Plasma beam generation from a helicon current-free double-layer

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Plasma expansion:fluid equations

Boltzmann relation for electrons (no electron drift):

$$\Delta p = \Delta(n_e T_e) = -e n_e E_z \quad \text{with } E = -\Delta\phi$$

taking isothermal ($T_e = C^{st}$), massless electrons

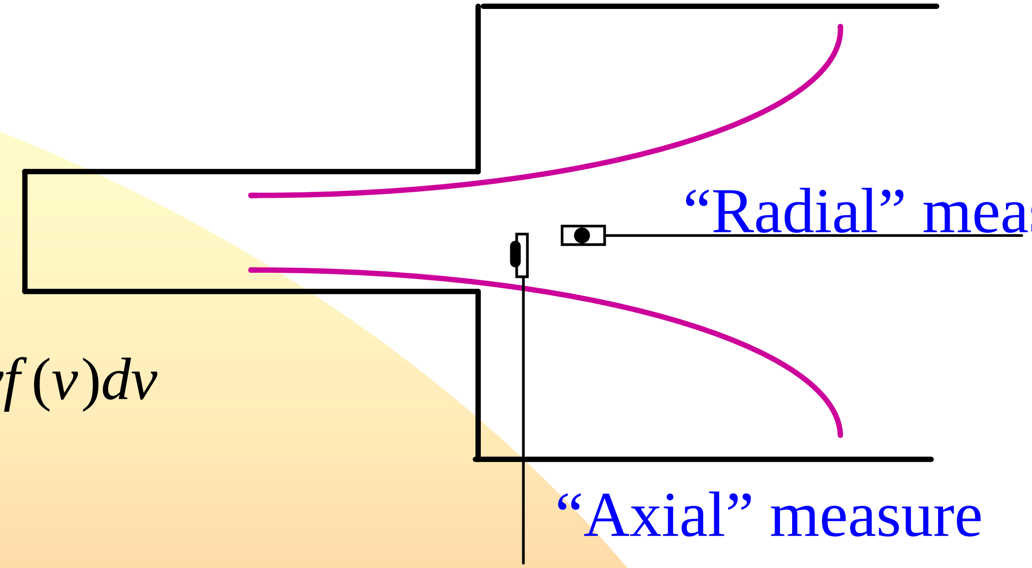
$$n(z) = n_o \exp(e\phi / kT_e) \quad \text{with } \phi = \phi(z) - \phi_0$$

