Methods for Remote Plasma Generation In Chamber

Igor D. Kaganovich,
PPPL

2 Talk Outline

- Why we may need plasma inside chamber.
- Plasma sources which can do the job.

3 Why we may need plasma inside chamber

Electrons follow the beam with $V_e \sim V_b n_b / n_e$.

After exit from plasma $n_b = n_e$ and $V_e \sim V_b$ => at the plasma boundary potential field $\sim m_e V_b^2$.

For fast, short beam pulses it may result in incomplete charge neutralization.

For more info:

I. D. Kaganovich, E. A. Startsev and R. C. Davidson, "Ion beam pulse neutralization by a background plasma in a solenoidal magnetic field", Proceedings of HIF symposium 2004 Princeton, NJ, to be published in Nuclear Instruments and Methods in Physics Research (2004).

I. Kaganovich, E. A. Startsev and R. C. Davidson, "Nonlinear plasma waves excitation by intense ion beams in background plasma", Phys. Plasmas 11 3546-3552 (2004). http://www.pppl.gov/pub_report//2004/PPPL-3942-abs.html

I. D. Kaganovich, E. A. Startsev and R. C. Davidson, "Analytical and numerical studies of the complex interaction of a fast ion beam pulse with a background plasma", Physica Scripta T107 54-59 (2004), invited talk at ITCPP 2003. http://www.pppl.gov/pub_report//2004/PPPL-3909-abs.html

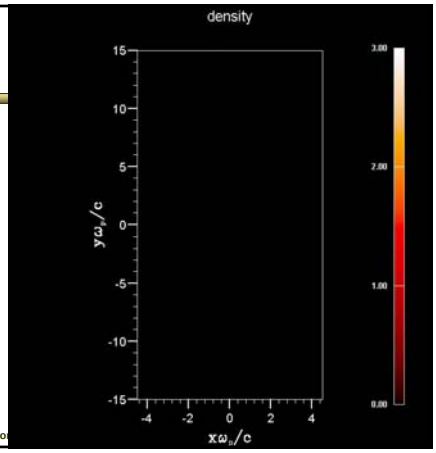
4 Results of 2D PIC-MC Code

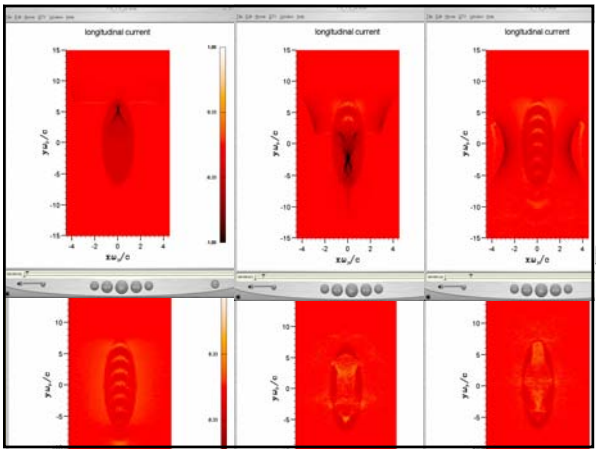
Beam propagation in the y-direction,
Beam length 7.5 c/ω_p; beam radius 1.5 c/ω_p;
Beam density equal to the half of plasma density $n_b = 0.5 n_p$;
beam velocity $c/2$.

I=10kA , $t_b = 30/\omega_p$, *for* $n_b = 1.2\ 10^9 cm^{-3}$ t_b=11ns.

Shown is the electron current.

5 Movie of the electron density





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Results of 2D PIC-MC Code

Beam propagation in the y-direction,
beam length 10. c/ω_p;
beam radius 0.5 c/ω_p;
beam density equal to the half of plasma density;
beam velocity 0.28*c*.

I=600A , $t_b=71/\omega_p$, *for* $n_b = 5\ 10^9 cm^{-3}$ t_b=13ns.

Shown are electron density.

