Empirical study of multidimensional Child-Langmuir law with plasma ion source extraction using round apertures

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1 Background

- 1D Child-Langmuir (CL) law is used to describe space charge limited current density between infinite large anode and cathode in diode gap

$$J_{1D} = \frac{4}{9}\epsilon_0\sqrt{\frac{2q}{m}}\frac{V^{3/2}}{D^2}$$

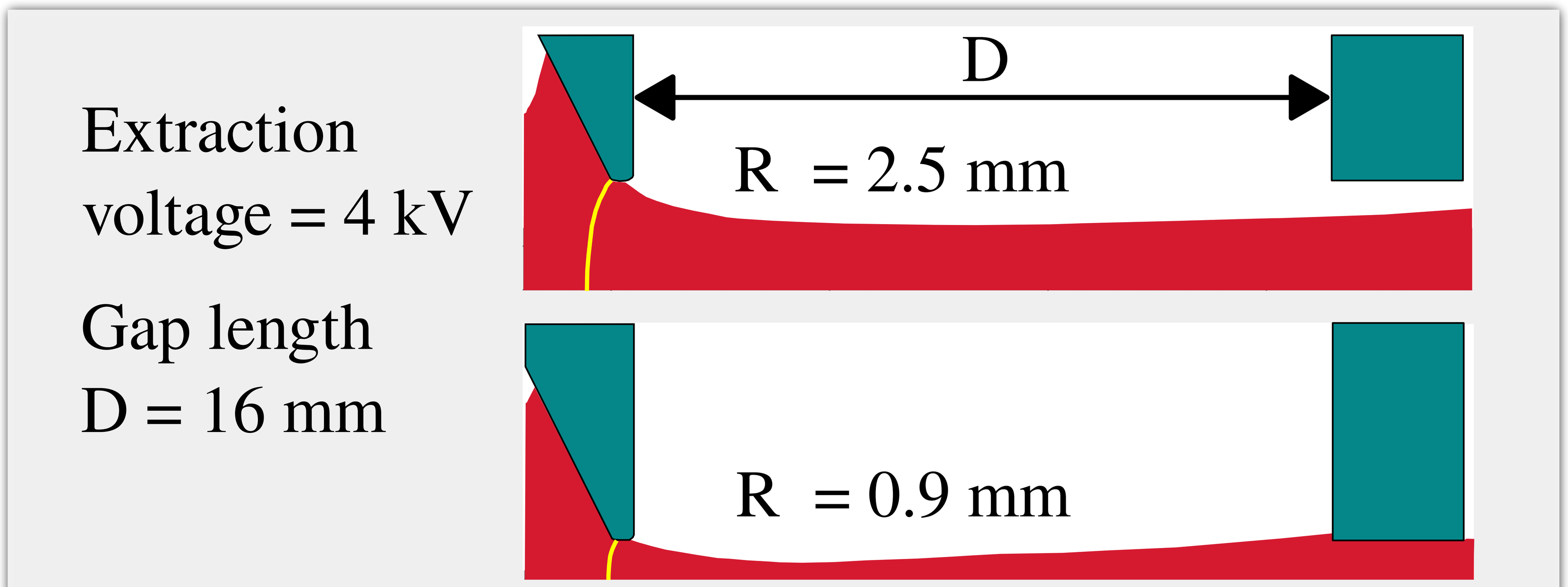
- 3D CL law as a enhancement factor for 1D law. For round aperture

$$J_{3D} = J_{1D}(1 + \frac{1}{4}\frac{D}{R})$$

- **Physical interpretation**: excessive space charge present in the gap restricts the accelerating electric field which limits the maximum current that can be extracted from the electrode
- **Problem**: CL laws not strictly valid for plasma ion extraction
  - Dynamic plasma meniscus: shape and location changes
  - Initial ion velocity is not zero
- **Goal**: study the applicability of 3D CL law to plasma ion source extraction

