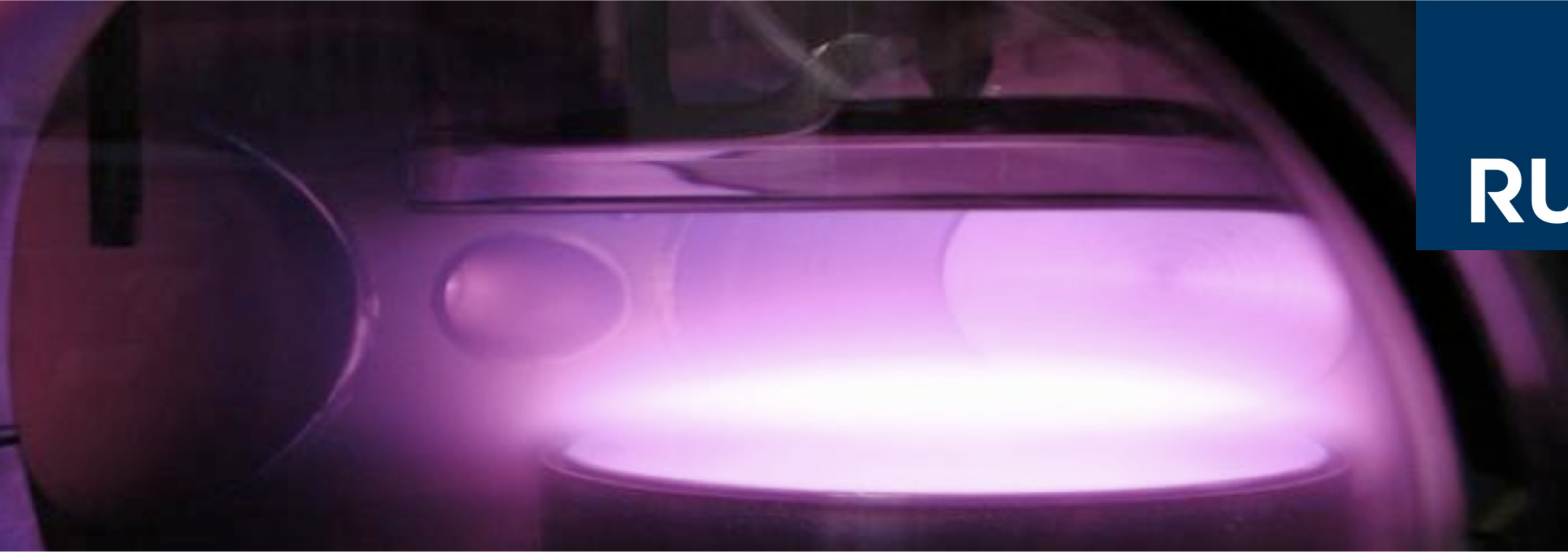
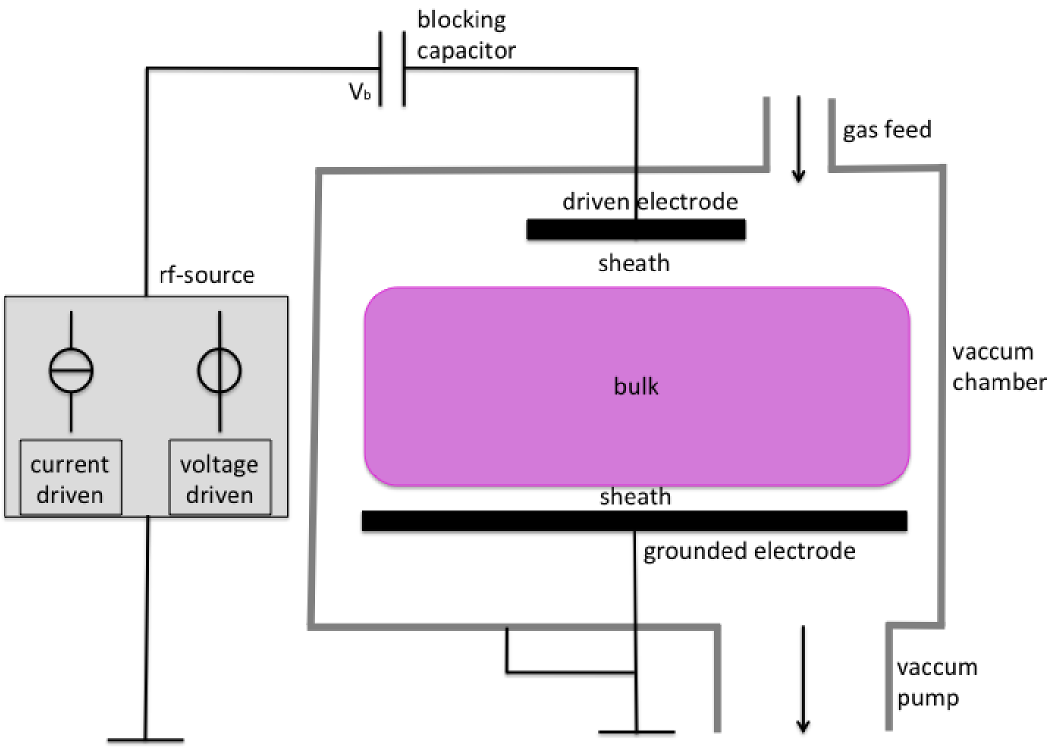