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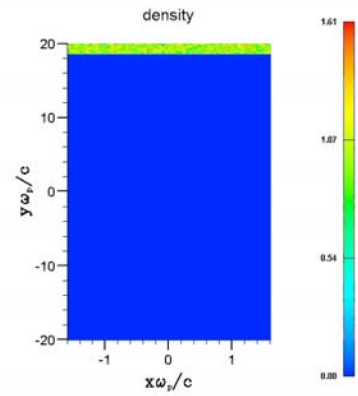
Movie of the electron density



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Plasma sources which can do the job.

- **Plasma production by the beam itself**
  $\sigma \sim 10^{-16} cm^{-2}$, mean free path $1/n\sigma \sim 1m$
- **Remote plasma sources:**
  - **Shoot plasma from outside on distances ~ meters**
  - **$n_e > 10^{-10} cm^{-2}$ in magnetic field**

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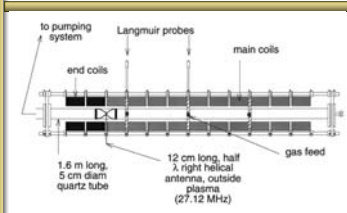
Helicon Sources



160-cm long,
5-cm diam.,
a uniform magnetic field.

the *m* = +1 (RH) azimuthal mode dominates over the *m* = – 1 mode;
there is low-B density peak around 50G,
helicon coupling to Trivelpiece-Gould (TG) modes.

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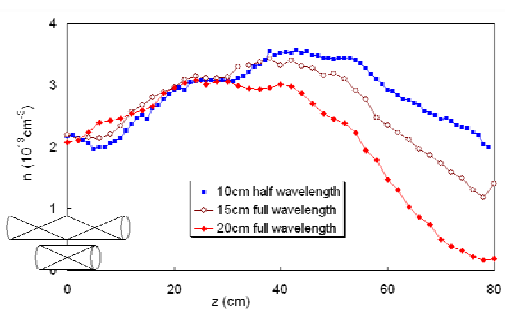
Helicon sources produce the density peaked far downstream instead of near the antenna



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Pros and Cons of Helicon Sources

- **Pros:**
  - **Naturally fits modular chamber**
  - **Commercially available**
  - **High Density**
- **Cons:**
  - **Antenna design and wave propagation are complicated**

Direct Current Plasma Source

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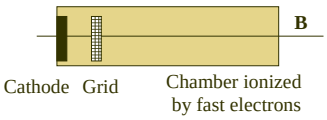

- **Used in**
  - **Ion thrusters and**
  - **Large plasma Sources for processing (NRL) and Basic Studies (UCLA)**

Large Plasma Device in UCLA

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19 meters long

75 centimeter diameter

Magnetic field up to 3.5 kiloGauss

DC current up to 11 kA

- **Fully ionized plasmas $5x10^{12}$ cm-3 and electron temperatures in the 10-20 eV range.**
- **The confining magnetic field can also be controlled and varied to generate various mirror and cusp configurations.**

Pros and Cons of DC current Sources

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- **Pros:**
  - **Naturally fits modular chamber, except for grid**
  - **Commercially available**
  - **High Density**
- **Cons:**
  - **Cathode and Grid Reliability**
  - **Complex Magnetic field to confine fast electrons**
  - **Instability of large DC currents**

Another Plasma Sources

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Plasma arcs (hall thrusters)

Compact torus (coaxial rail guns)

Hall Thruster

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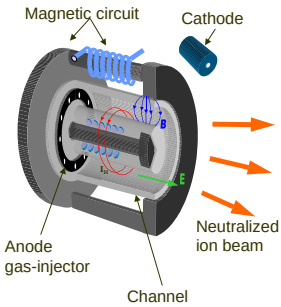

Magnetized electrons

Non-magnetized ions

$E=-v_e \times B$

Equipotential magnetic field surfaces

No space charge limitation

Plasma density ~ 10^{12} cm^{-3}

T_e ~ 10-100 eV

Ion kinetic energy ~ 0.1-10 keV

Current density ~0.1-1 A/cm^2