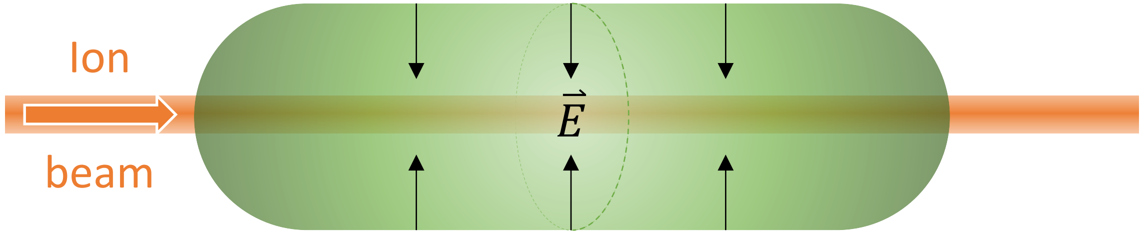
Proton and Ion Capture

Gabor Lens

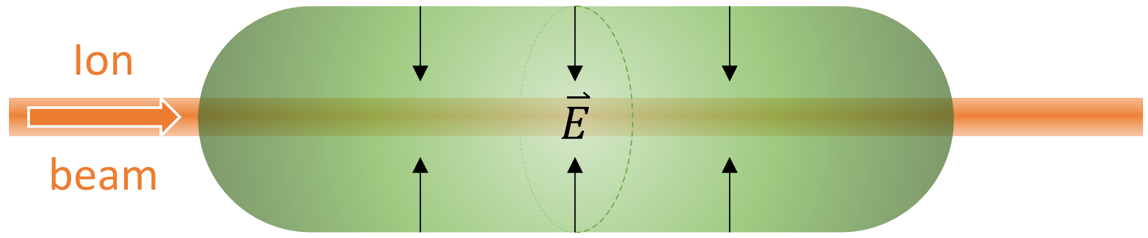


- **The focal length (f) of the Gabor lens:**

$$\frac{1}{f} = \frac{e^2 n_e l}{4\epsilon_0 U}$$

where e is electric charge of the electron
n_e is the plasma density
l is the length of the plasma
ϵ_0 is the permittivity of free space
U is the kinetic energy of the positively charge particle.

Gabor Lens



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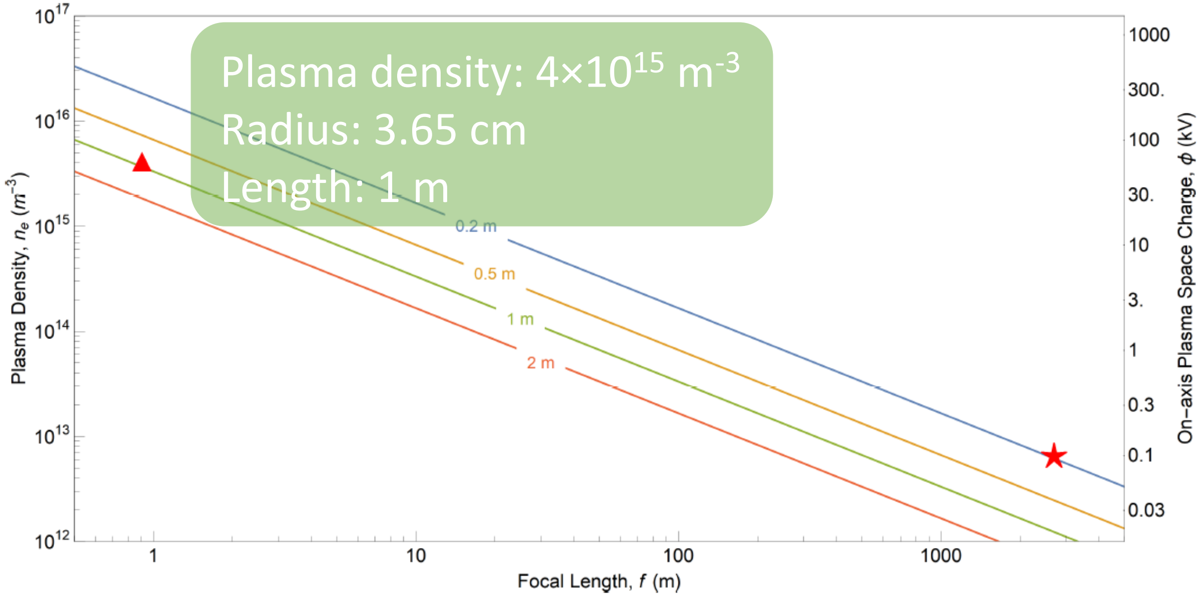
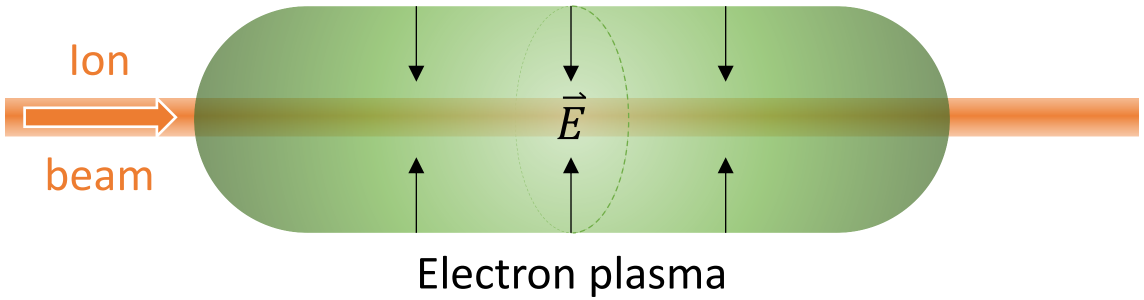


Gabor Lens



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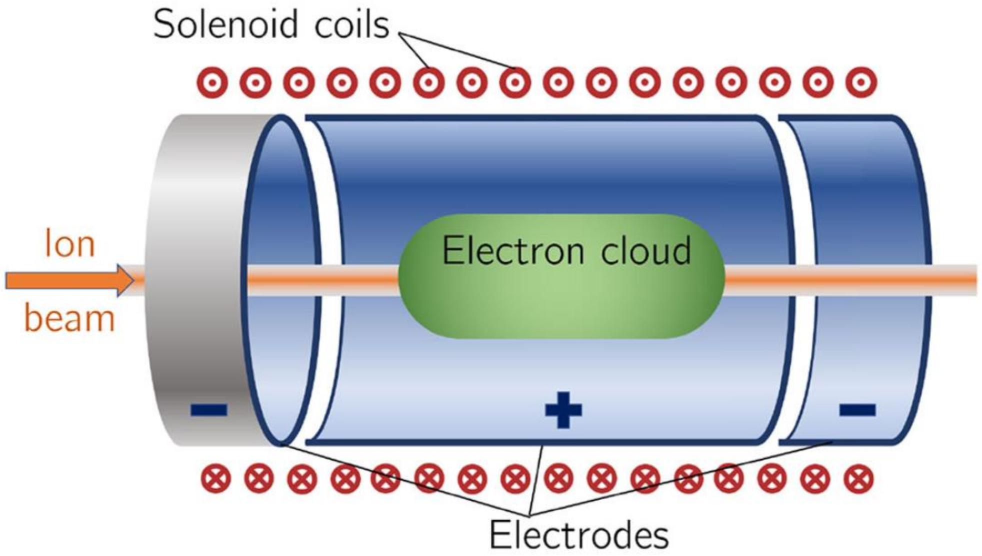
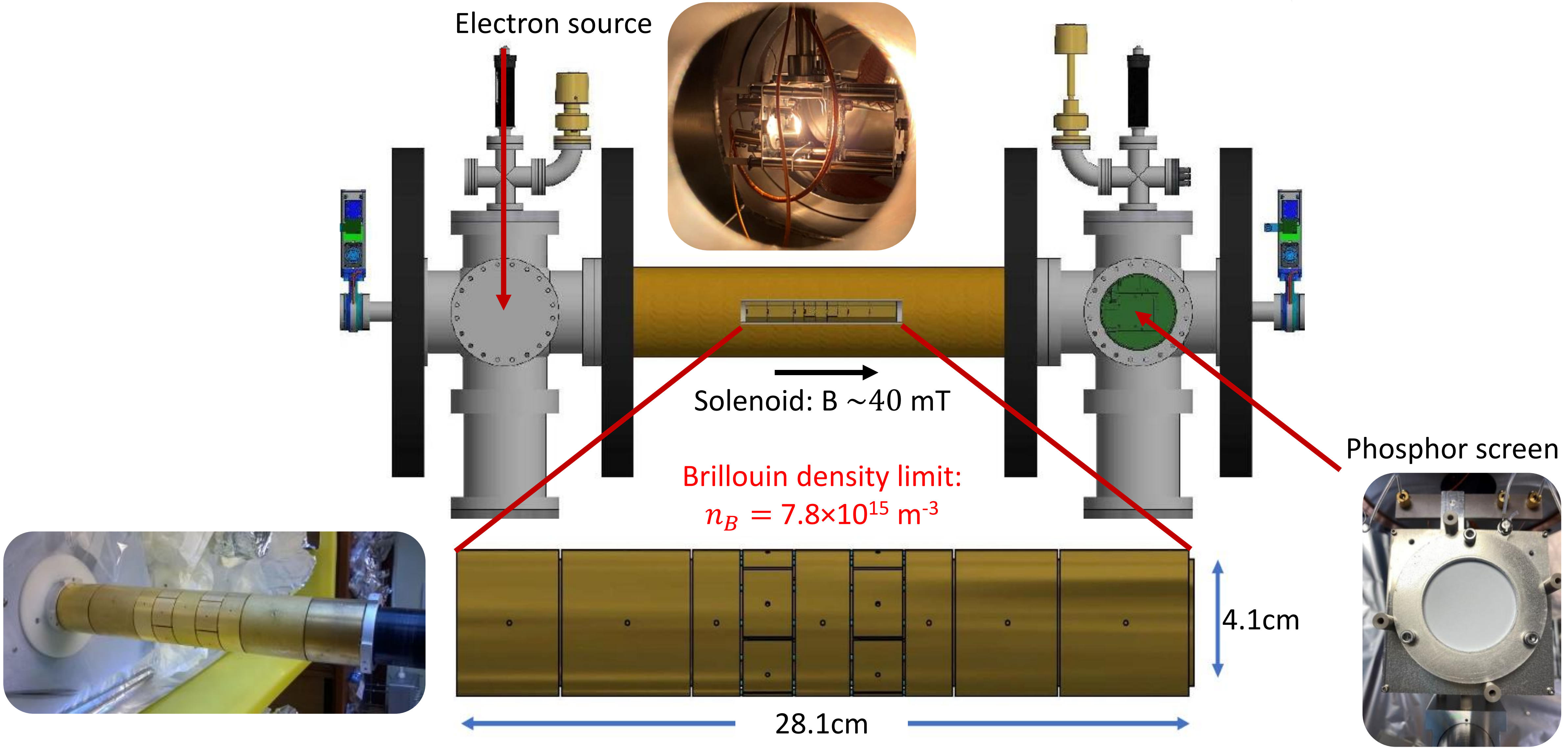
- **Penning-Malmberg Trap**



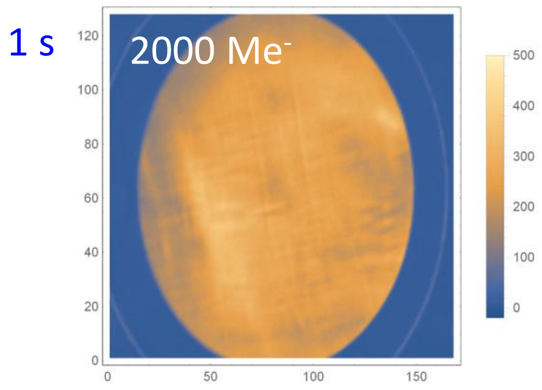
Aymar, G., Becker, T., Boogert, S., Borghesi, M., Bingham, R., Brenner, C., ... & Xiao, R. (2020). LhARA: the laser-hybrid accelerator for radiobiological applications. Frontiers in Physics, 8, 567738.