Voltage vs. Current Driven CCRF Discharges: Differences in Electron and Ion Dynamics

S. Wilczek[1], J. Trieschmann[1], J. Schulze[1], R. P. Brinkmann[1], A. Derzsi[2], P. Hartmann[2] , Z. Donkó[2], T. Mussenbrock[1]

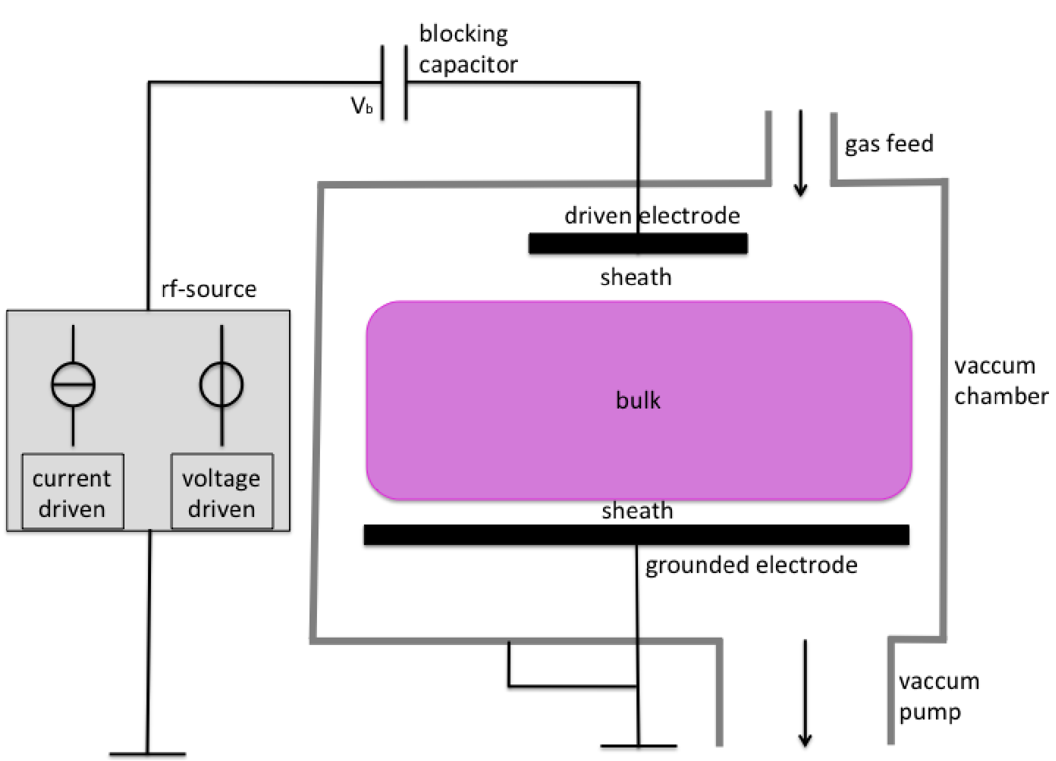
[1]Ruhr-University Bochum, Germany
[2]Wigner Research Centre for Physics, Budapest, Hungary

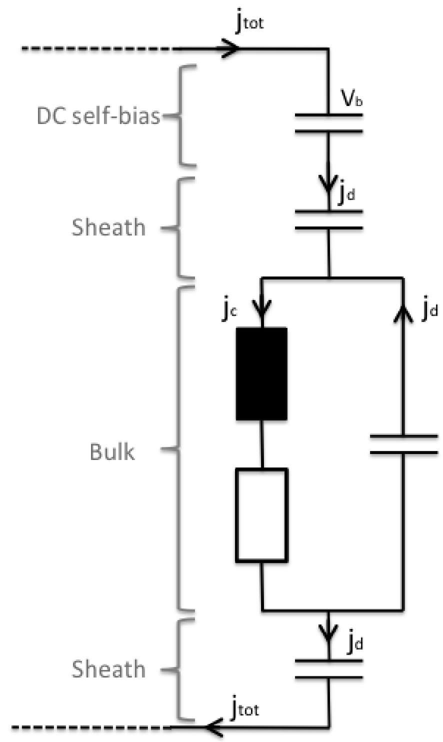
Power input for asymmetric ccrf discharges



- most ccrf discharges are asymmetric, electrode surfaces are naturally grounded
- experiments: power is coupled via matchbox into the system
- simulation and models: voltage and current sources are frequently used
- what are the differences in low pressure ccrf discharges?