An electric field is created to retard the mobile electrons

↓

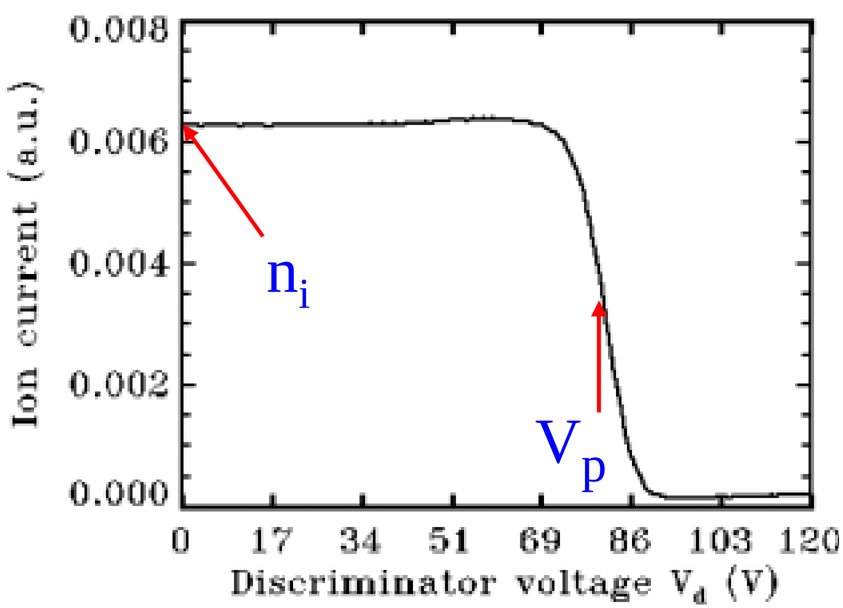
Ions are accelerated

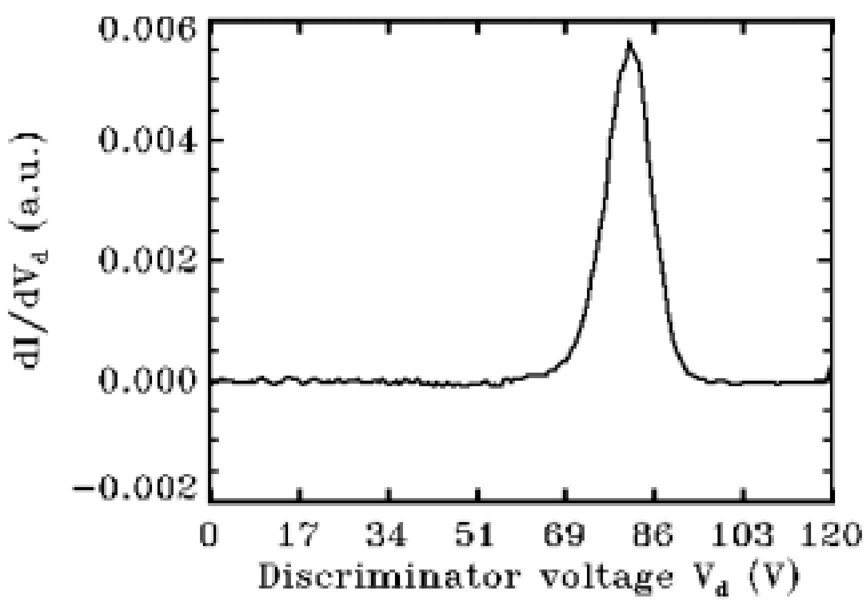
Movable energy analyser



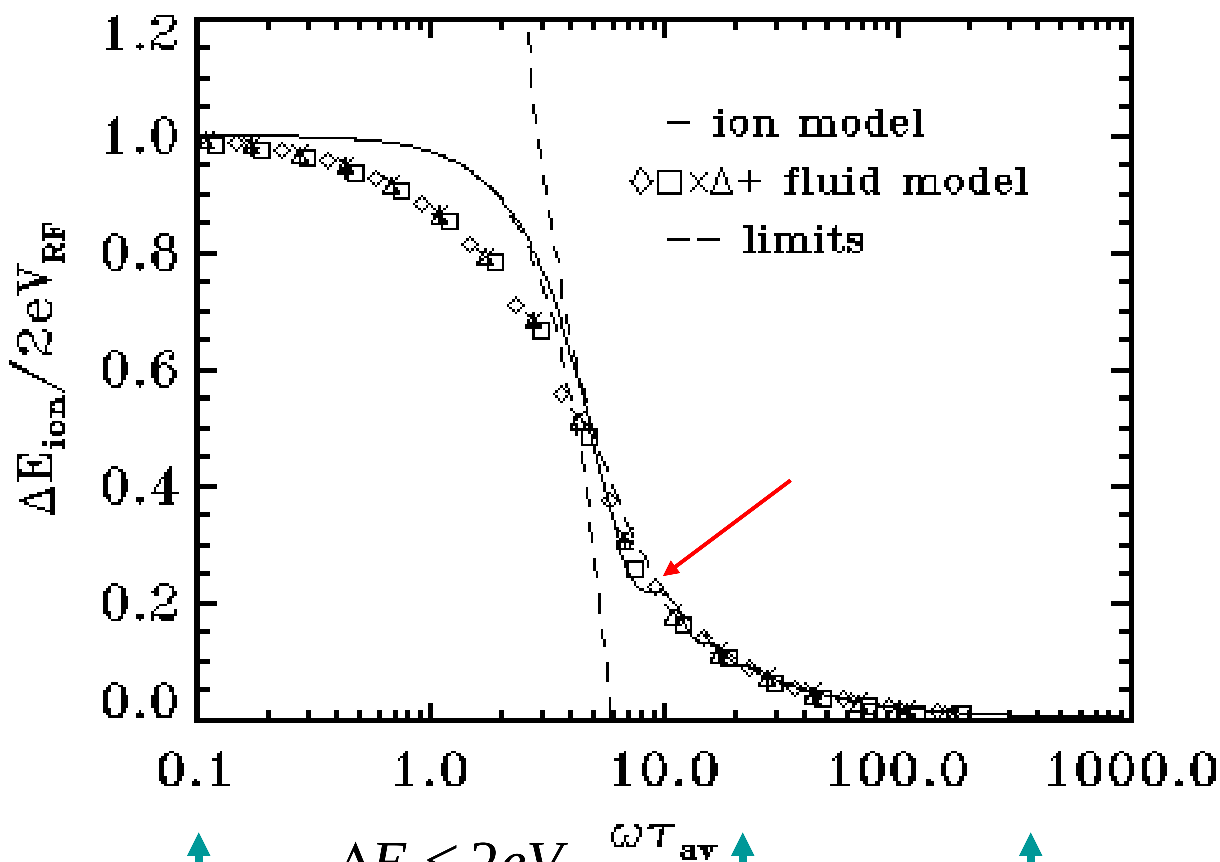
$$I(v_0) = eAT^4 \int_{v_0}^{+\infty} v f(v) dv$$