3 Simulations

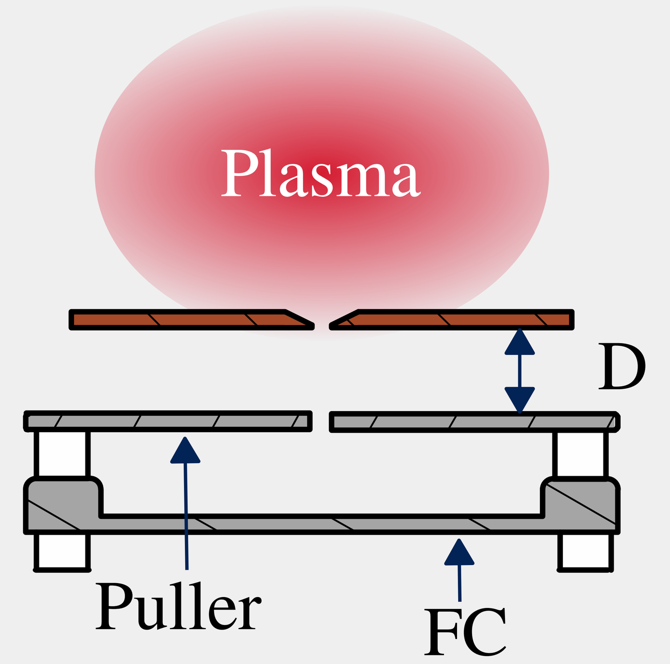
- Ion optical code IBSimu was used to study behavior of meniscus
- With bigger R the meniscus is more sensitive to extraction voltages
  - Location changes more (changing gap length D)
  - (**Area of the meniscus / area of the aperture**) changes more with bigger R. For example with 4 kV: **4%** bigger with R = 0.9 mm and **21%** with R = 2.5 mmm



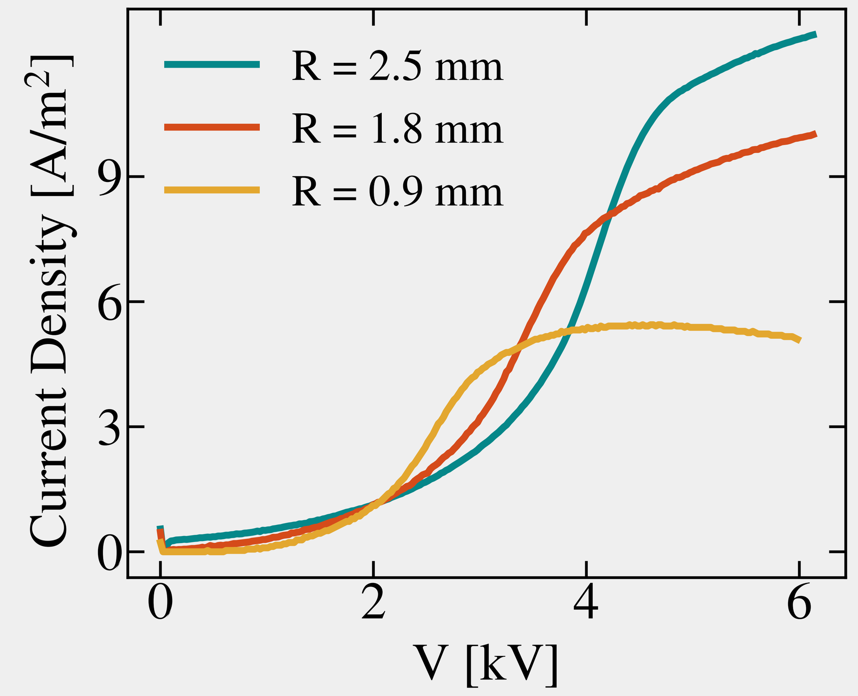
2 Setup & Results

- The experiments were carried out with a filament-driven DC-discharge multicusp ion source using Ar+ beam → stable and repeatable beam
- Two different extraction systems were built to study the 3D CL law effects
- **Below** : CL law not applicable to total extracted beam current density
- **Right**: 1) 3D CL effects in space charge limited region
  2) Bigger R → higher emission limited J
  3) Smaller R → emission limited J with lower voltages