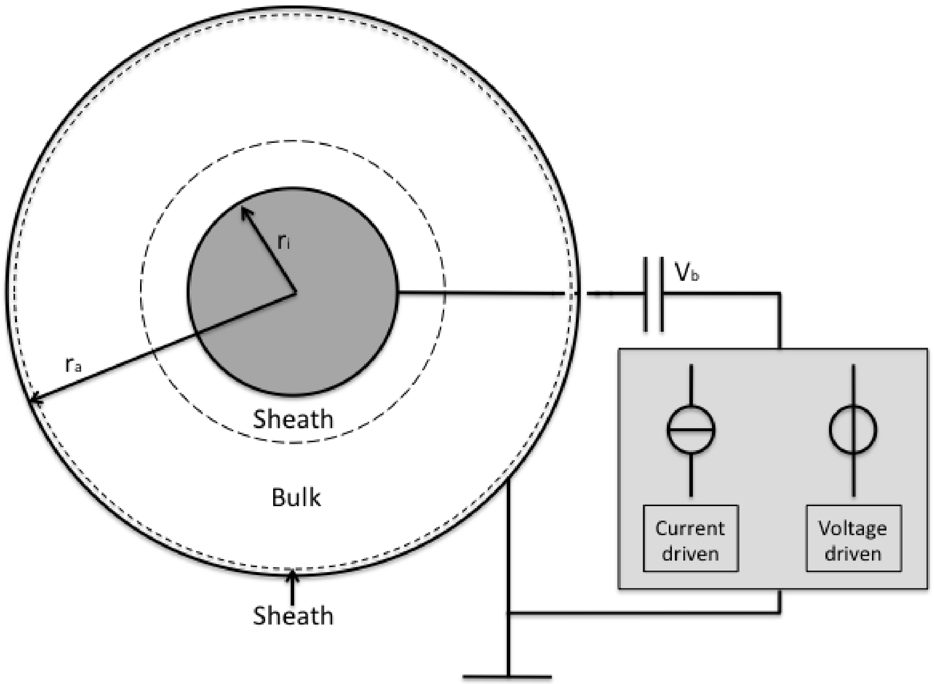
Resonance phenomena in asymmetric ccrf discharges





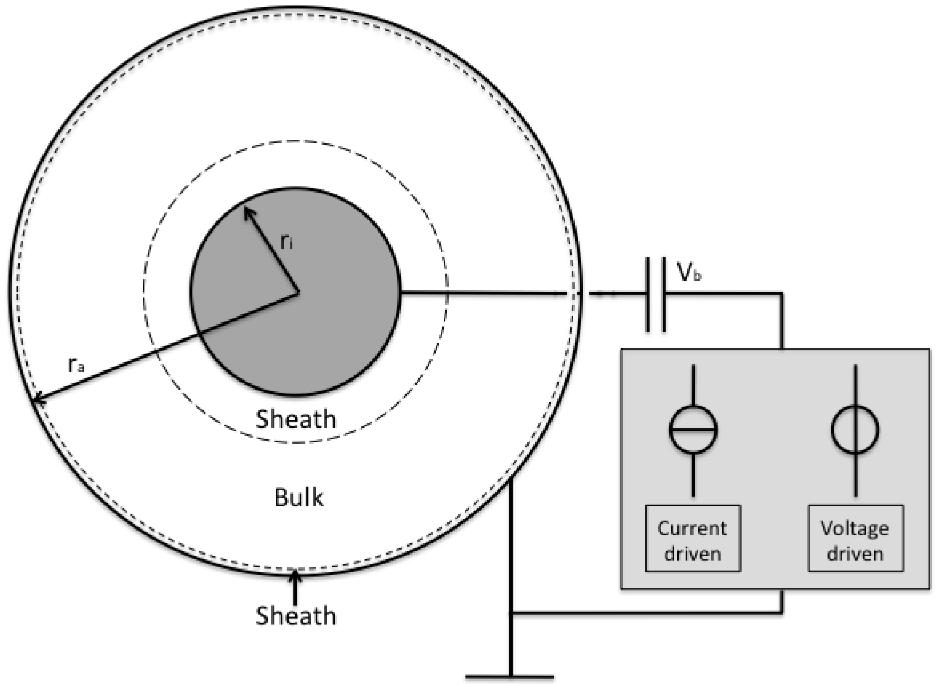
- global model to determine plasma series resonance (PSR)
- self-excitation of PSR is eliminated using current sources (no harmonics)
- focus on the nonlinear interaction between sheath and bulk on a nanosecond timescale to understand the differences in voltage and current driven systems

Particle-In-Cell simulation of an asymmetric ccp



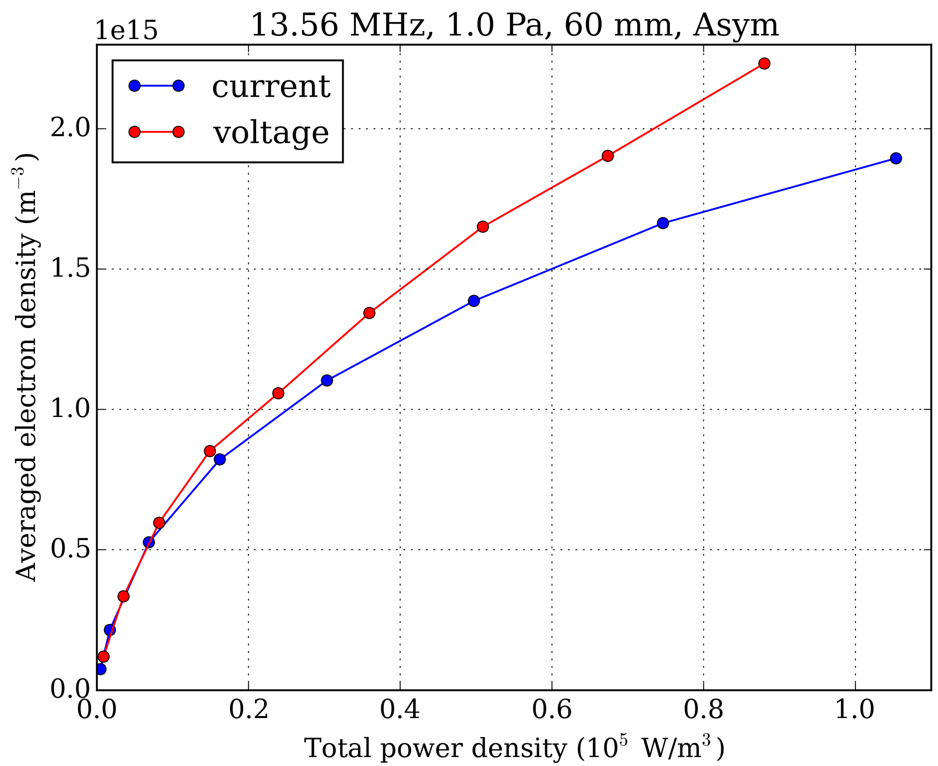
- 1d3v PIC simulation with a spherical grid
- system is spherical symmetric $\Longrightarrow$ purely 1d along r
- obtain geometrical asymmetry and a self-consistent self-bias