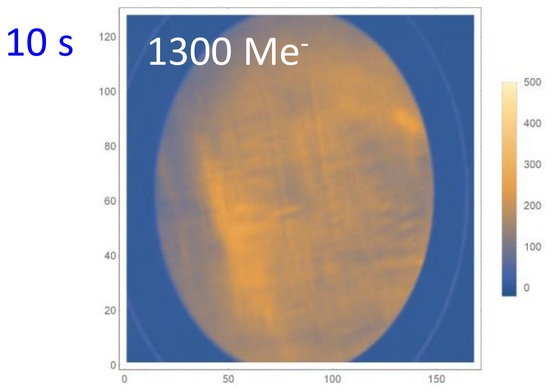
Experimental Setup

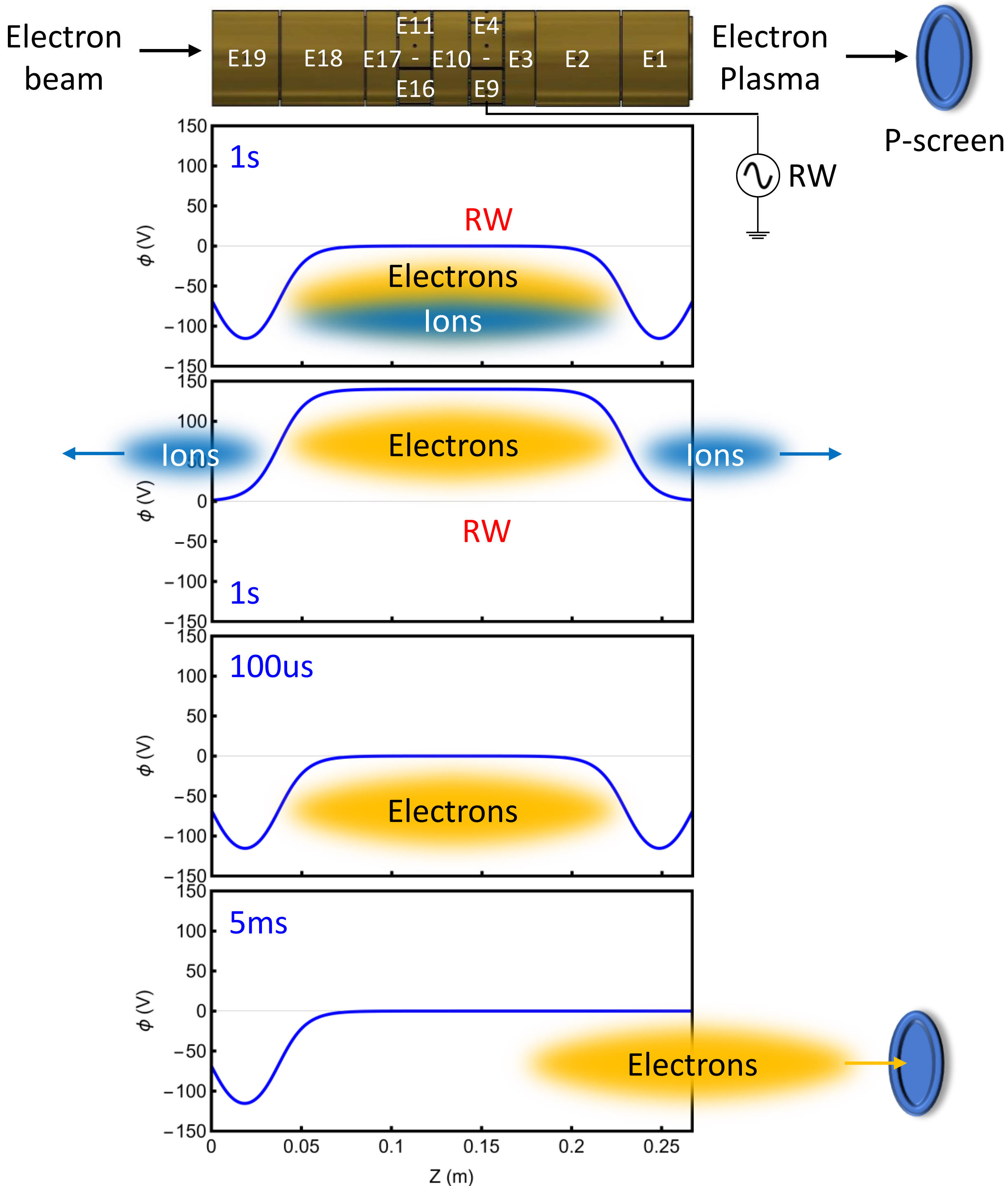


Previous Results

- **140 voltage trap, Rotating wall (RW) + Cooling gas (CO_2)**

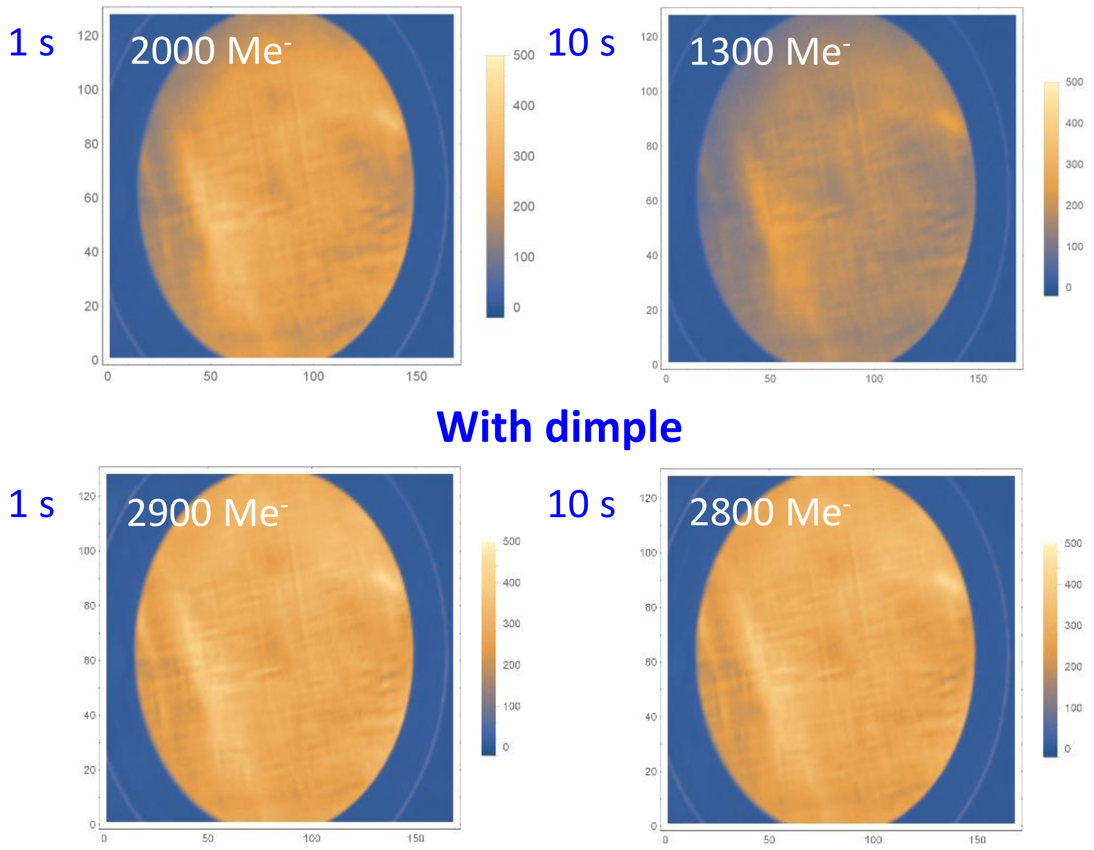




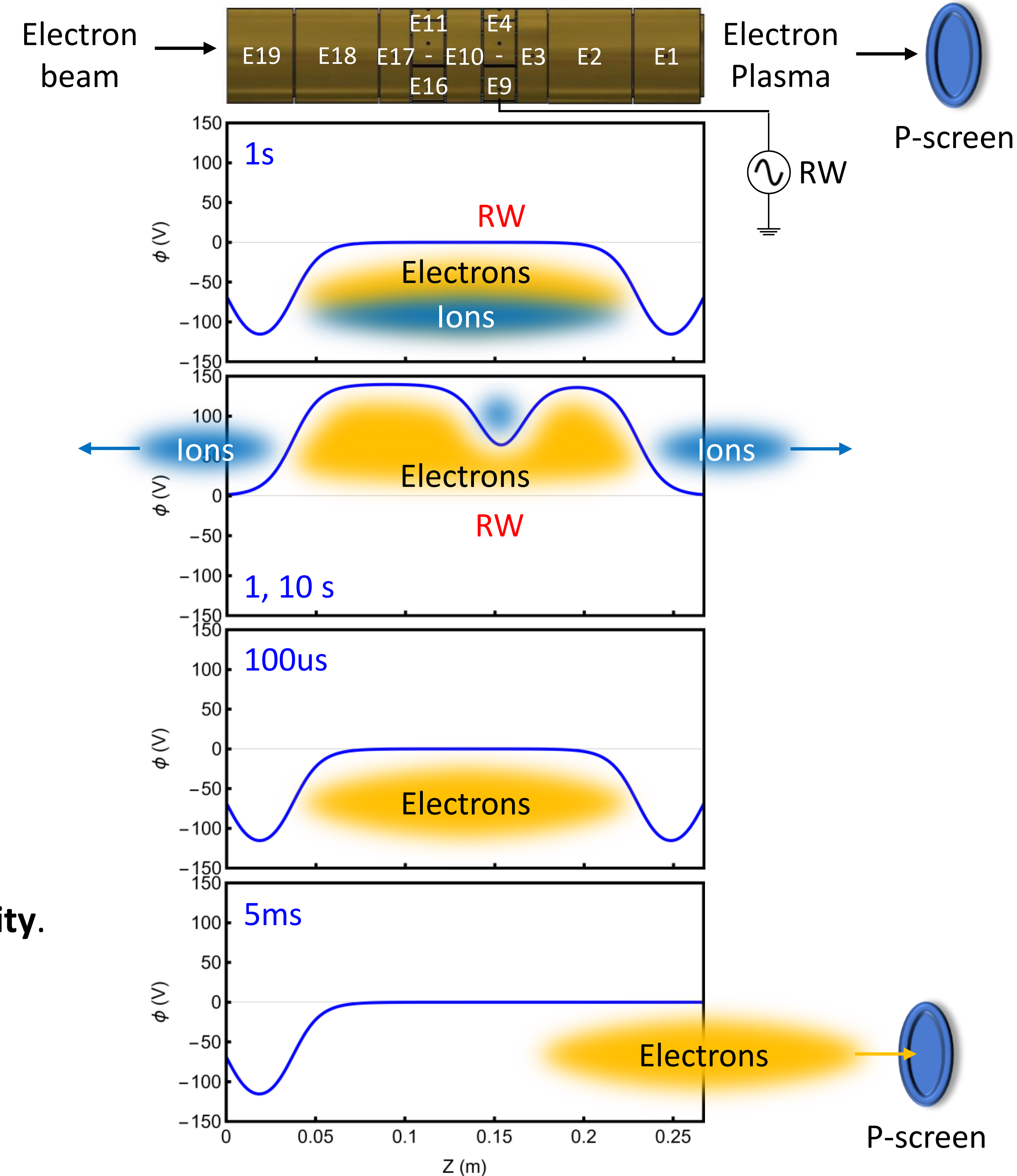


Previous Results

- **140 voltage trap, Rotating wall (RW) + Cooling gas (CO_2)**



- The plasma has a high electron number and exhibits **high density**.
- The plasma remains **stable** as long as the RW is applied.



Results

1. Investigate the mechanism responsible for the creation of this high-density, stable plasma.

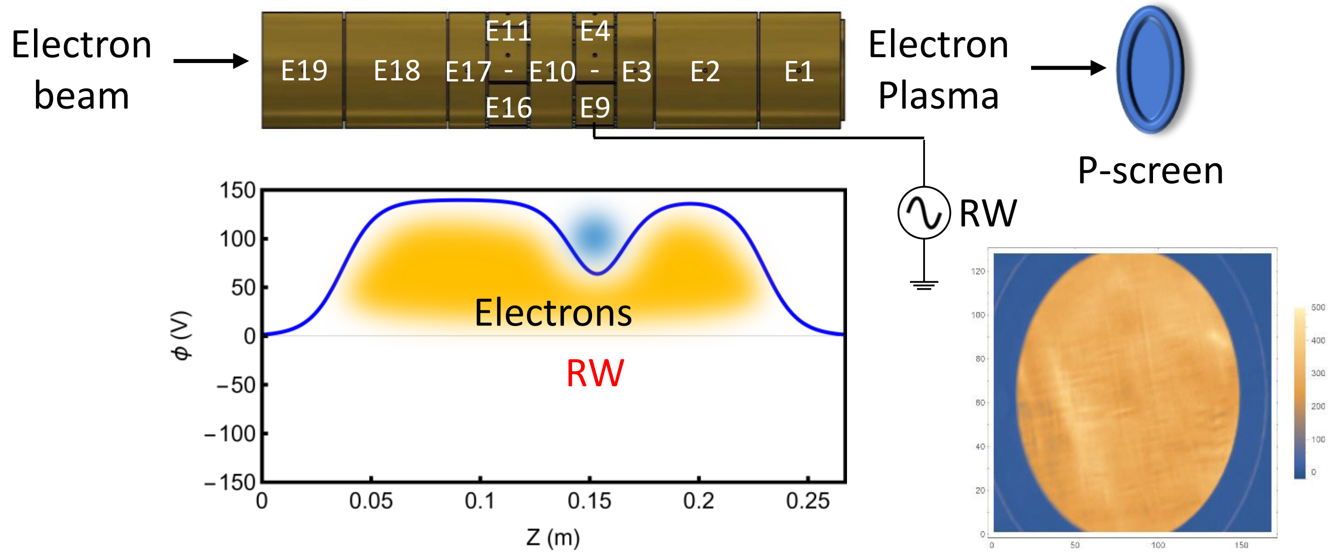
2. Investigate the required initial electron number for high density plasma formation.