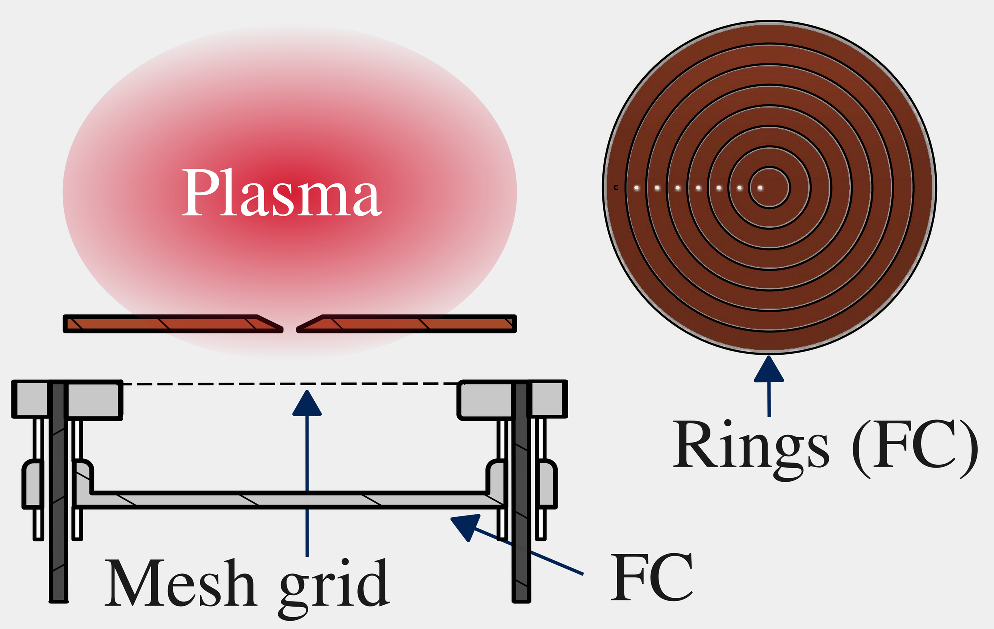
2nd Extraction system:
equal size apertures



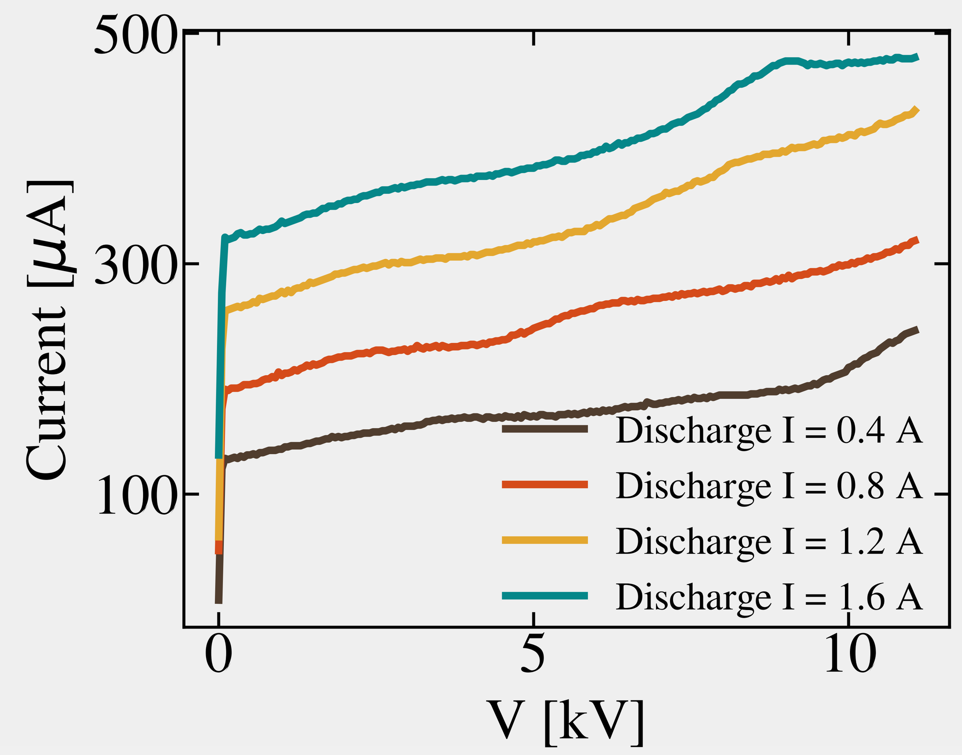
Current densities with different R (same n_e)