Voltage and current variation: setup



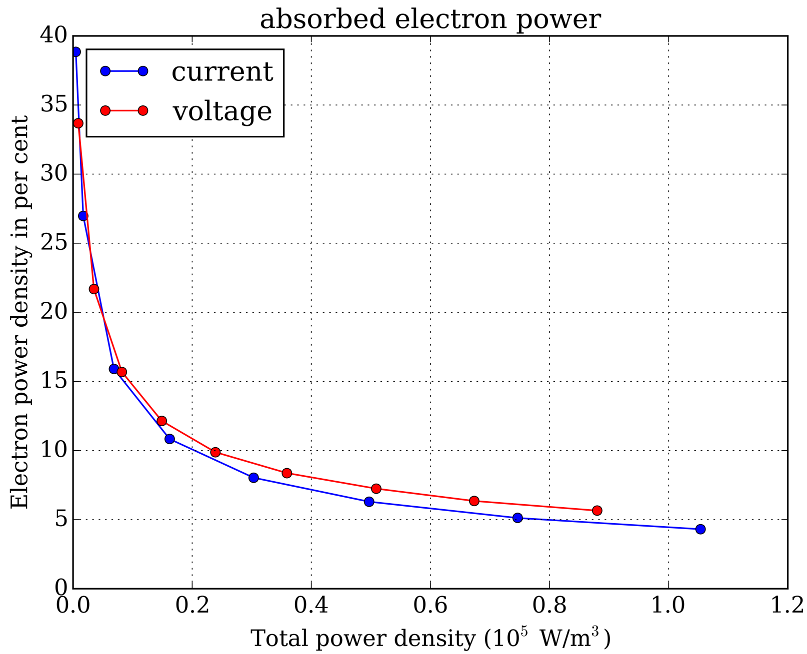
- $f_{\mathrm{rf}} = 13.56$ MHz
- $L_{gap} = 60$ mm
- $V_{\mathrm{rf}} = 100.....900$ V
- $p_{gas} = 1$ Pa argon
- $\frac{A_g}{A_d} = 16$
- $J_{\mathrm{rf}} = 10.....140$ A/m^2
- to compare both variations $\Longrightarrow S_{abs} = S_e + S_i = < \vec{j}_c \cdot \vec{E} >_{x,t}$

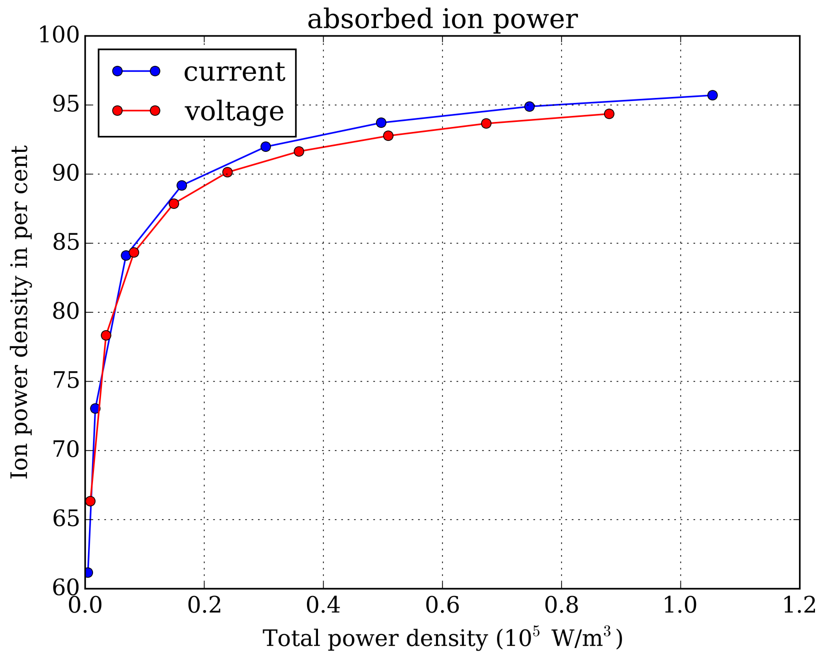
Voltage and current variation: electron density