3. Examine the plasma mode.

Results

1. Investigate the mechanism responsible for the creation of this high-density, stable plasma.

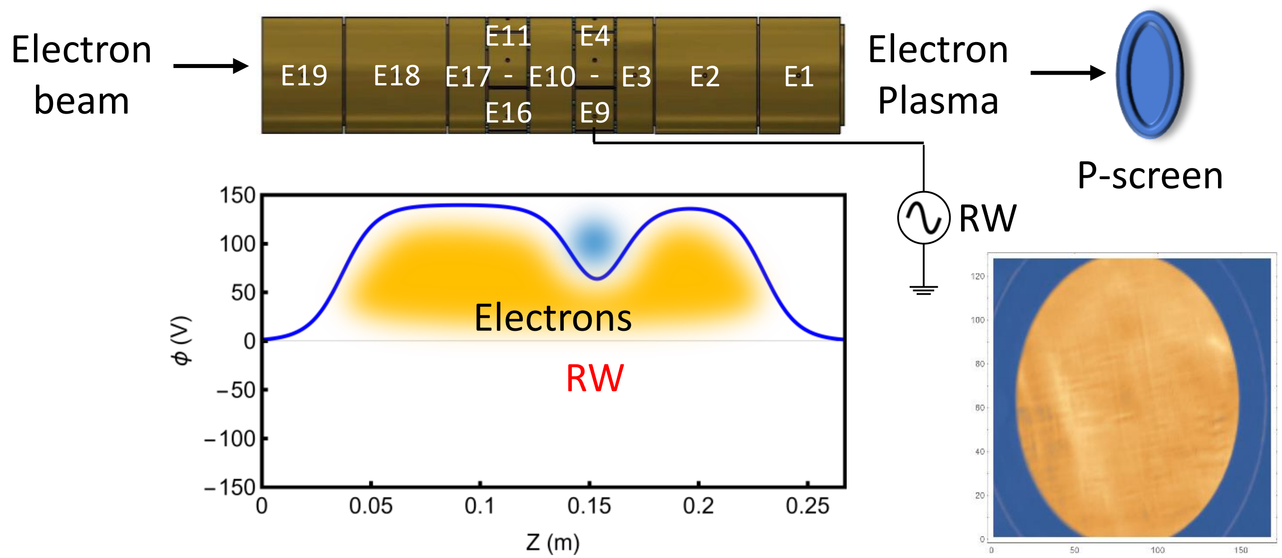
Key features	Mechanism
1. High electron number and high density	Ionization between the RF heating (from RW) and the background gas (CO_2)
2. Stable	Dimple that confines trapped ions

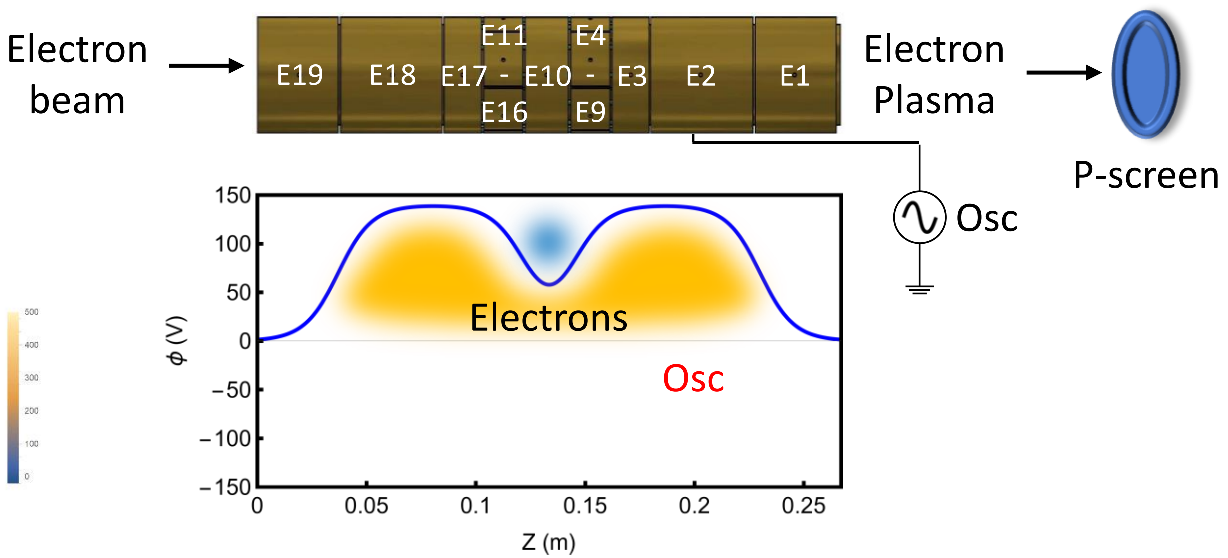


Results

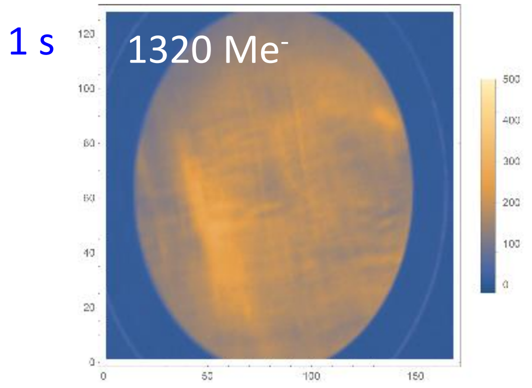
1. Investigate the mechanism responsible for the creation of this high-density, stable plasma.

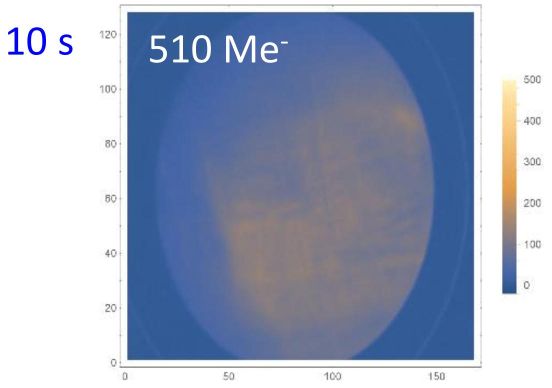
Key features	Mechanism	Experiment simplification
1. High electron number and high density	Ionization between the RF heating (from RW) and the background gas (CO_2)	Apply an oscillating field to E2
2. Stable	Dimple that confines trapped ions	Create a dimple on E10

