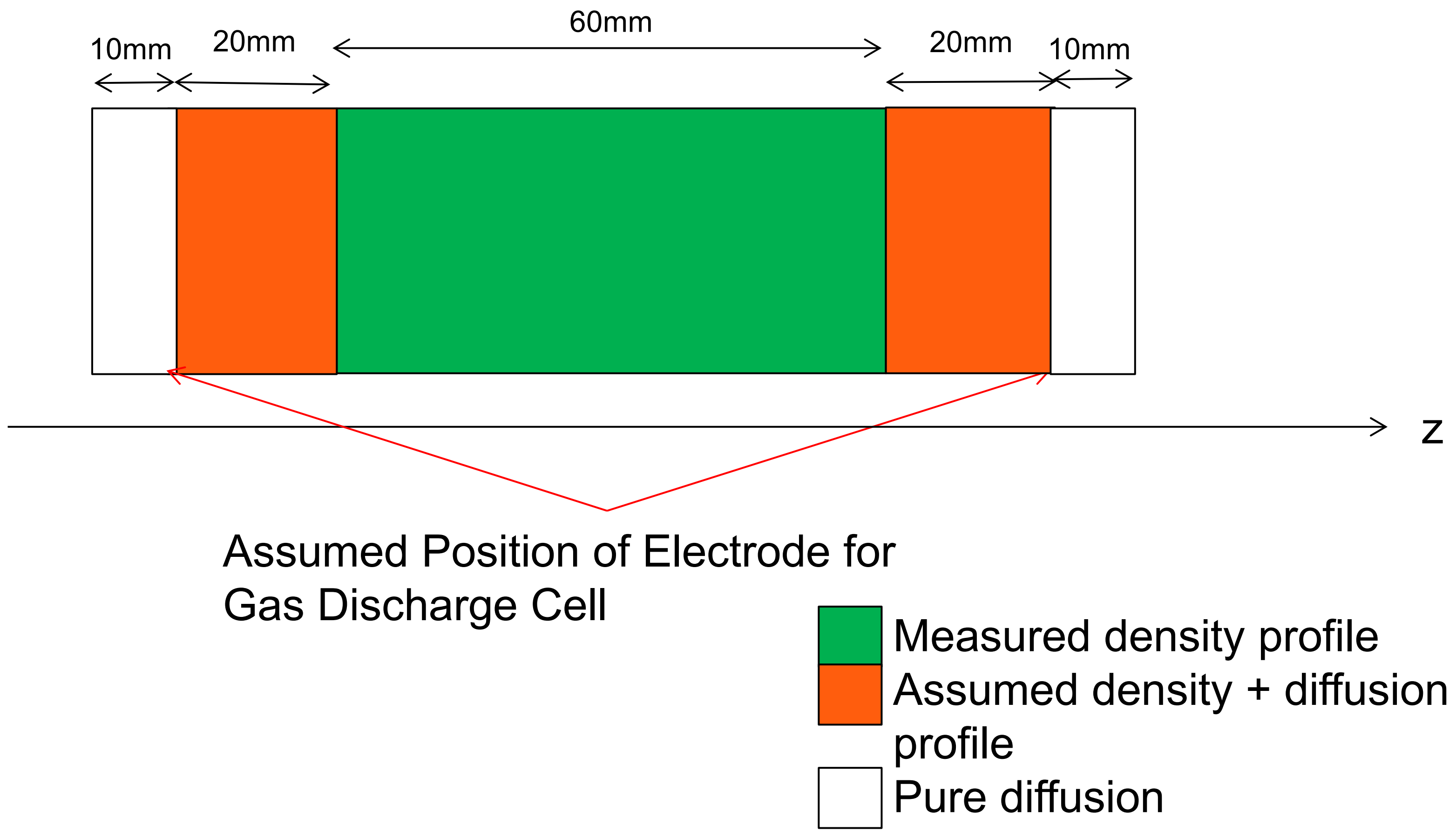
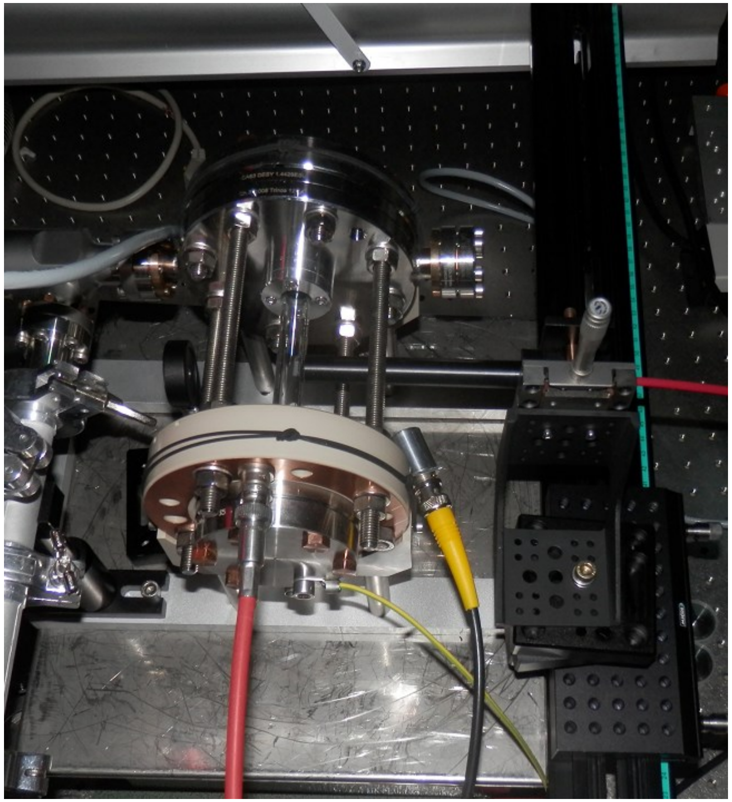