- voltage source leads to higher densities (same input power!!!)
- especially for higher absorbed power, density difference about 20%
- how is the absorbed power divided? $\Longrightarrow S_{abs} = S_e + S_i$

Voltage and current variation: power distribution



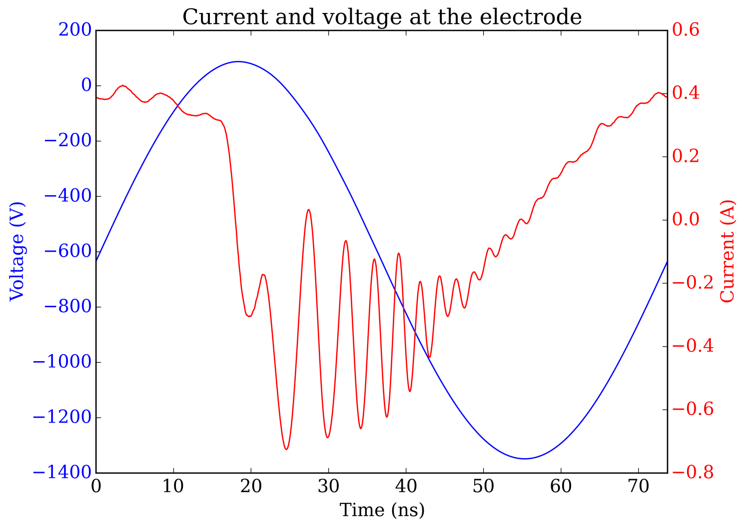


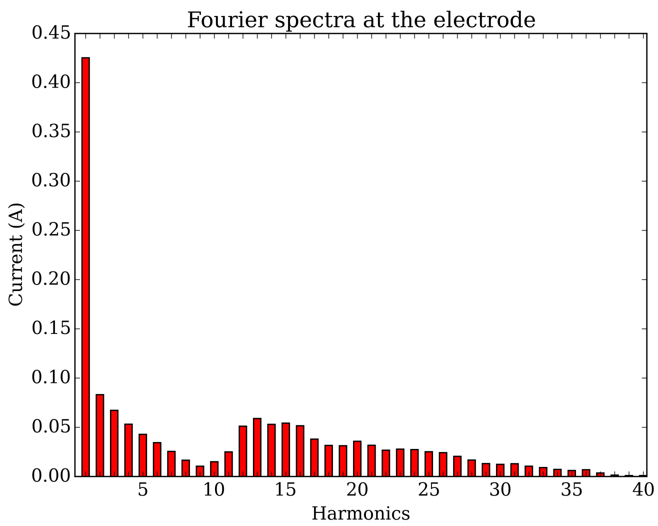
- ion power absorption dominates for higher input power
- 1-2% differences in the electron an ion power absorption
- voltage source puts more power into the electron dynamics
- nonlinear electron resonance heating[1] (NERH) enhances the ionization
- compare 700 V and 100 A/m^2 $(0.5 \cdot 10^5$ W/m$^3)$ in more detail

[1] T. Mussenbrock and R.P. Brinkmann, Appl. Phys. Lett. 88, 151503 (2006)

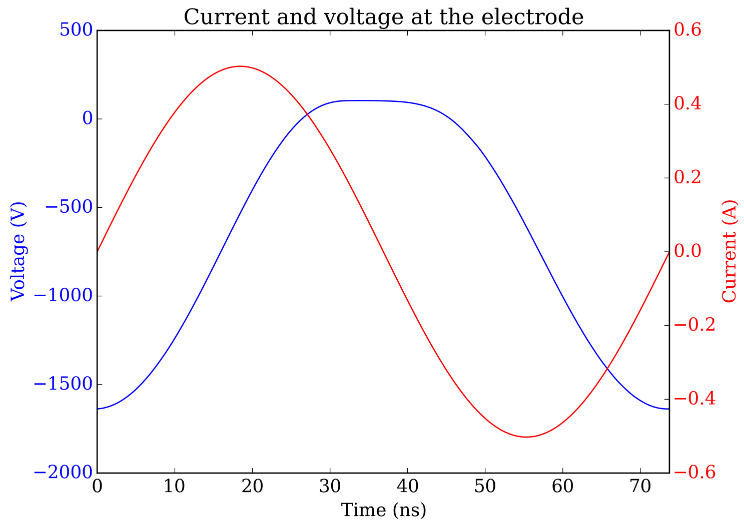
Current/Voltage at the electrode and the Fourier spectra