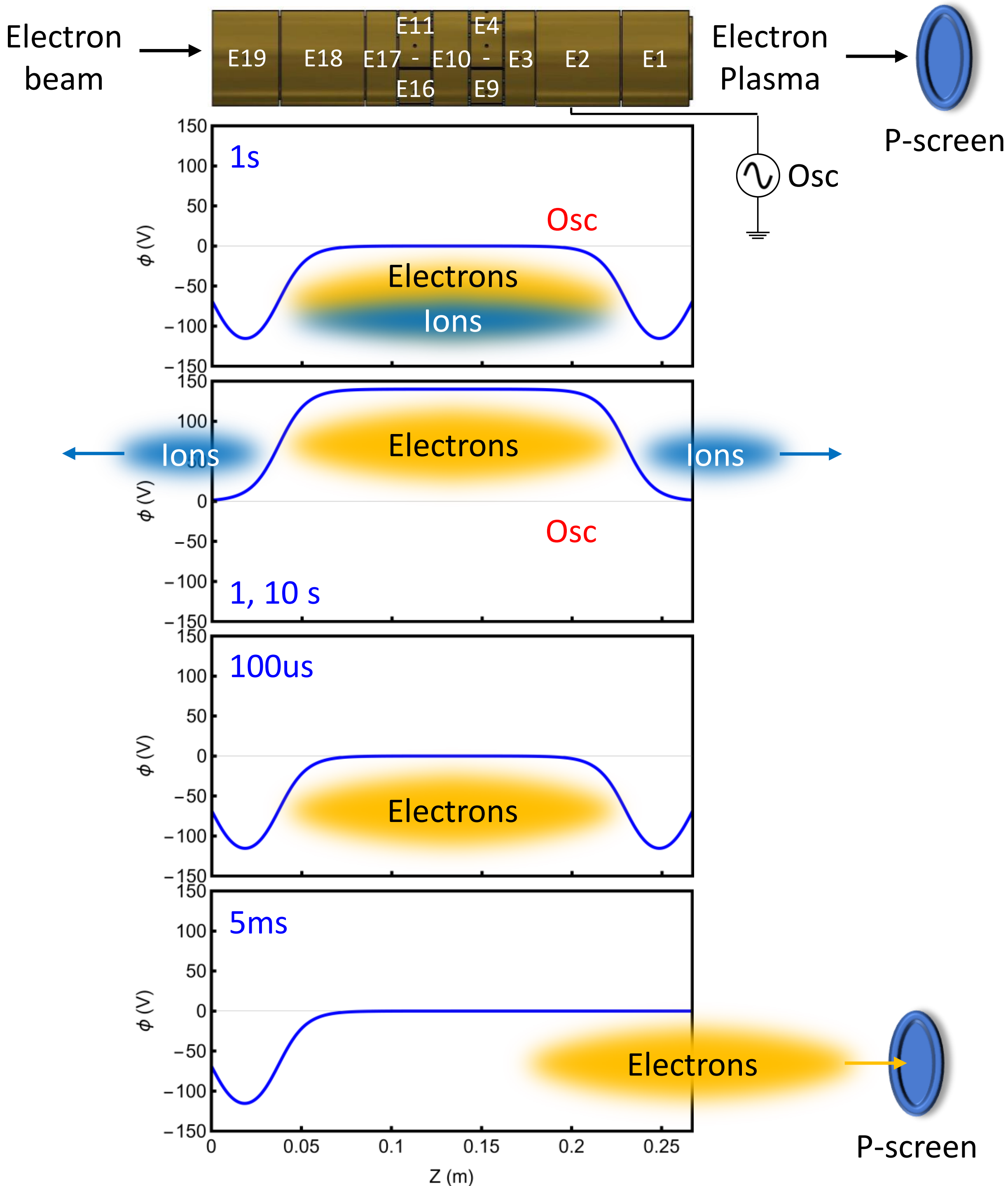




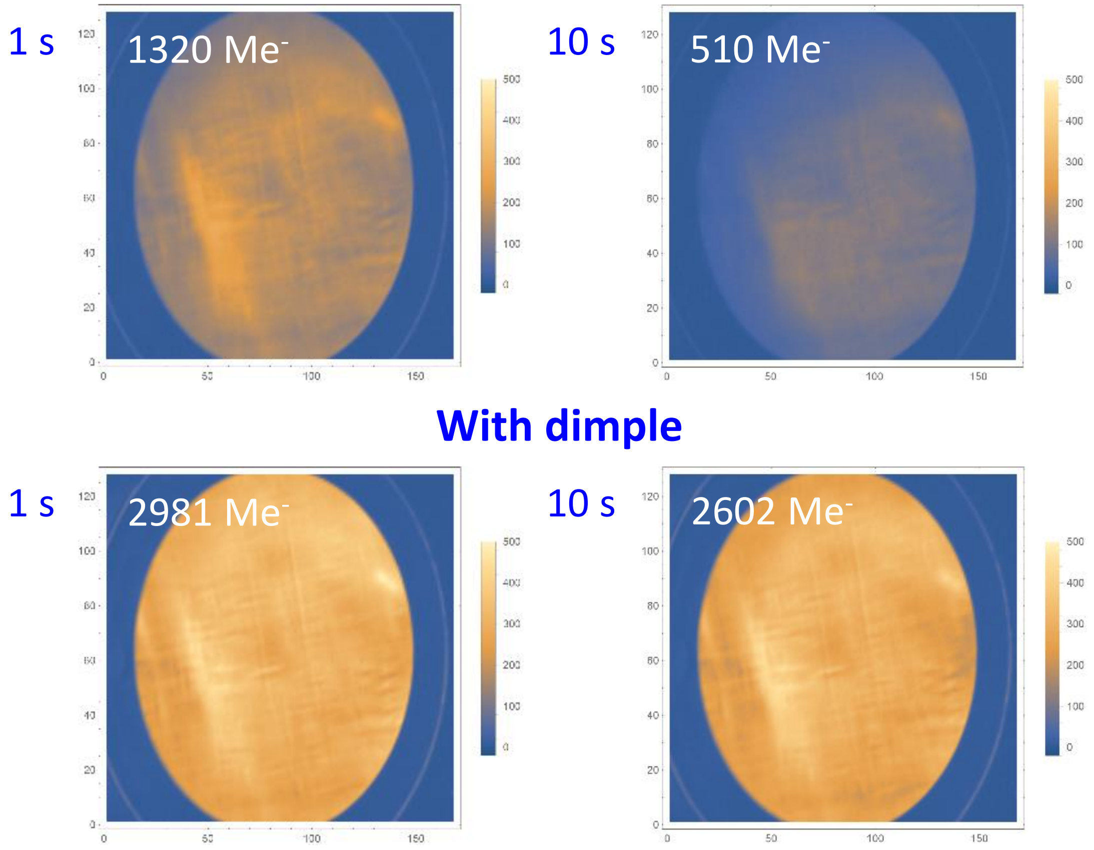
Apply Oscillating field

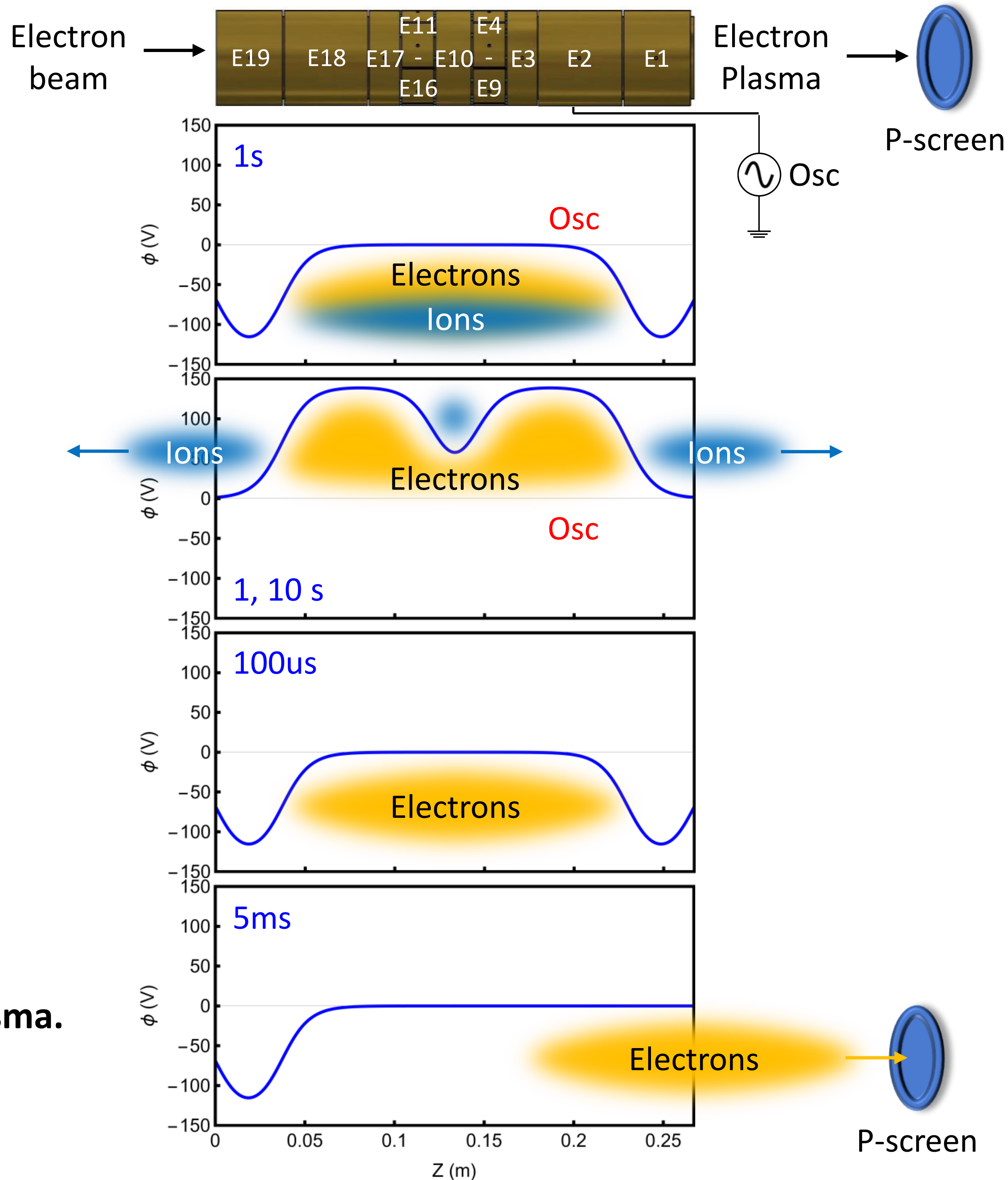






Apply Osc + Dimple

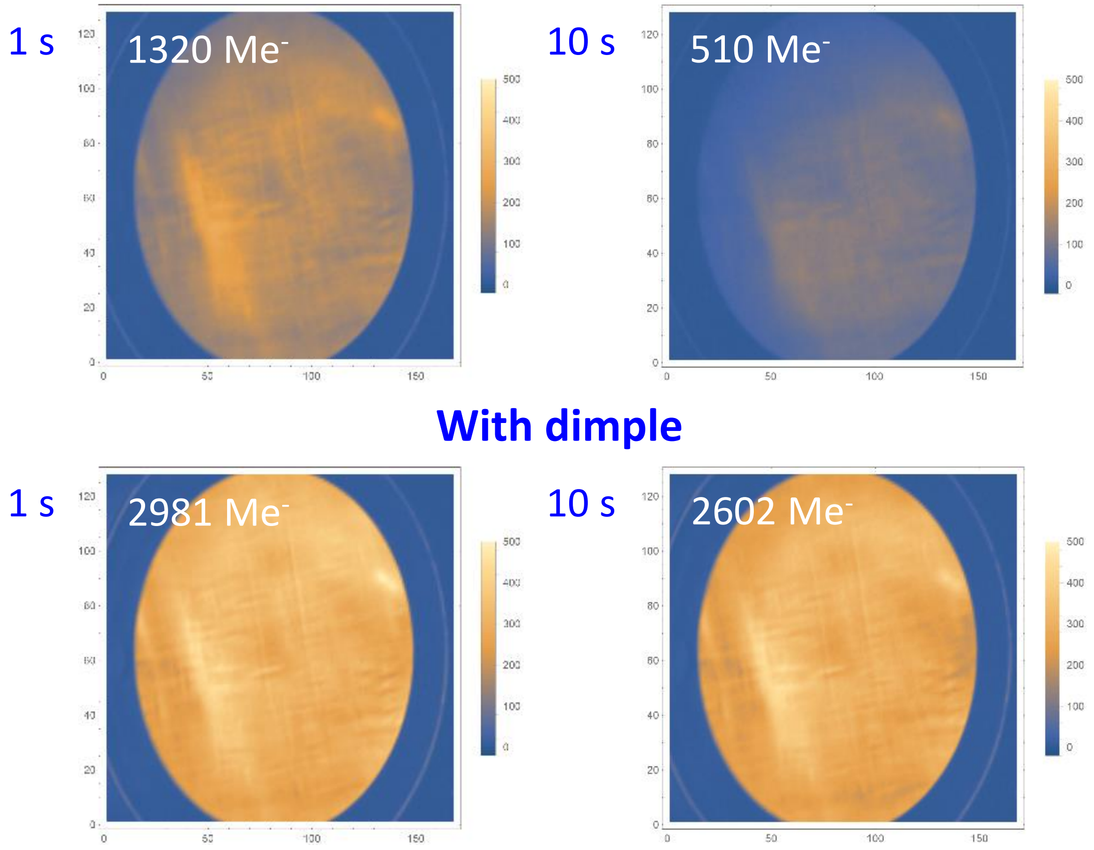


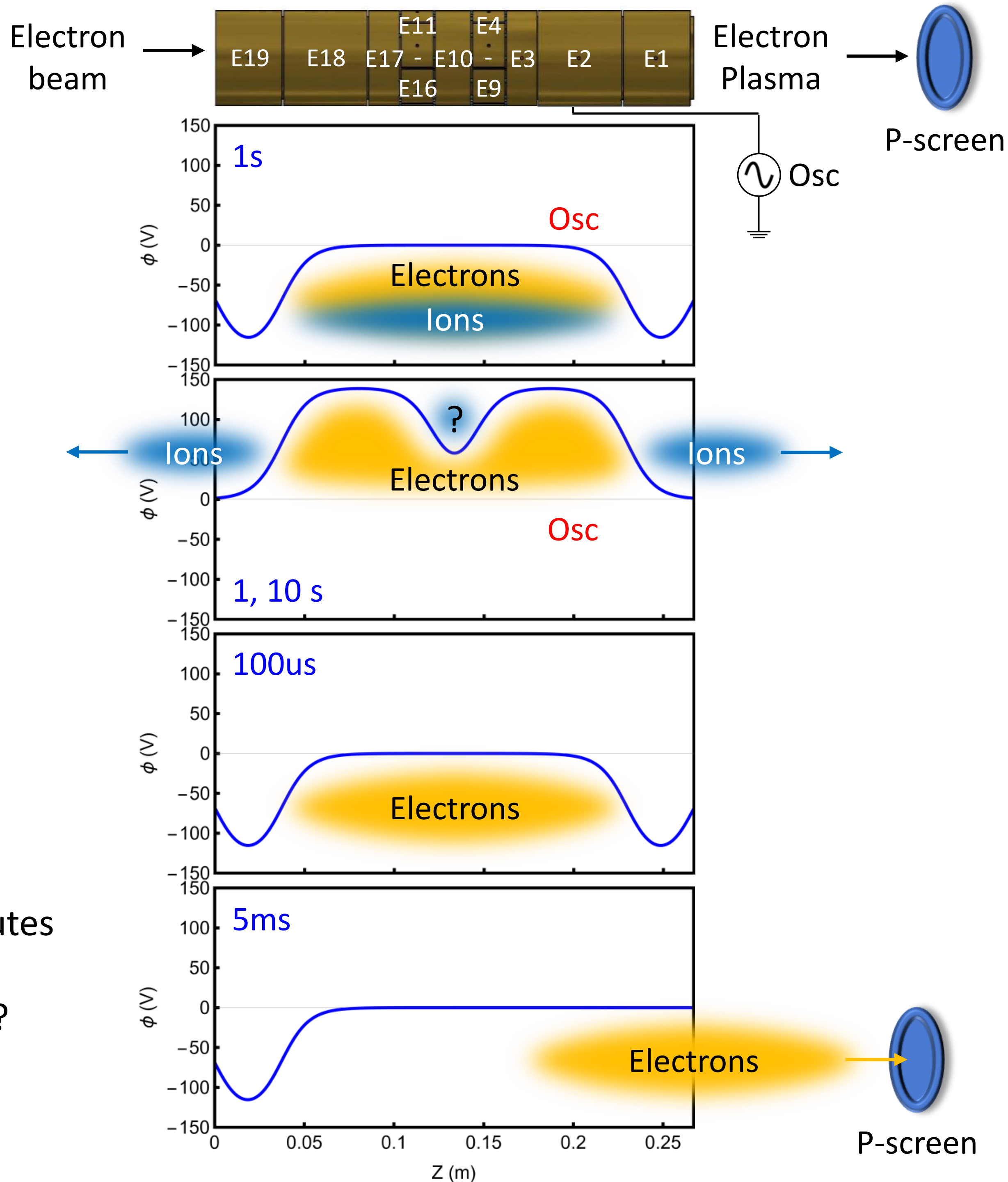


Discussions:

- The oscillating field alone can generate a plasma; however, the resulting electron density is low, and the plasma lacks stability.
- **The dimple is essential for producing a stable, high-density plasma.**

Apply Osc + Dimple





Question:

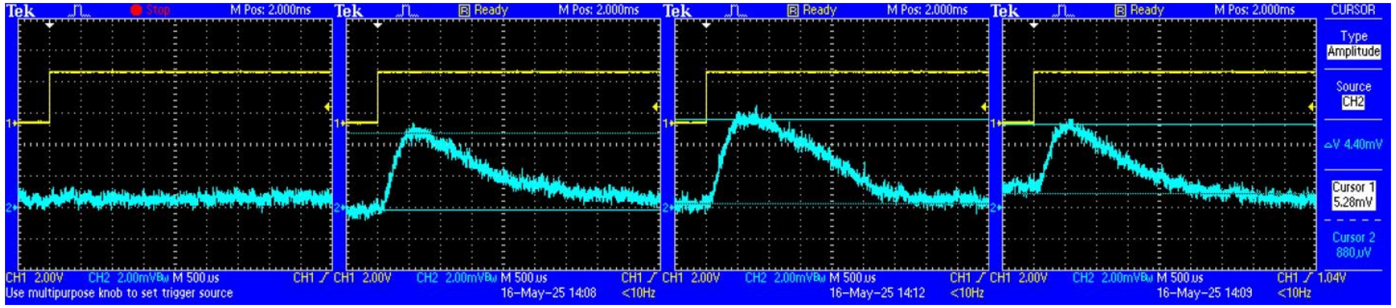
- What is the underlying mechanism by which the dimple contributes to the stability and high-density of the plasma? Is it due to the dimple or the trapped ions or both the dimple and trapped ions?