$$\frac{1}{2} m_i v_0^2 = eV_d$$

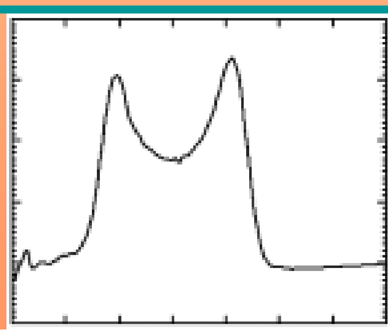


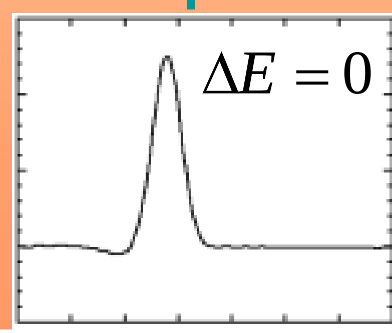


Generalised Curve



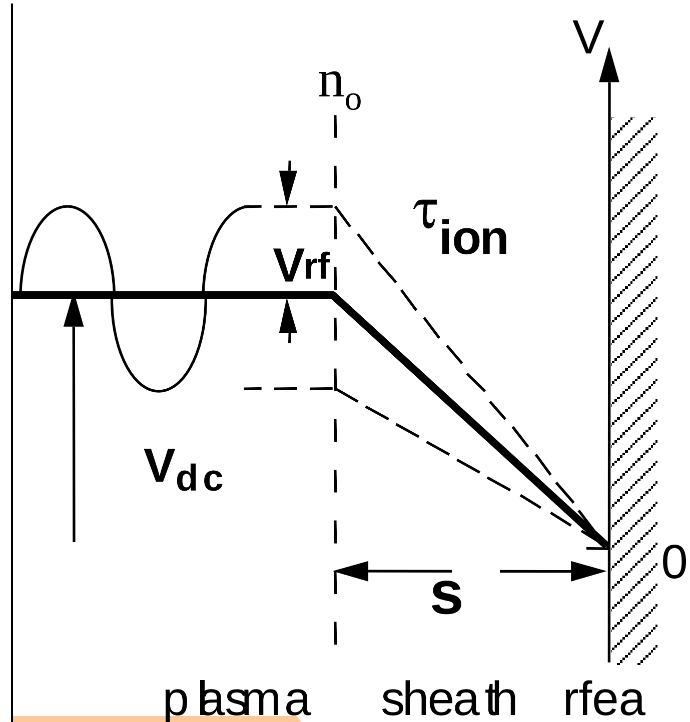
$\Delta E \leq 2eV_{rf}$





$\Delta E = 0$

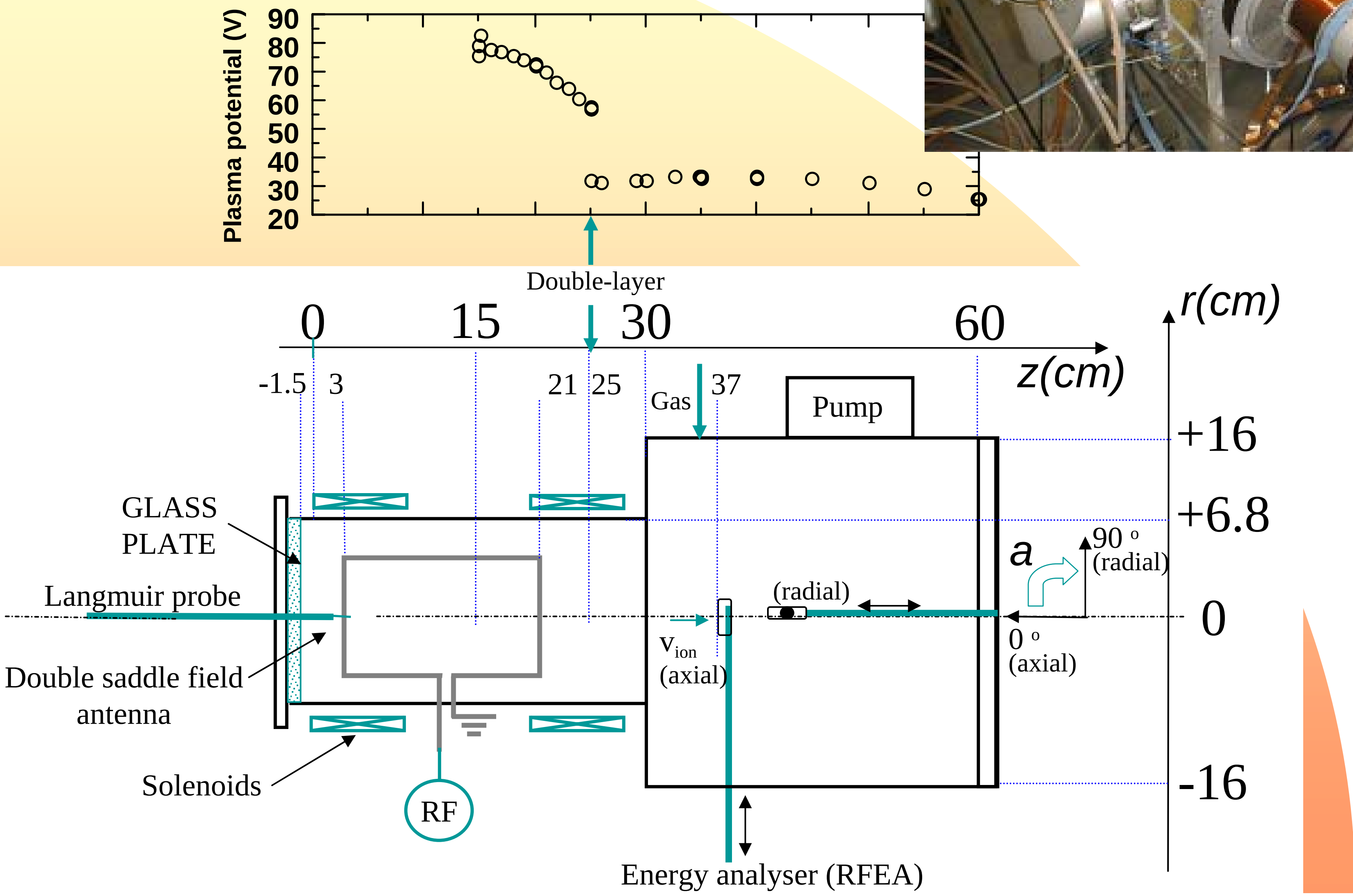
Ion transit time τ_{ion}



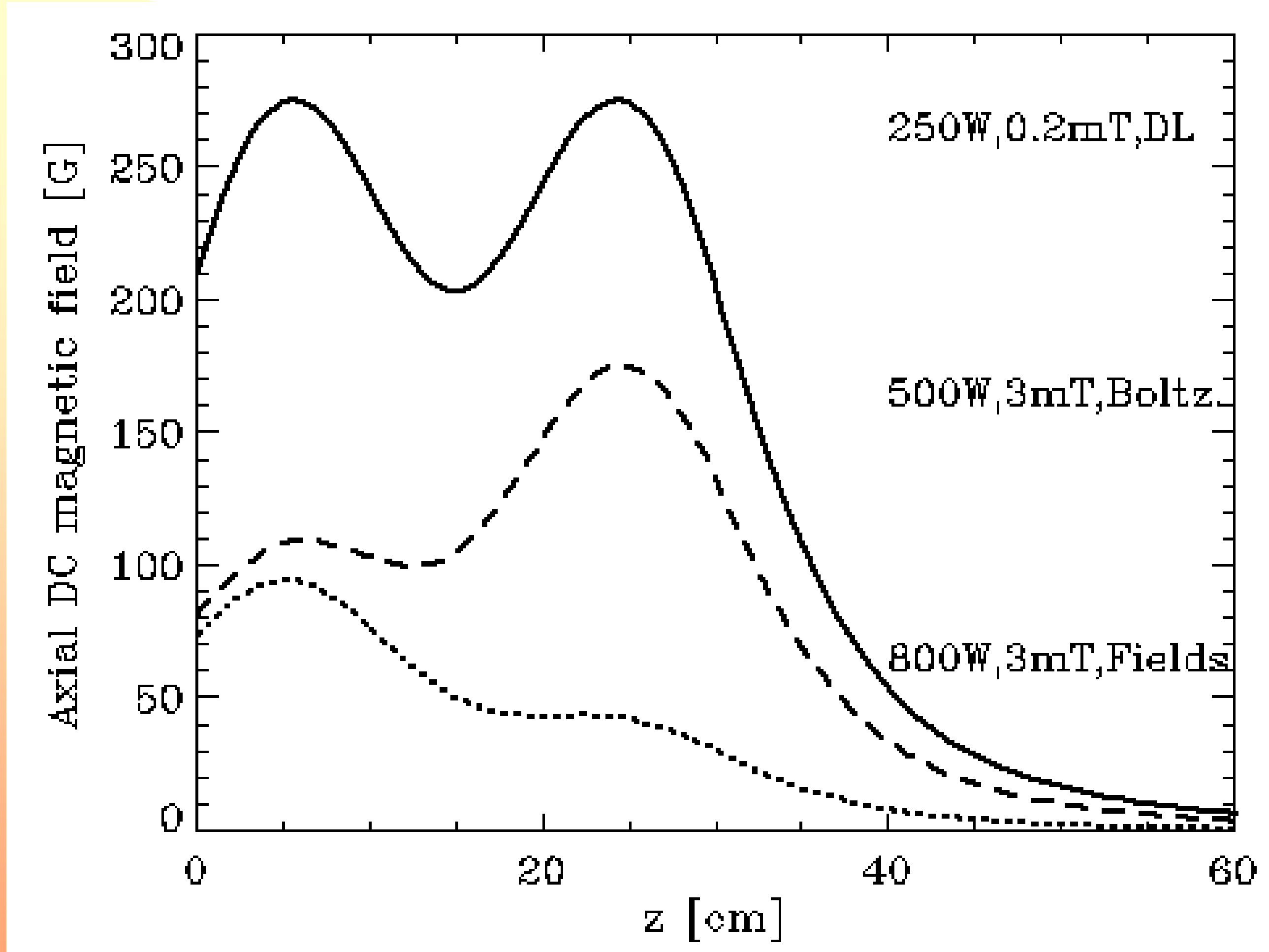