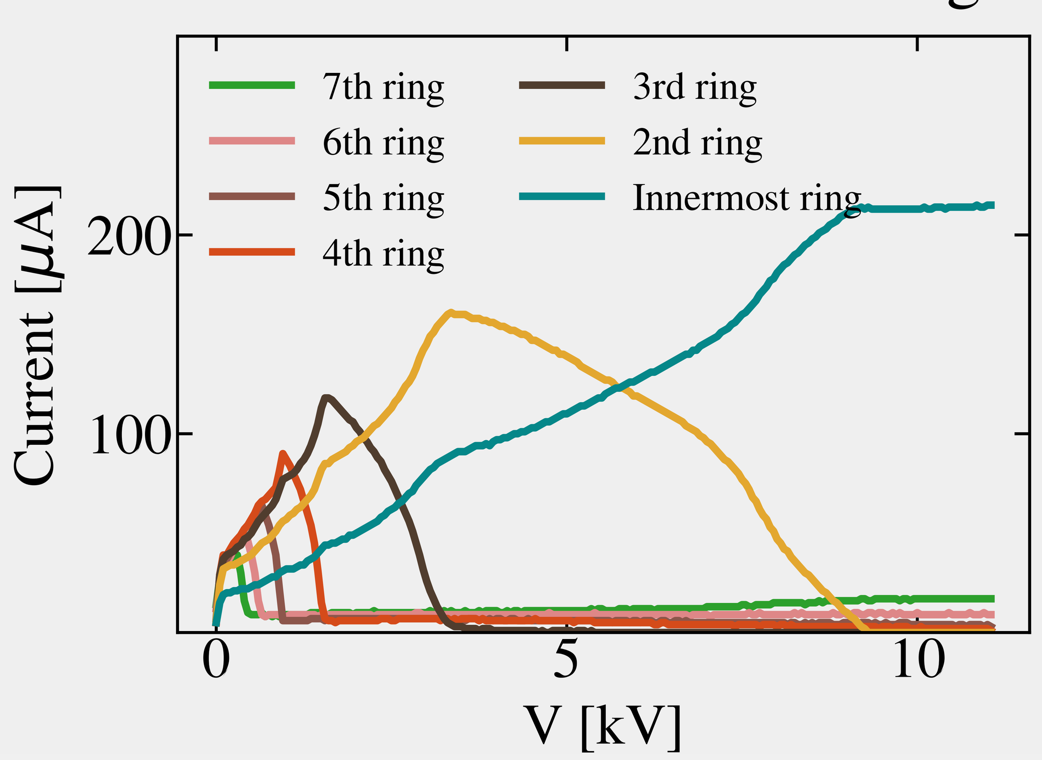
1st Extraction system:
mesh grid puller



Total measured currents



Currents on individual rings



4 Conclusions

CL laws not applicable to total extracted beam currents

At low voltages the beam is spread out due to the convex meniscus. After initial jump current rises almost linearly.

With puller electrode three extraction voltage regions are identified

1) The emission (or plasma density) limited saturation currents are reached with high extraction voltage
2) The beam is space charge limited at moderate voltages
3) The current densities are almost equal at low voltages.

In space charge limited region 3D CL effects are observed

3D CL predicts that with bigger R the space charge limited current densities are smaller, which is experimentally observed.

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