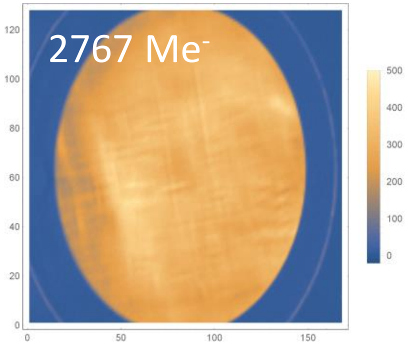
Ion detection

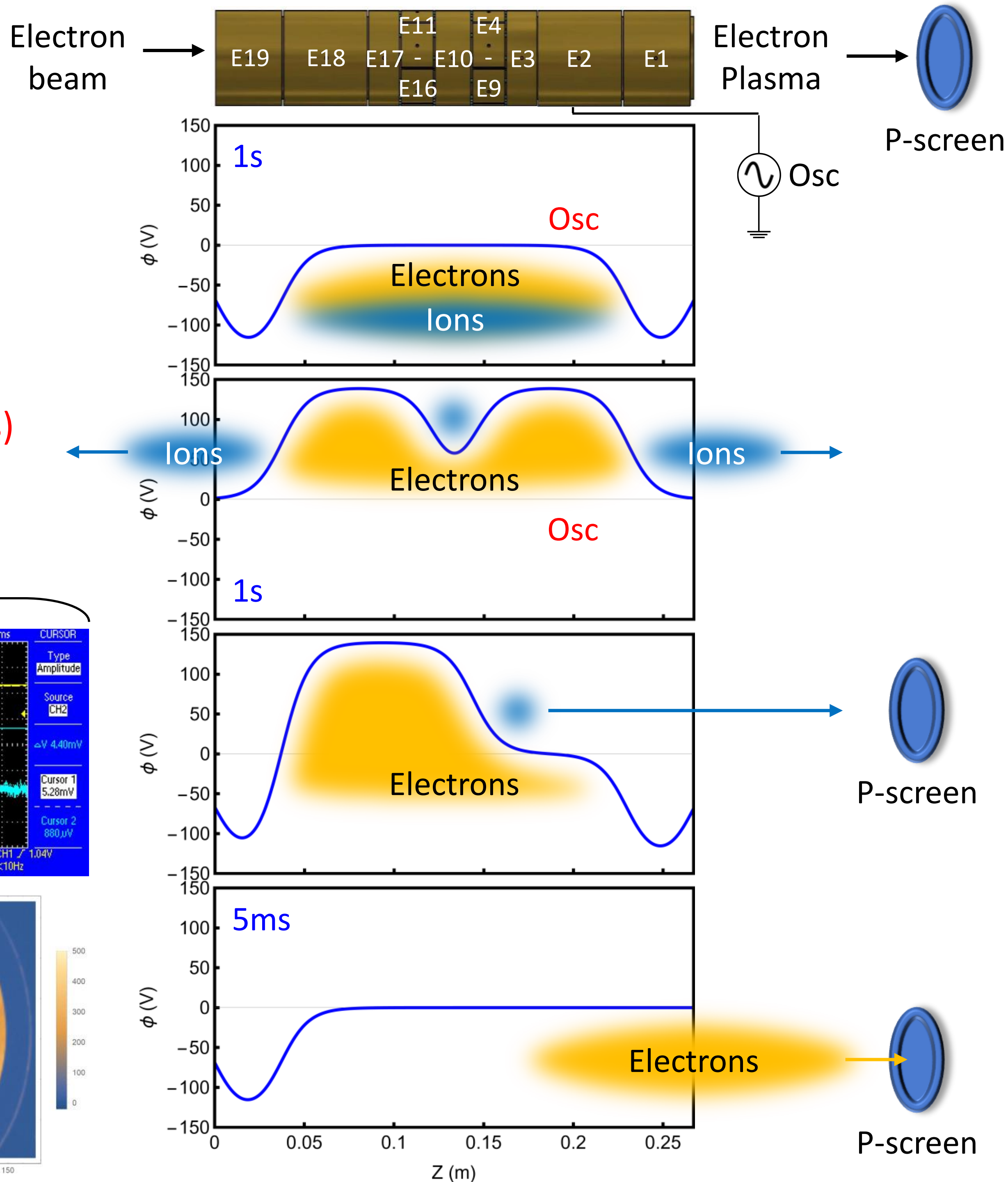
Voltage amplitude: 4.88 mV (29.2 M ions)

Background signal
(Turn off Osc field)

Ion signals
(Osc field applied)

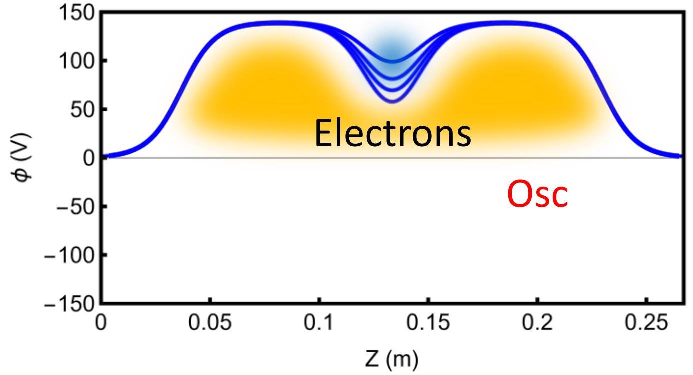


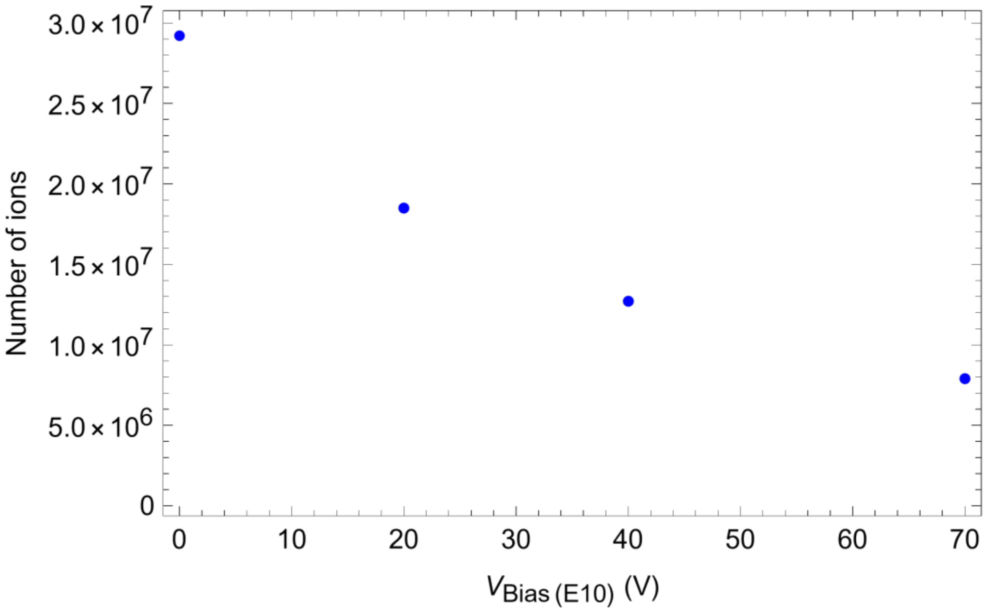


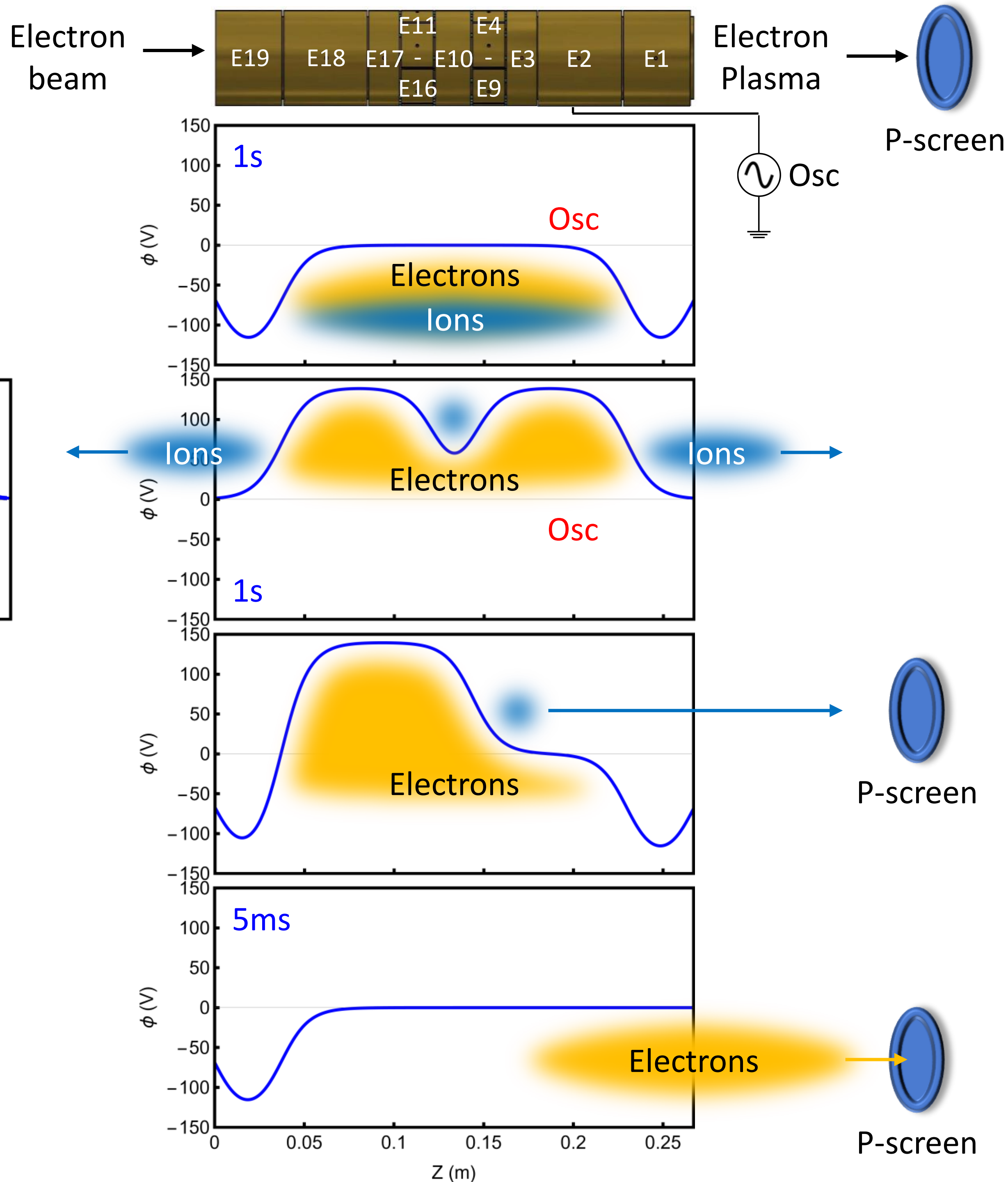


Ion detection

V_{bias} (E10): 0, 20, 40, 70 V







Conclusions

1. Investigate the mechanism responsible for the creation of this high-density, stable plasma.

To generate a stable and high-density plasma, two key components are required:

1. Oscillating electric field
2. Dimple that traps ions

Results

1. Investigate the mechanism responsible for the creation of this high-density, stable plasma.

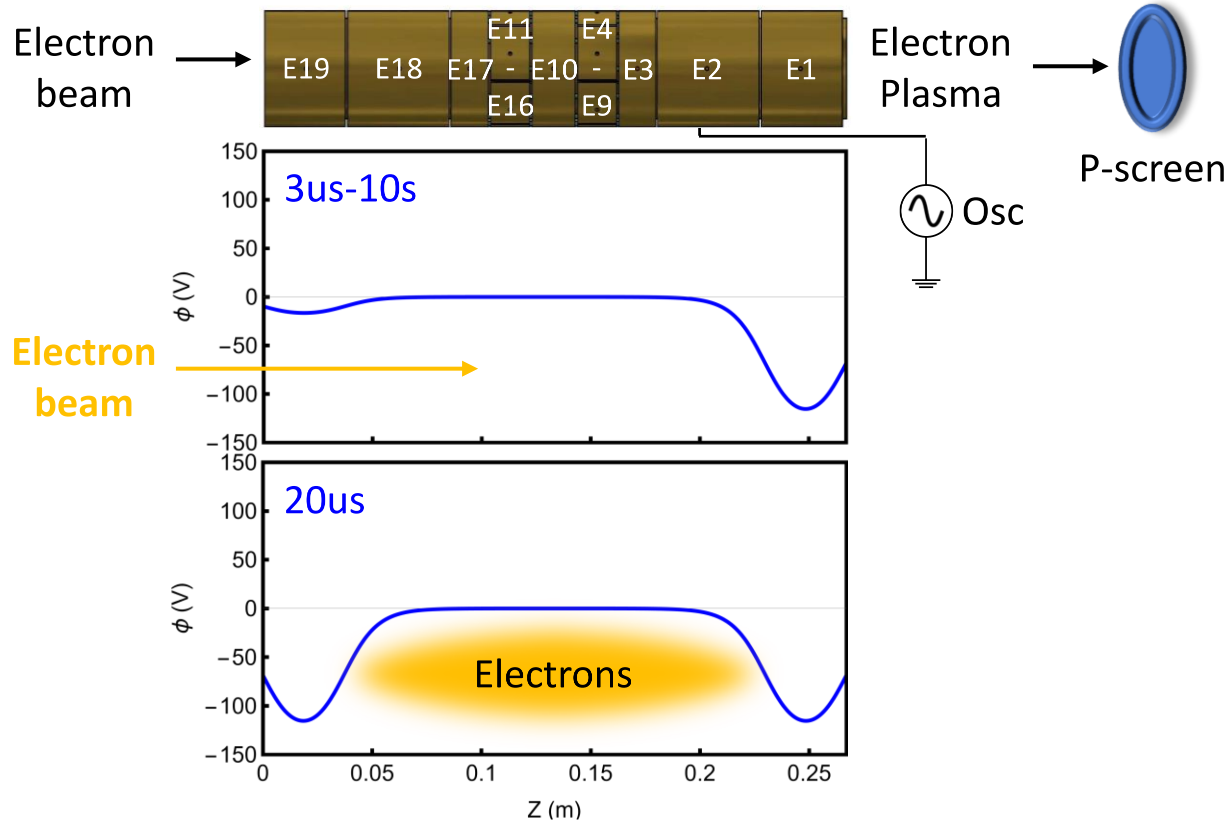
2. Investigate the required initial electron number for high density plasma formation.