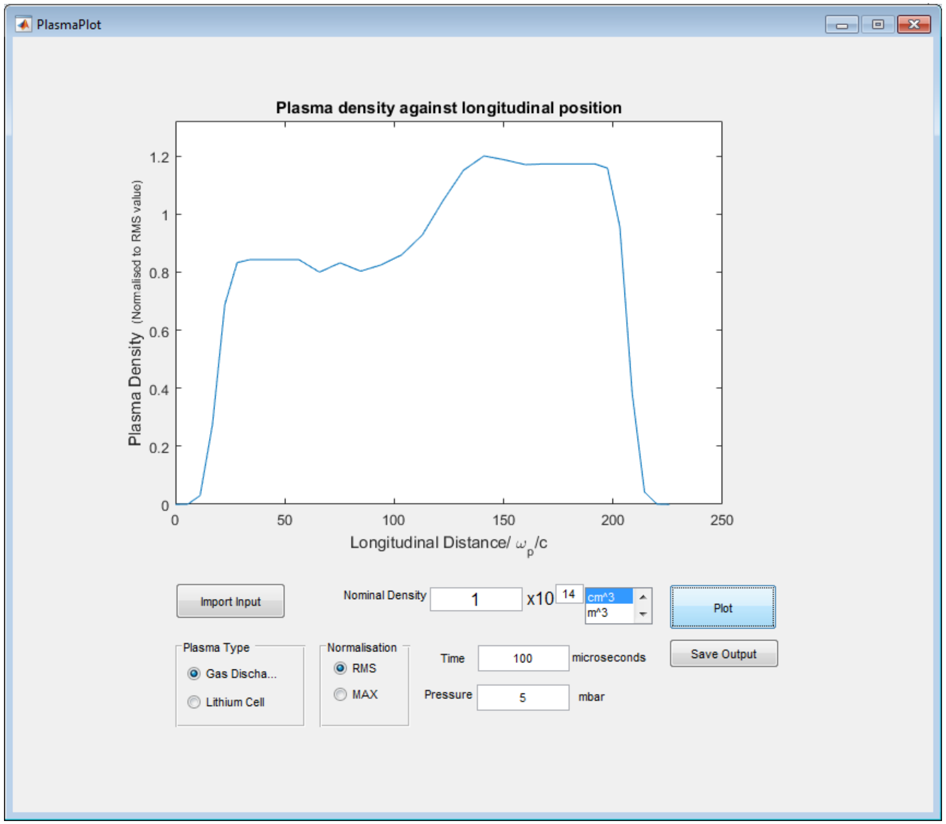