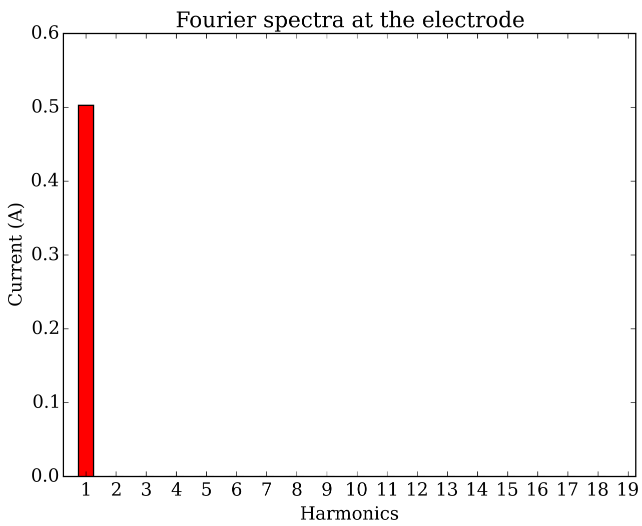
voltage source: 700 V





current source: 100 A/m^2

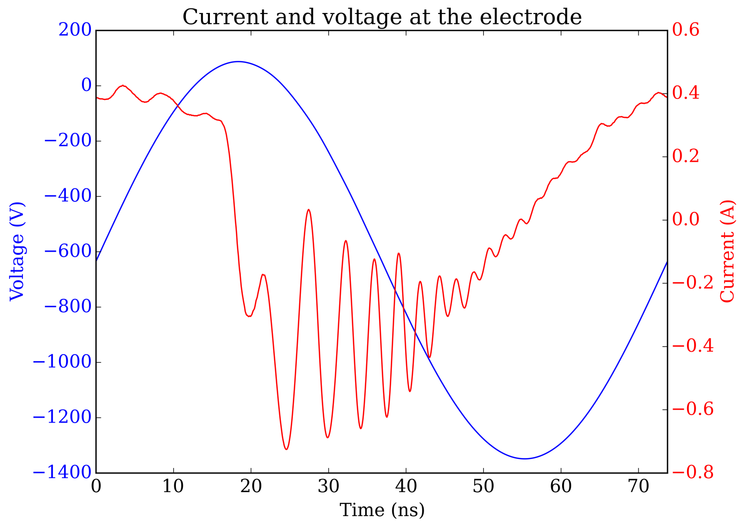


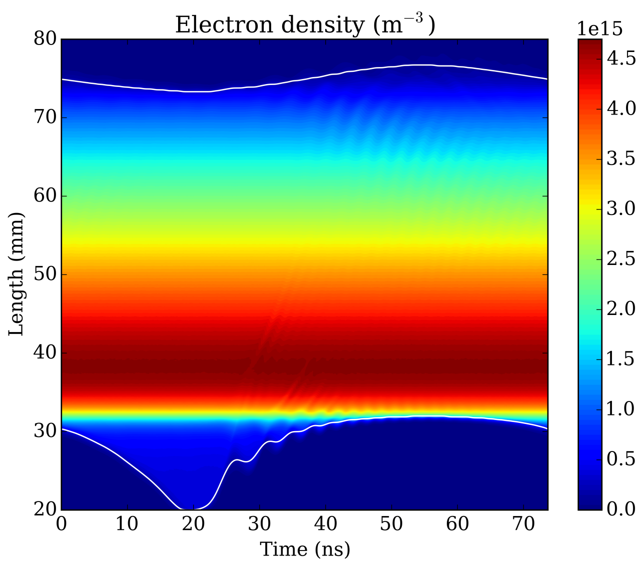


Spatio-temporal electron density

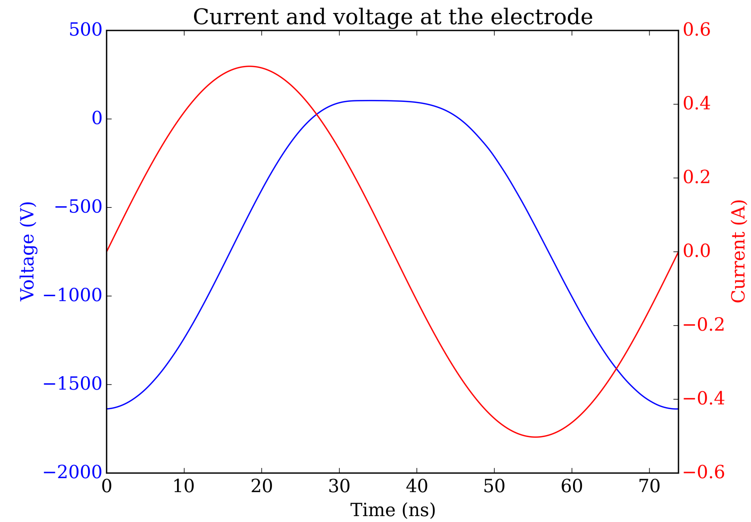
RUB

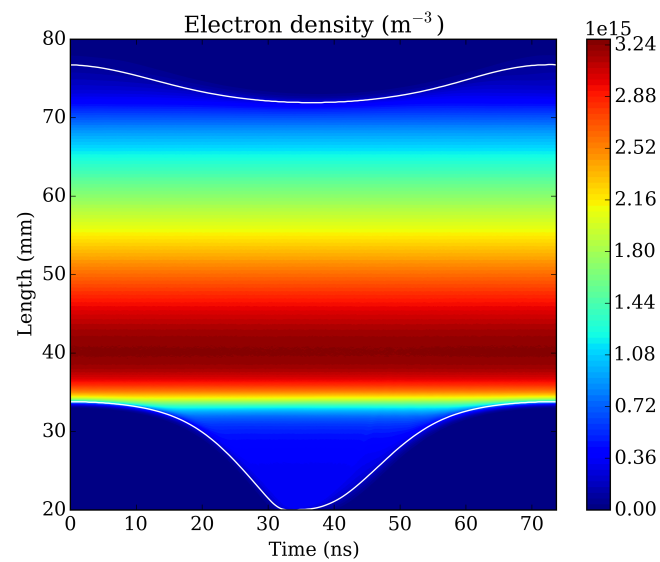