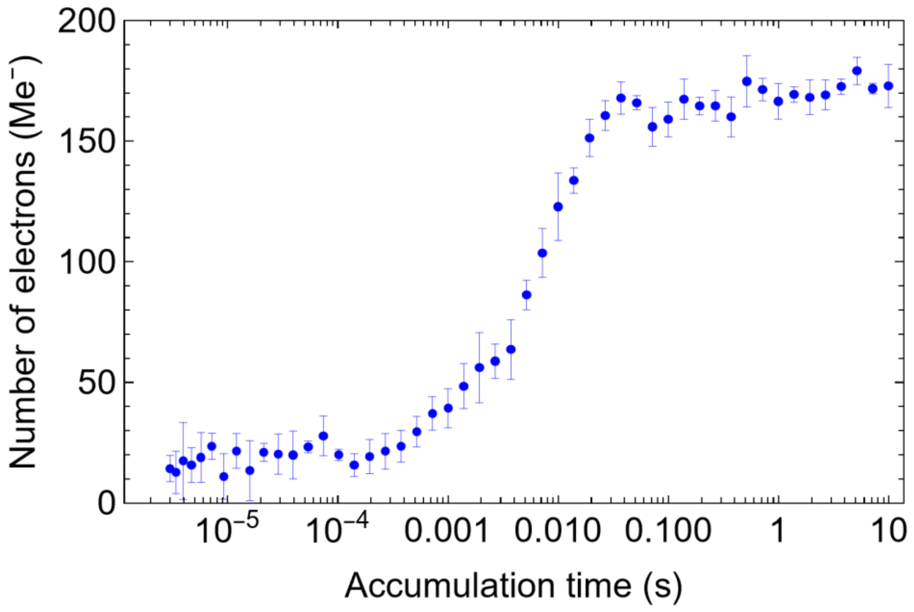
3. Examine the plasma mode.

Results

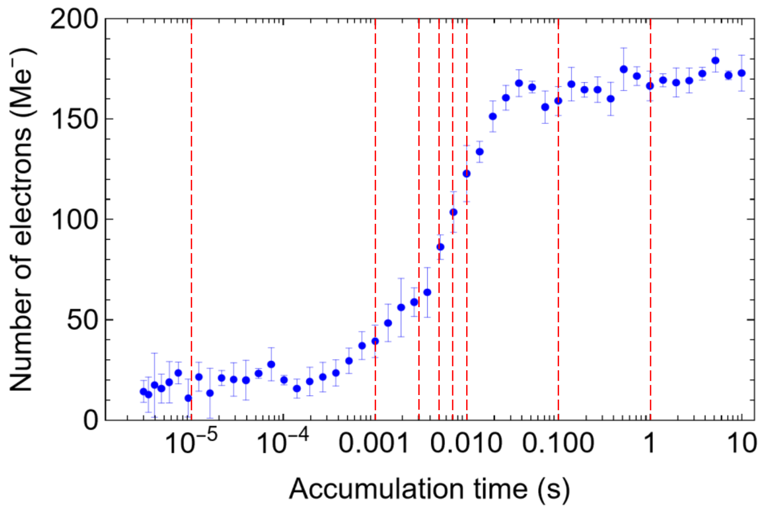
2. Investigate the required initial electron number for high density plasma formation.

Vary the initial electron number by adjusting the accumulation time.

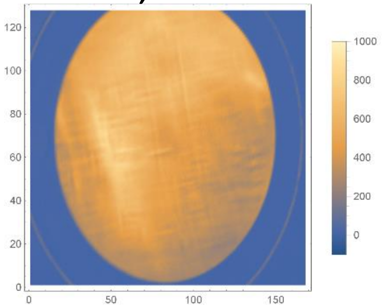




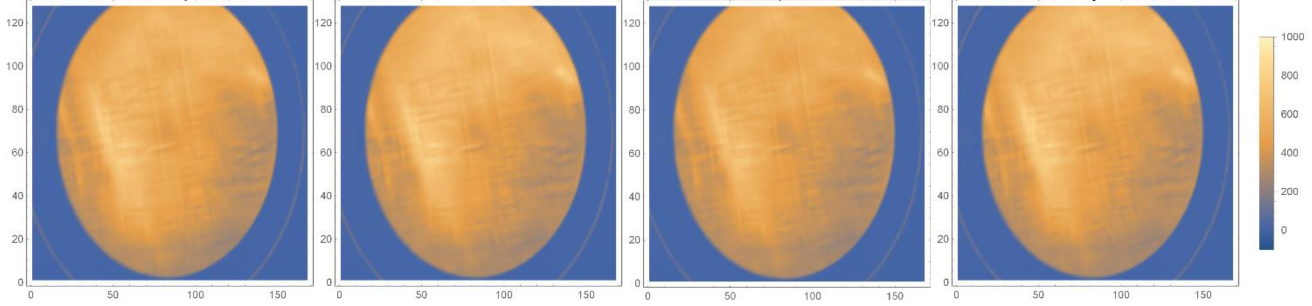
Vary initial e⁻ number



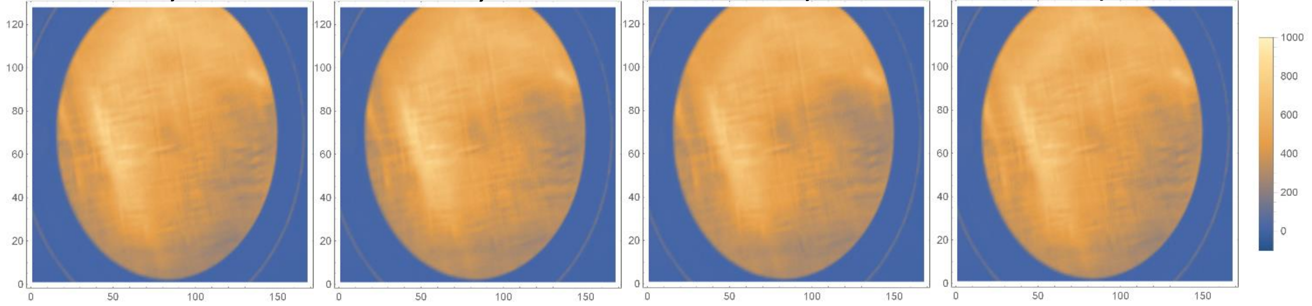
1 s, 165 Me⁻

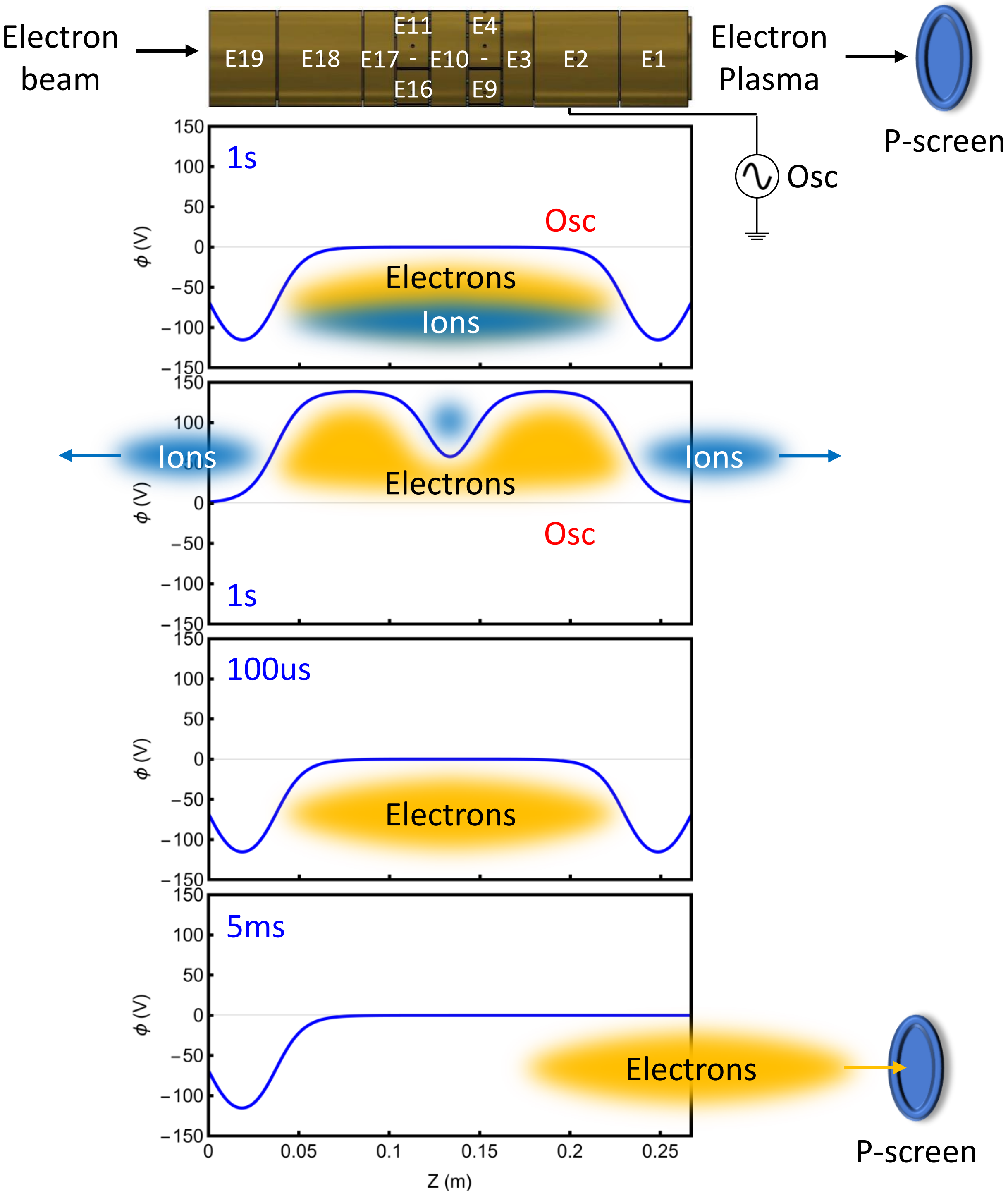


100 ms, 160 Me⁻ 10 ms, 125 Me⁻ 7 ms, 105 Me⁻ 5 ms, 85 Me⁻



3 ms, 60 Me⁻ 1 ms, 40 Me⁻ 100 us, 20 Me⁻ 10 us, 15 Me-





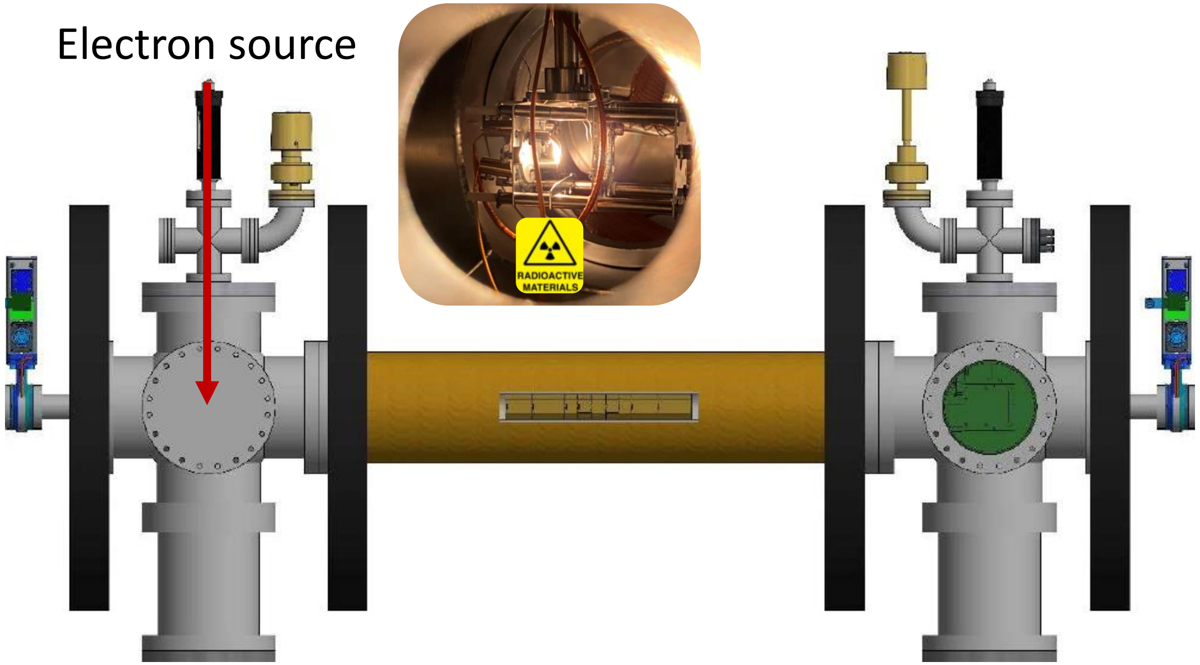
Conclusions

2. Investigate the required initial electron number for high density plasma formation.

To generate a stable and high-density plasma, two key components are required:

1. Oscillating electric field
2. Dimple that traps ions

Notably, this plasma can be initiated using a very small number of seed electrons.