Simplest fit

$$\frac{\Delta E}{2eV_{RF}} = \frac{1}{\sqrt{1+\left(\frac{\omega\tau_{av}}{2}\right)^2}}$$

Helicon Double-Layer (DL)



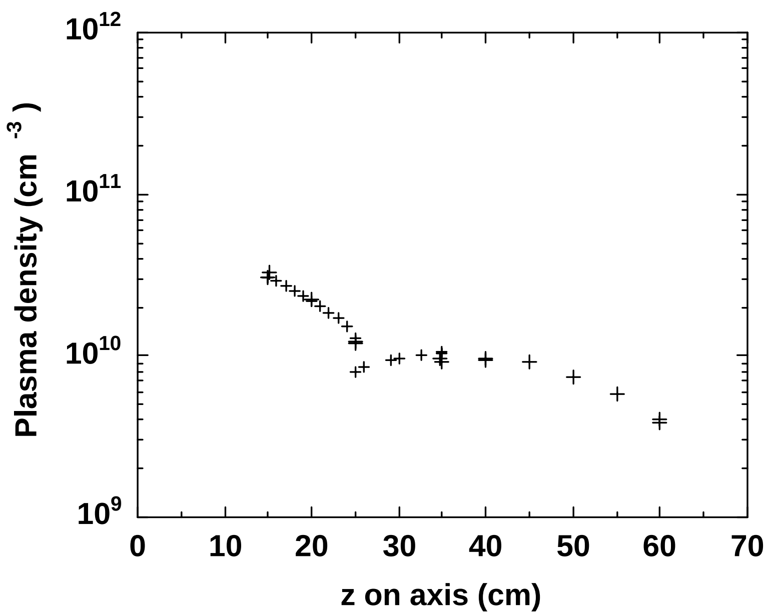
DL:expanding magnetic field+p<1 mTorr

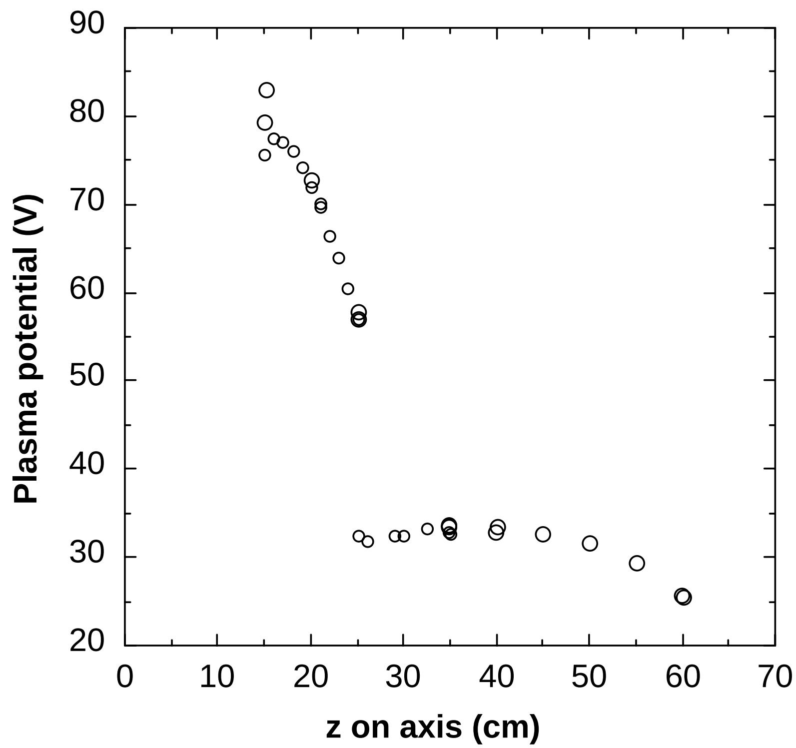


Large mean free paths at low pressure ----> anomalies (charge-exchange+scattering)