voltage source: 700 V





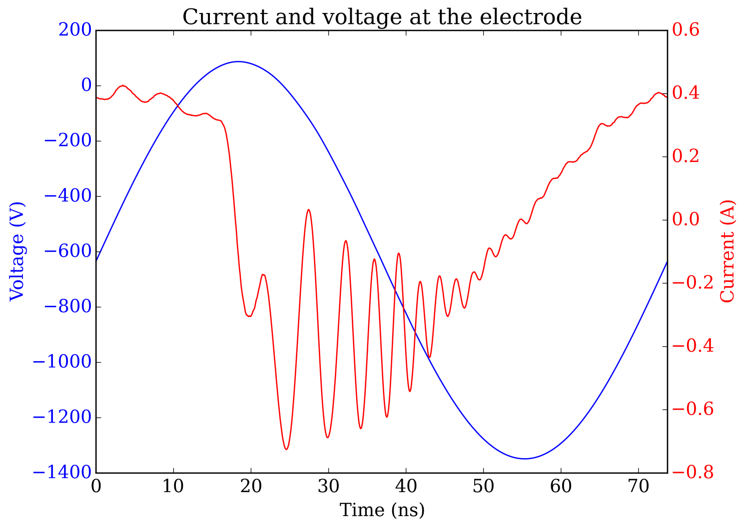
current source: 100 A/m^2

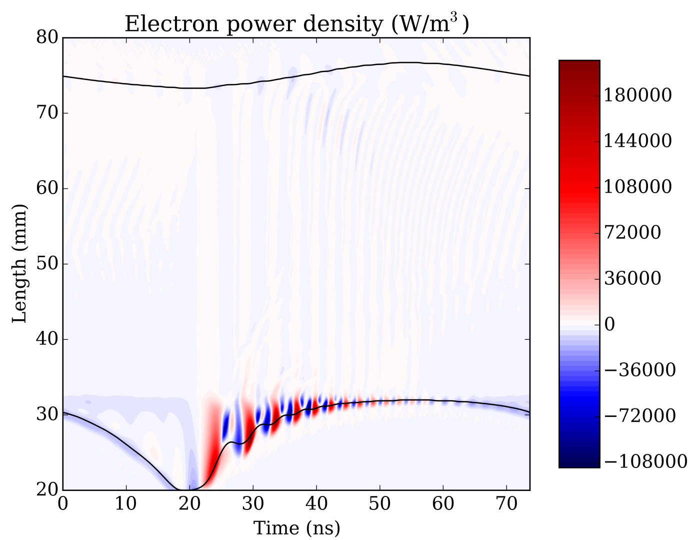




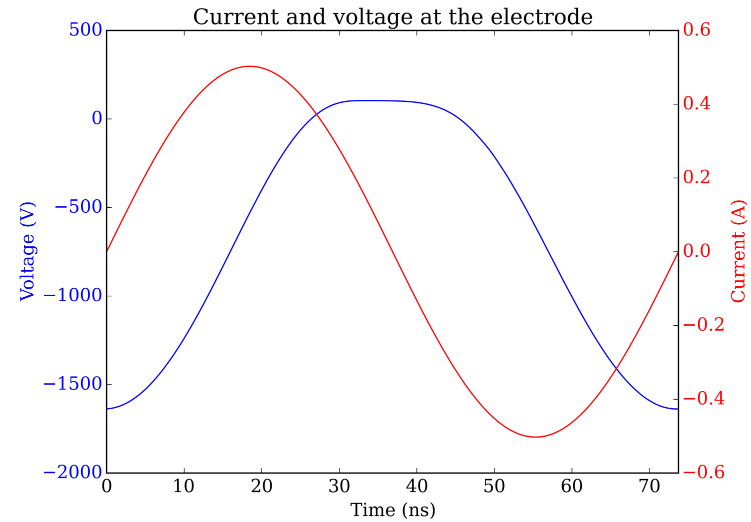
Spatio-temporal electron power density

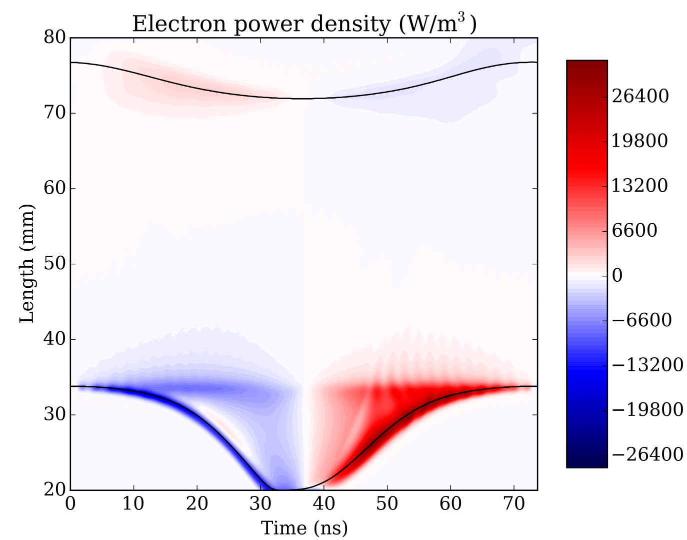