Results

1. Investigate the mechanism responsible for the creation of this high-density, stable plasma.

2. Investigate the required initial electron number for high density plasma formation.

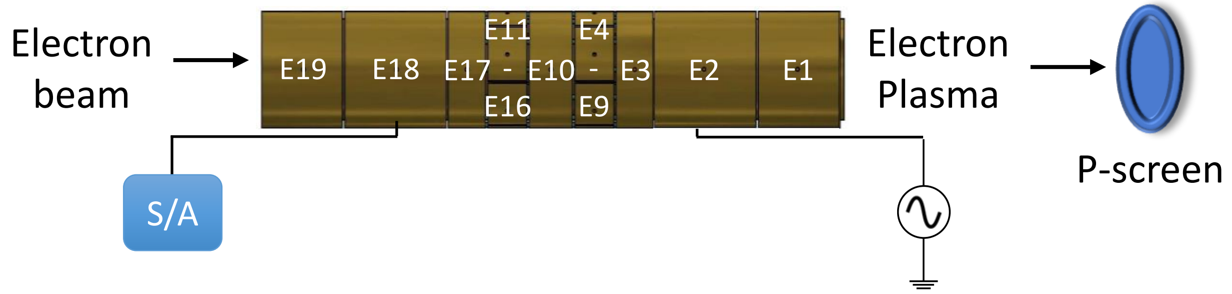
3. Examine the plasma mode.

Results

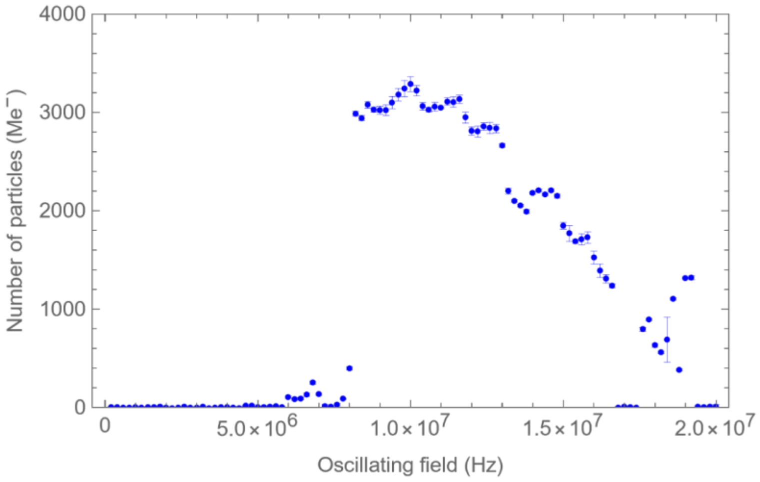
3. Examine the plasma mode.

Plasma mode refers to the collective oscillations or wave-like behaviour exhibited by a plasma.
Studying plasma modes is important because they provide valuable insights into:

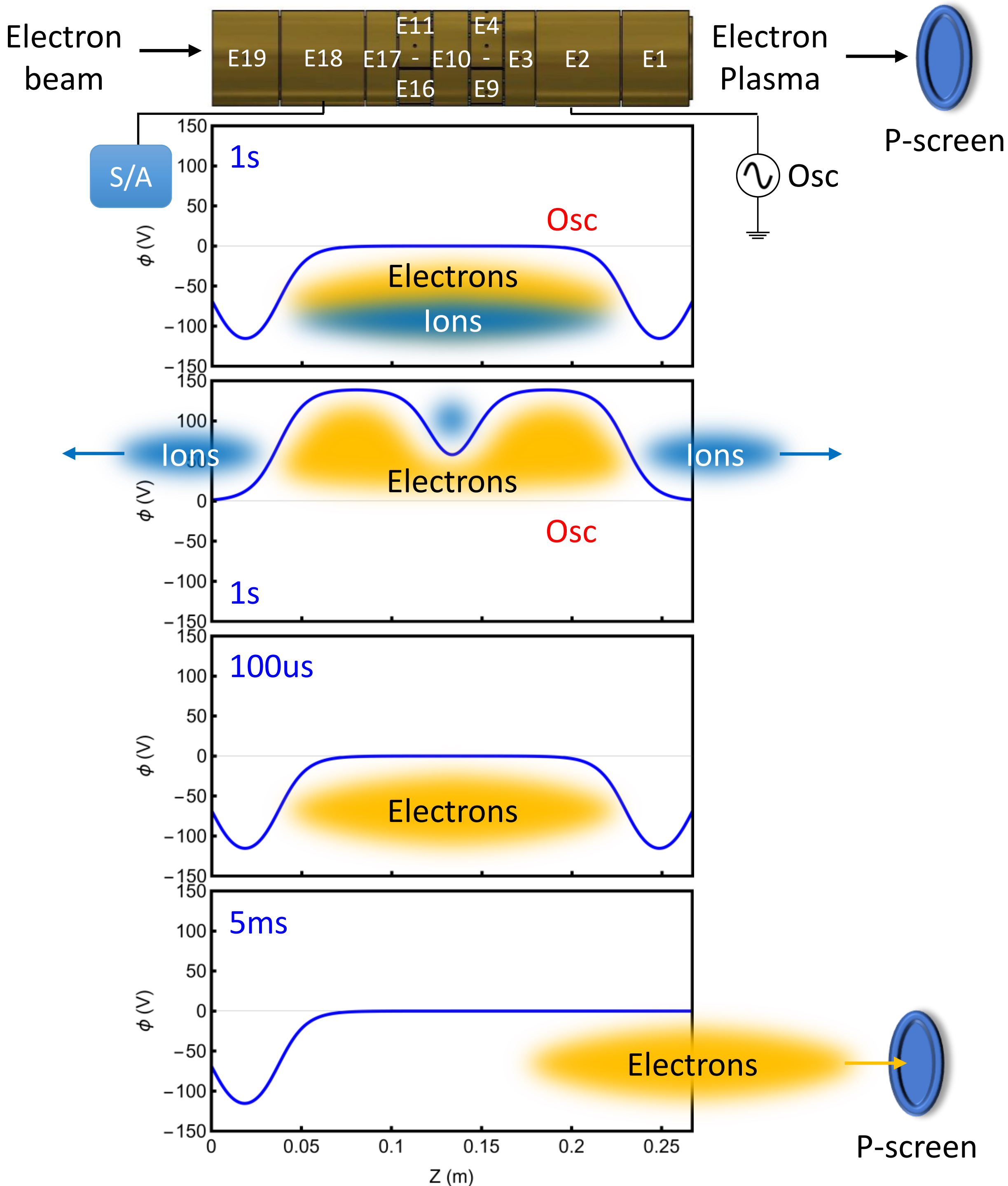
Plasma properties such as density, temperature, and particle number.
Plasma stability and confinement within the trap.



Plasma mode

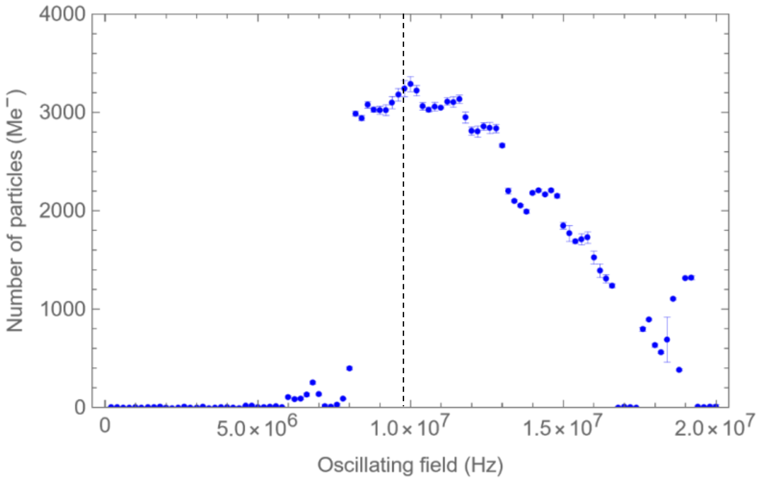


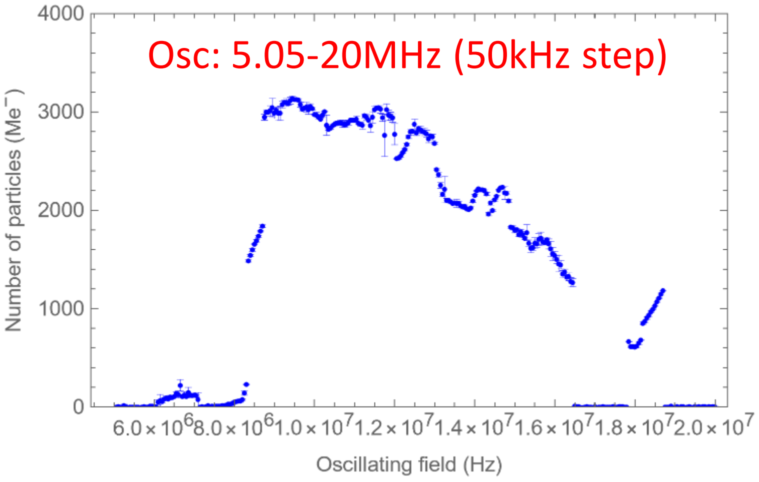
Number of particles (Me⁻)
Oscillating field (Hz)

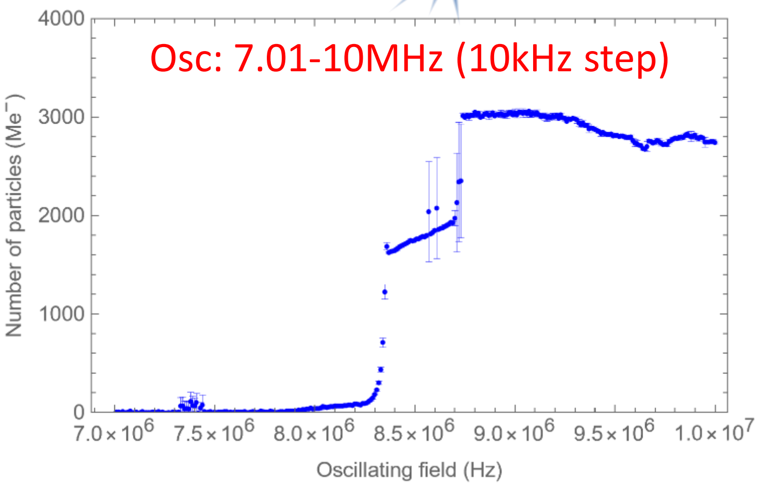


Electron beam
E19
E18
E11
E17 - E10
E16
E4
E9
E3
E2
E1
Electron Plasma
P-screen
S/A
Osc
1s
Osc
Electrons
Ions
Ions
Ions
Electrons
Osc
1s
100us
Electrons
5ms
Electrons
P-screen
ϕ (V)
Z (m)

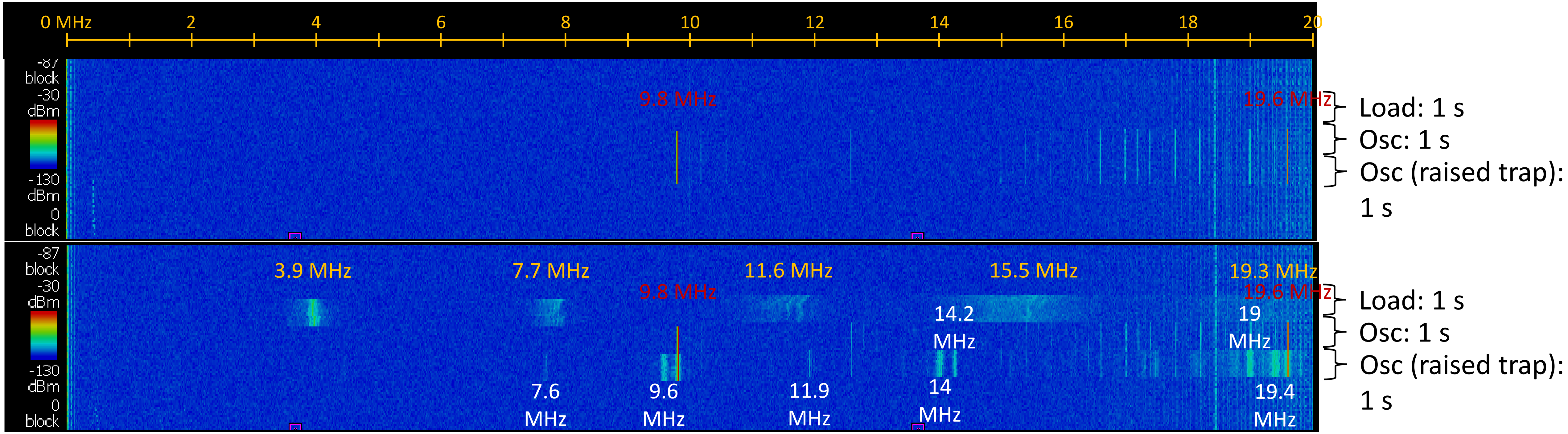
Plasma mode







Background measurement: E-gun off



Conclusions

3. Examine the plasma mode.

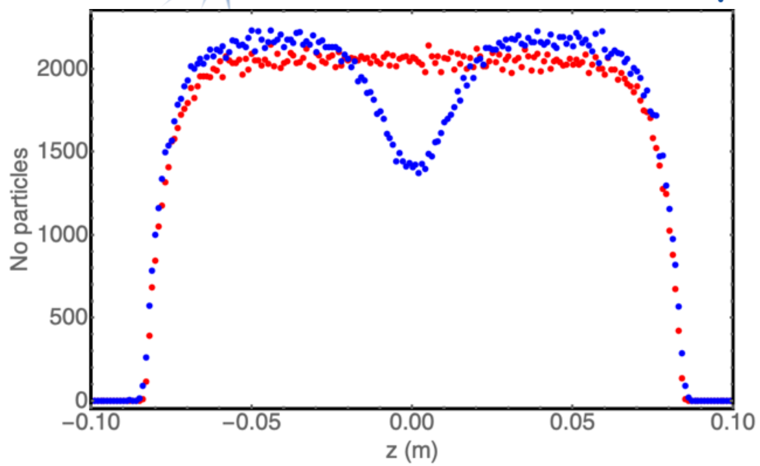
The plasma mode results indicate the presence of multiple modes, requiring further investigation to understand what these modes are.