Plasma Cell



Density Measurement Gas Discharge Plasma Cell



MATLAB GUI

Measurement of Plasma Electron Density

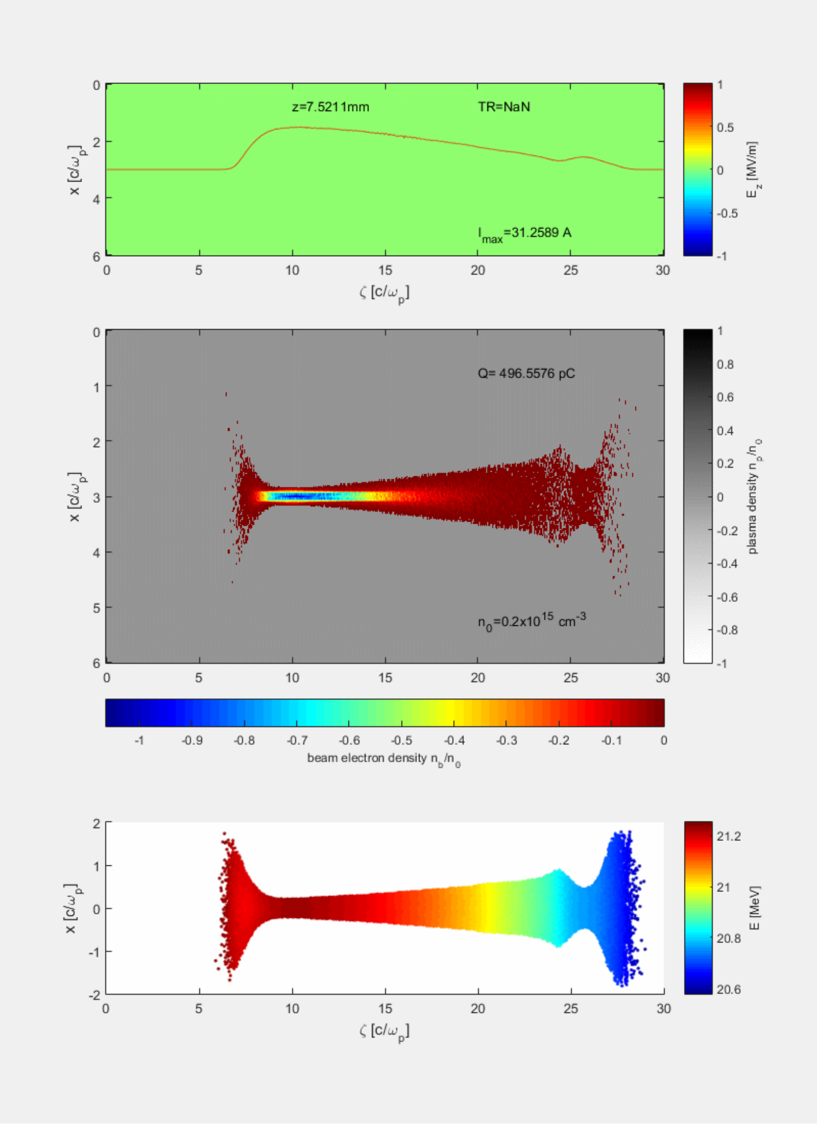
- Done by supervisor, Gregor Loisch.
- Inject hydrogen gas into plasma cell.
- Varying electron density creates varying electric field strength.
- Stark broadening of hydrogen electrons.
- Measure spectroscopically during recombination the broadening of Balmer series due to Stark broadening of hydrogen electrons.

GUI

- Normalised longitudinal direction to plasma skin depth for HiPACE simulation input:

$$\delta = c\left(\frac{\varepsilon_0 m_e}{e^2 n_e}\right)^{1/2}$$

Input longitudinal profile in HiPACE



→ HiPACE simulates beam without any interaction with plasma particles

reason unknown, input is not the problem… investigation ongoing in HH

References

- Chen, Francis F. Chapter 5. In *Introduction to Plasma Physics and Controlled Fusion*, 155-65. New York: Plenum Press, 2006.
- Figures taken from:
  - Litos, M., E. Adli, W. An, C. I. Clarke, C. E. Clayton, S. Corde, J. P. Delahaye, R. J. England, A. S. Fisher, J. Frederico, S. Gessner, S. Z. Green, M. J. Hogan, C. Joshi, W. Lu, K. A. Marsh, W. B. Mori, P. Muggli, N. Vafaei-Najafabadi, D. Walz, G. White, Z. Wu, V. Yakimenko, and G. Yocky. "High-efficiency Acceleration of an Electron Beam in a Plasma Wakefield Accelerator." *Nature* 515.7525 (2014): 92-95.
  - Ruth, R. D., Chao, A. W., P. L. Morton, and P. B. Wilson. "A Plasma Wake Field Accelerator." *SLAC Publications* (1984

THANK YOU

Thanks for your attention!