DOUBLE LAYER: n & V_p

radial measure, argon, 250 Watts, ~0.2 mTorr with expanding field





$$e\phi / kT_e \approx 3$$

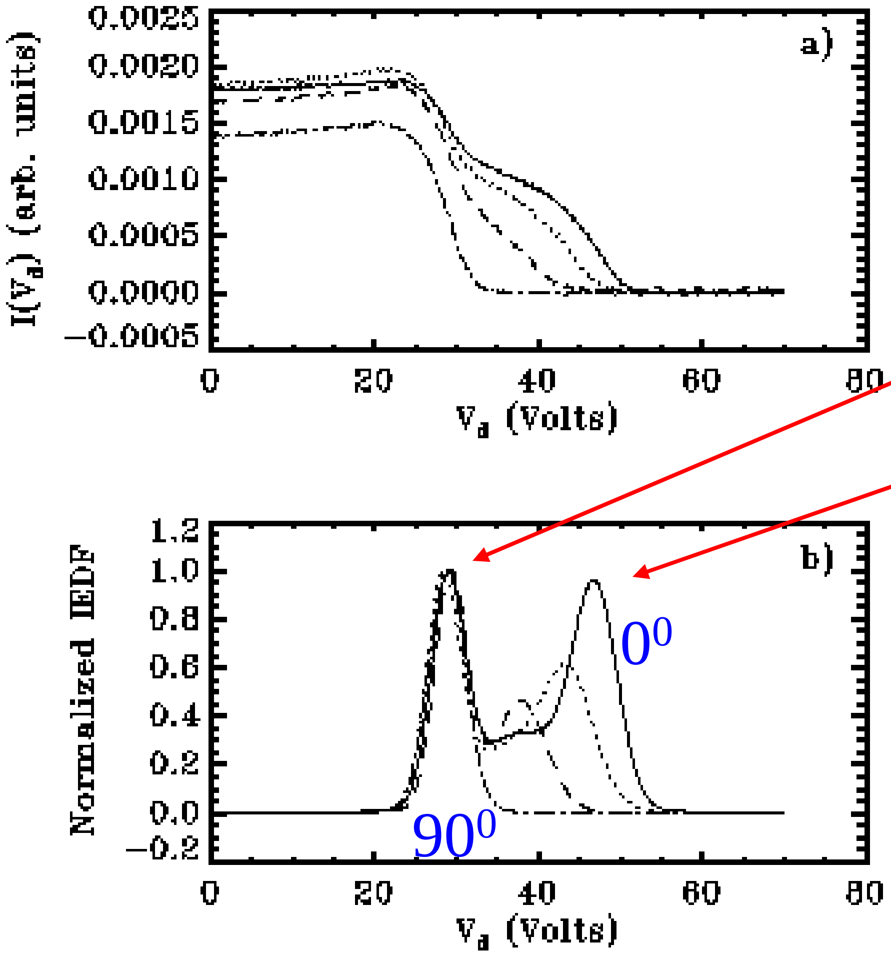
$$thickness \approx 50\lambda_d$$

Source field 220 $V.m^{-1}$

Potential drop ~25 V

T_e downstream~8eV

Radial and axial measurement I(Vd): angle



Argon, 250 watts,
0.35 mTorr
expanding field 250 to 50 G

$$V_p = 29V$$

$$V_{beam} = 47V$$

$$V_{beam} - V_p \approx 2.25T_e \approx 0.7e\phi_{DL}$$

$$v_{beam} \approx \sqrt{\frac{2e(V_{beam} - V_p)}{m_i}} \approx 2.1c_s$$

Bimodal distribution associated to local plasma potential and supersonic ion beam energy (not to rf sheath oscillation)

Ion beam: velocity and density

$$v_{beam} \approx \sqrt{\frac{2e(V_{beam} - V_p)}{m_i}} \approx 2.1c_s$$

$$I_{radial} = I_{radial}(0) = eAT^4 n_s c_s$$

$$I_{axial} = I_{axial}(0) = eAT^4 (n_s c_s + n_{beam} v_{beam})$$

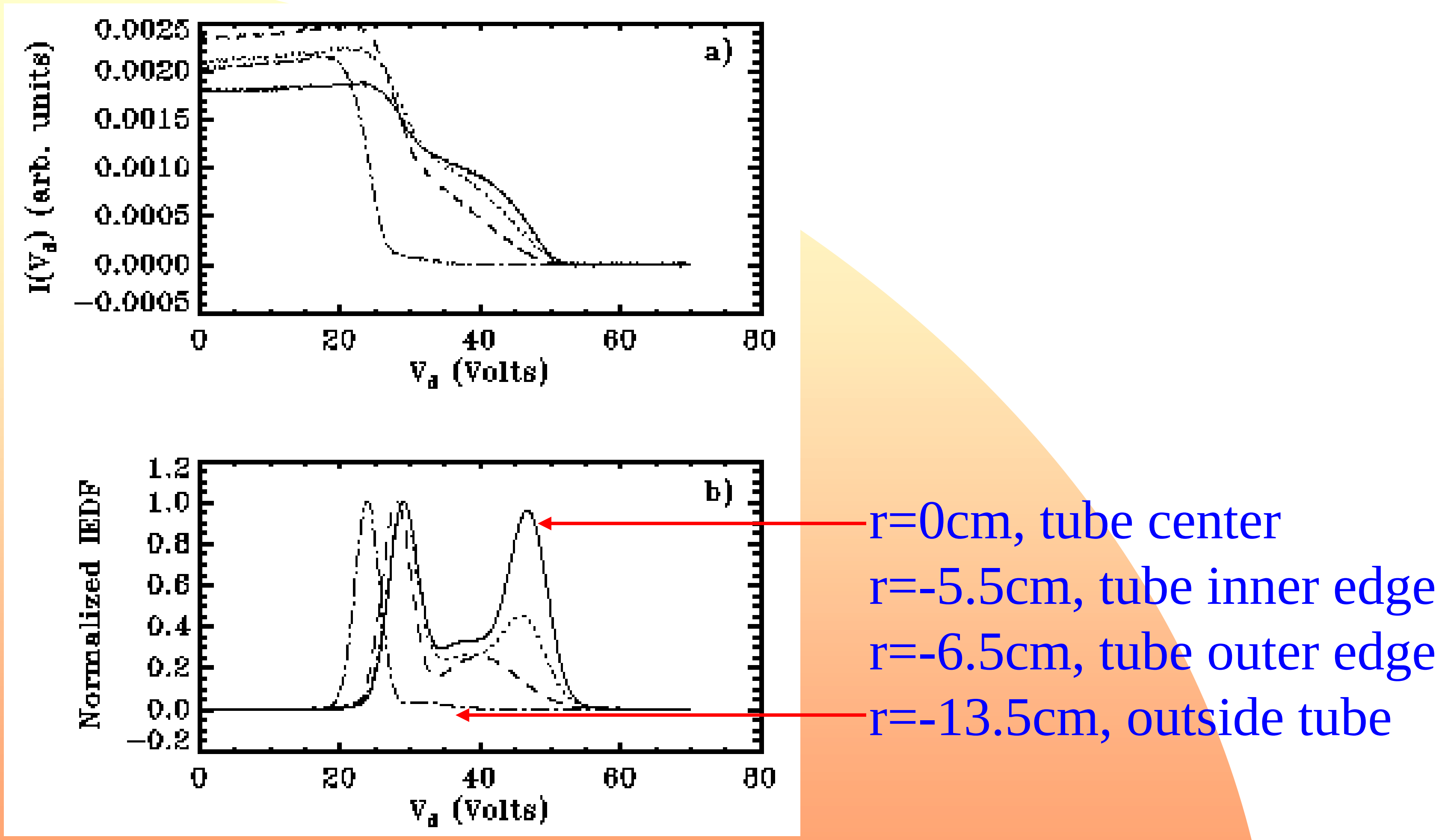
$$I_{axial}(v_{beam}) = eAT^4 n_{beam} v_{beam}$$