Conclusions and Outlook

To generate a stable and high-density plasma, two key components are required:

1. Oscillating electric field
2. Dimple that traps ions

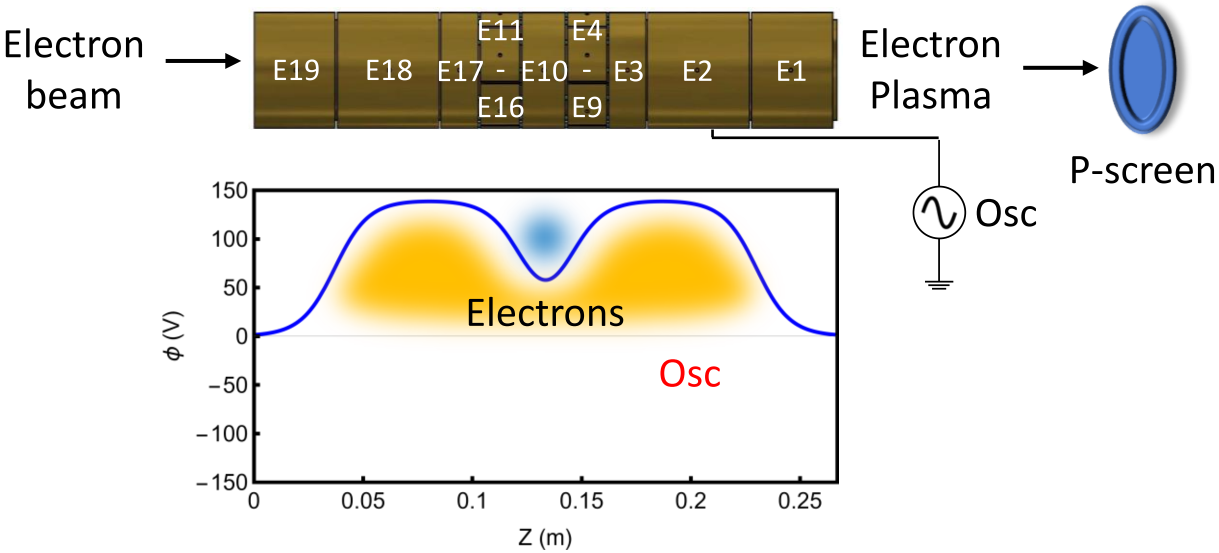
Notably, this plasma can be initiated using a very small number of seed electrons.

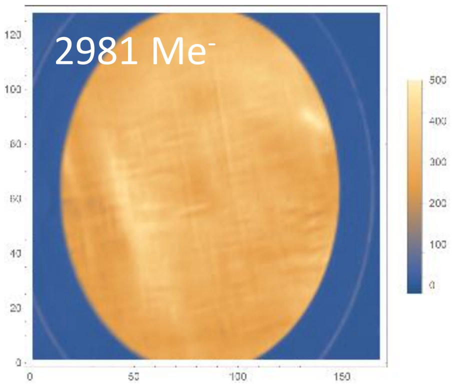


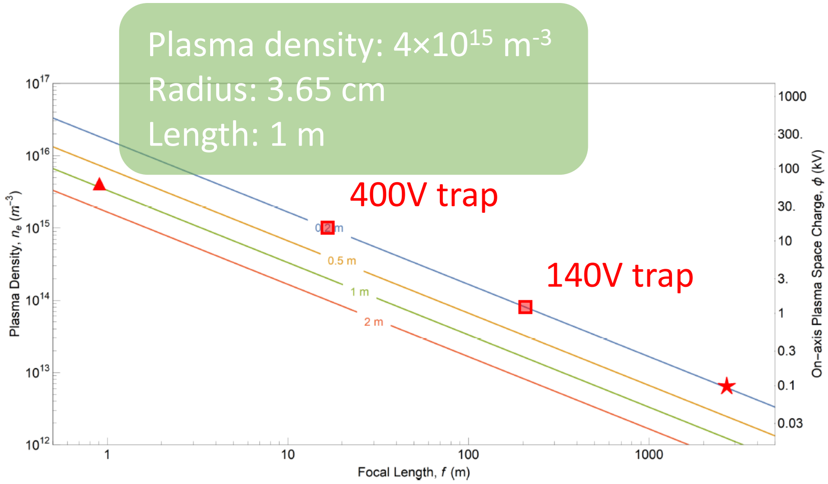
Simulated data by D. P. van der Werf

Next steps …

- Further investigation on plasma modes.
- Conduct the experiments using Ar instead of CO_2.
- Use numerical simulation to verify our diagnostics.





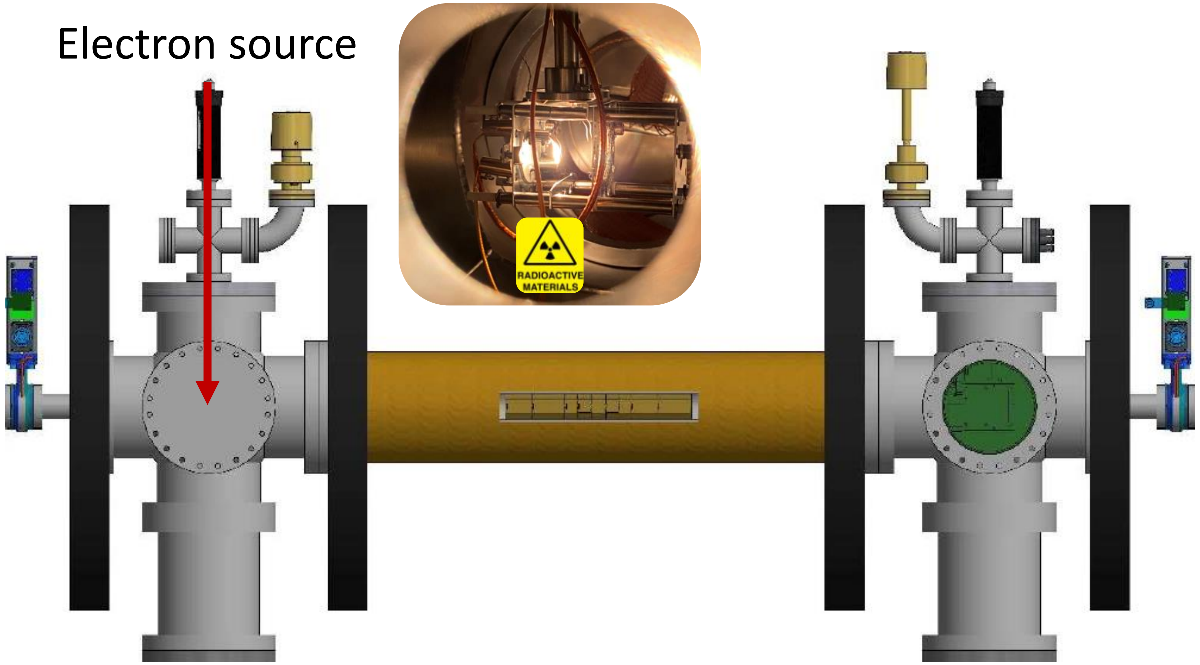


140V trap: Peak density ≈ 8×10^{13} m^{-3}

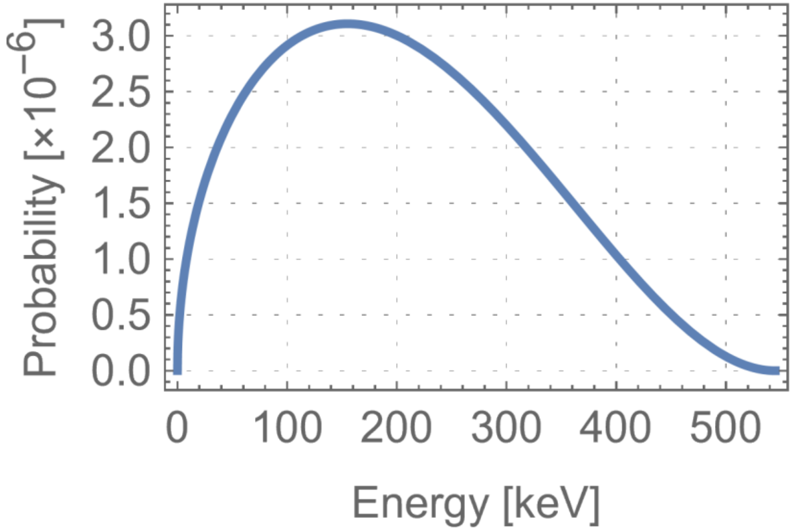
400V trap: Peak density ≈ 1×10^{15} m^{-3}

Conclusions and Outlook

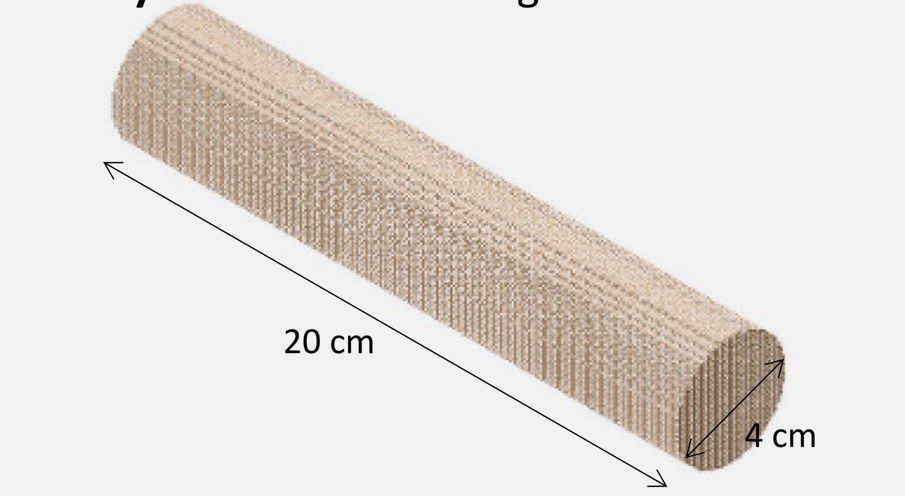
Electron source

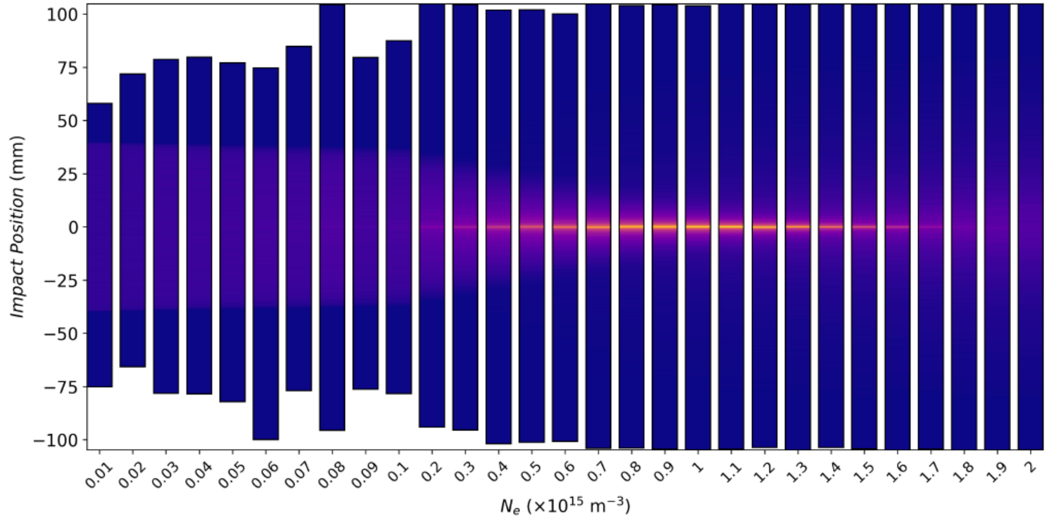


Energy distribution of positrons emitted from the source (^{22}Na)



Cylindrical lens: Charge distribution





Plasma lens group

LhARA
Laser-hybrid Accelerator for Radiobiological Applications

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M. Charlton
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