$$\frac{n_{beam}}{n_s} = \left(\frac{I_{axial}}{I_{radial}} - 1\right)\frac{c_s}{v_{beam}} \approx 0.14 \pm 0.03$$

$$\frac{n_{beam}}{n_s} = \left(\frac{I_{axial}(v_{beam})}{I_{axial} - I_{axial}(v_{beam})}\right)\frac{c_s}{v_{beam}} \approx 0.16 \pm 0.03$$

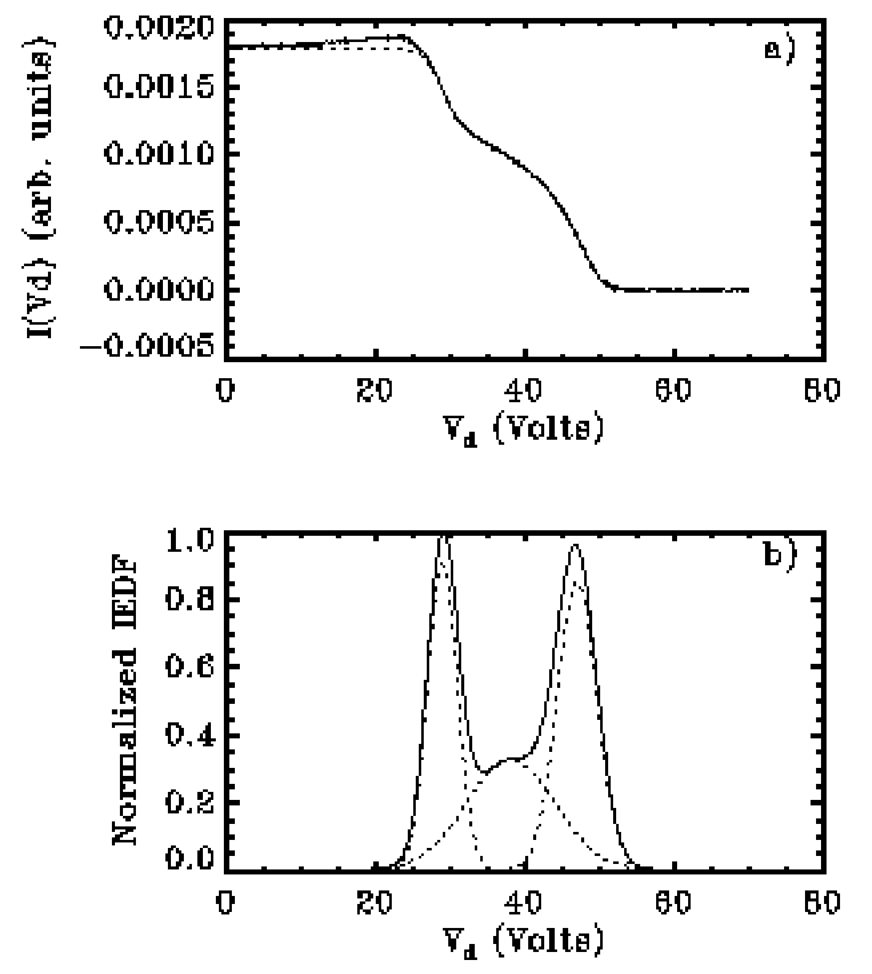
12 cm downstream of the DL, 15% of local density gives n_{beam}=1.5x10^9cm^{-3}

Axial measurement I(Vd): radius



V_p and V_{beam} decrease with increasing r
Need for a detailed analysis to access accurate beam profile

Deconvolution: 3 gaussians



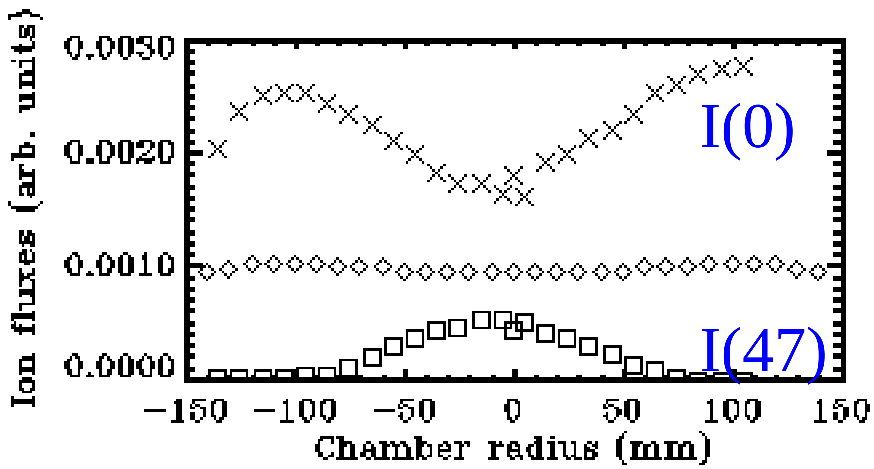
V_p and V_{beam}

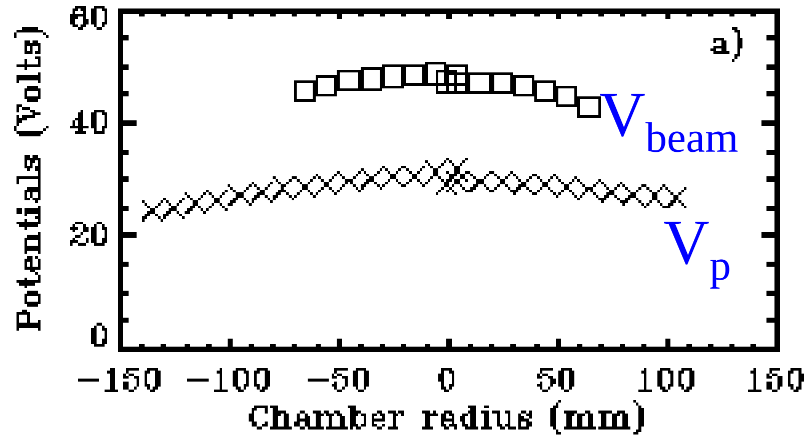
v_{beam}/c_s

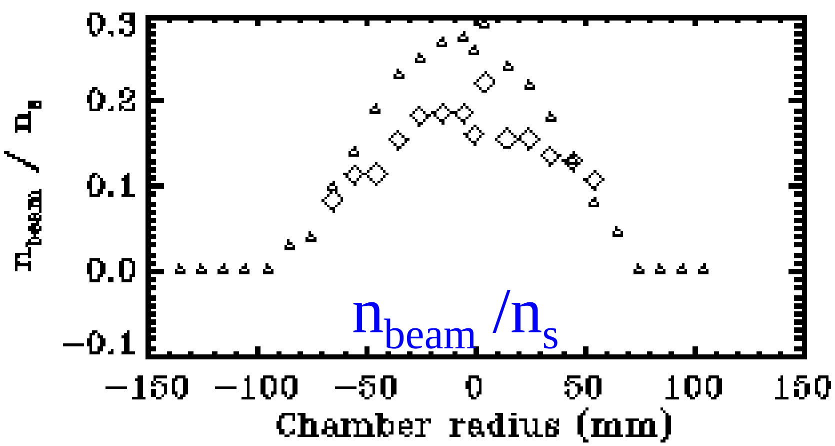
(exp. data) n_{beam}/n_s

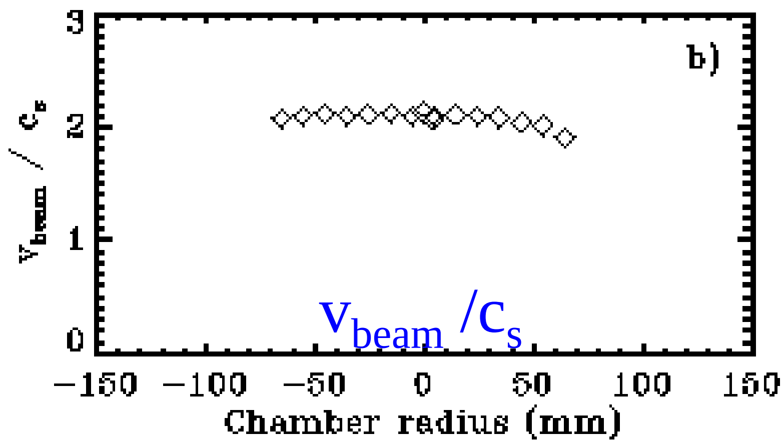
$$\frac{n_{beam\ max}}{n_s} \sim \frac{\int v f(v) dv / v_{beam}}{\int v f(v) dv / c_s + \int v f(v) dv / v_{int} + \int v f(v) dv / v_{beam}}$$

Profile from axial measurements on r axis



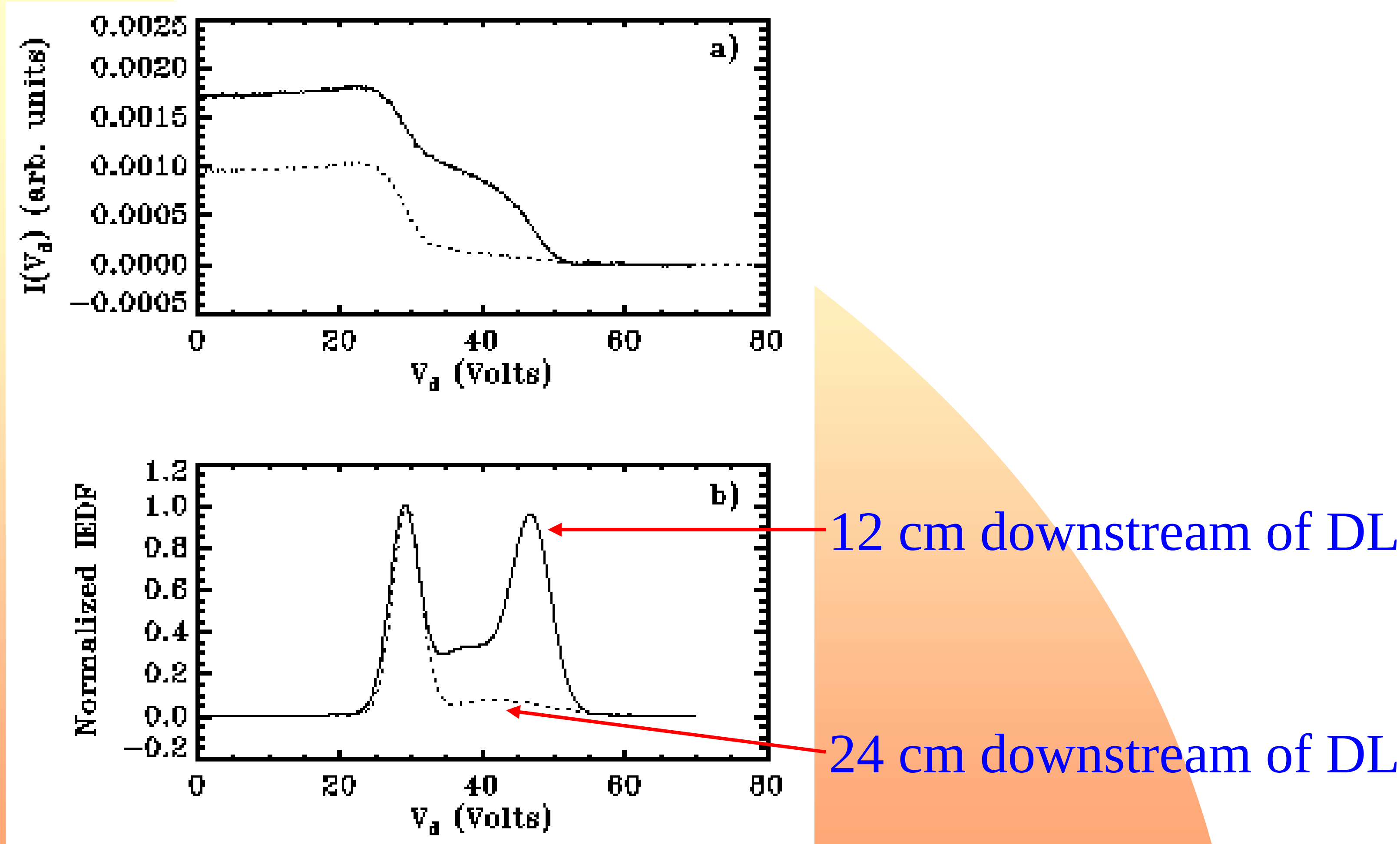






Not greatly affected by magnetic field (for 20 eV, ion larmor radius is 20 cm at z=25 cm and much greater in chamber)

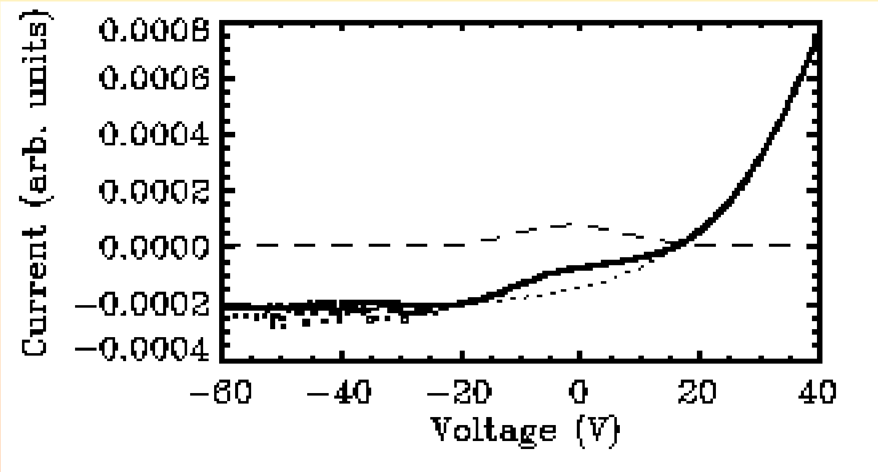
Axial distance



Beam affected by collisions with background gas (CE,EL):
Mean free paths: 11 and 13 cm for 0.01 eV, 22 and 26 cm for 20 eV

Electron beam in the source:

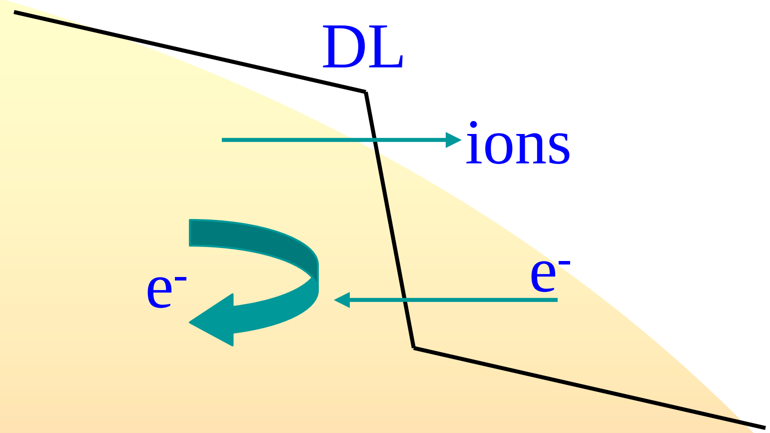
Fit=electron beam current (gaussian)
+maxwellian electron current
+ constant ion current



$$\frac{I_{beam}}{I_e} = \frac{n_{beam}}{n_e}\sqrt{\frac{T_{beam}}{T_e}}$$

V_f = 17 V, wall charging in source
Electron beam at about 17 V below V_f
$n_{beam}/n_e \geq 0.12$
Backwards acceleration through double-layer

Current-free DL: no electrodes



Forward and backward acceleration with beam formation

Neutral plasma on either side

Uniform supersonic ion beam

Not greatly affected by Bz

Plasma/Rocket thruster
Surface processing
Space science (aurora, solar wind…)
Basic plasma physics:

- **Double Layers**
- **Supersonic flows**
- **Ion heating**

The australian auroral thruster