voltage source: 700 V





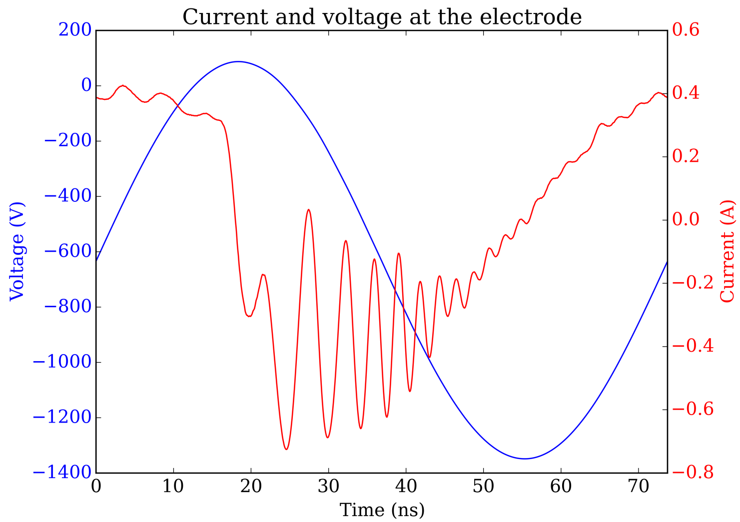
current source: 100 A/m^2

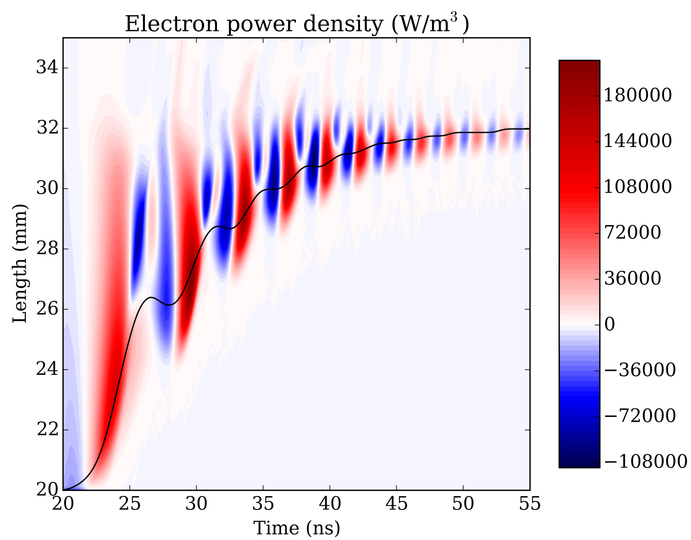




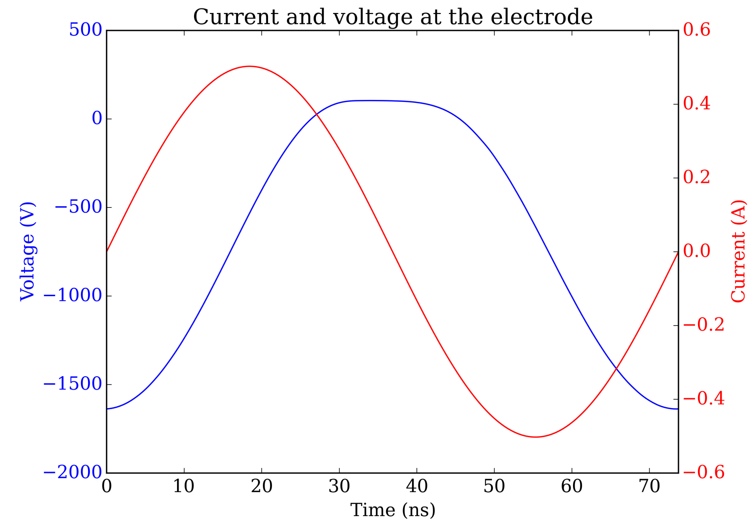
Spatio-temporal electron power density

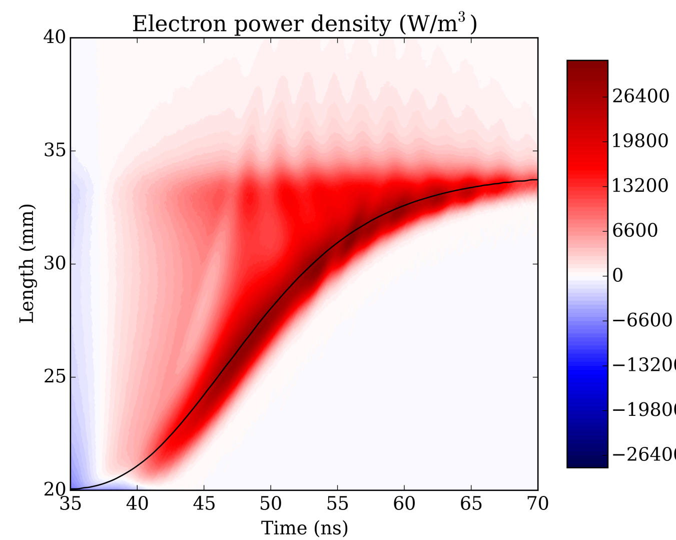
voltage source: 700 V





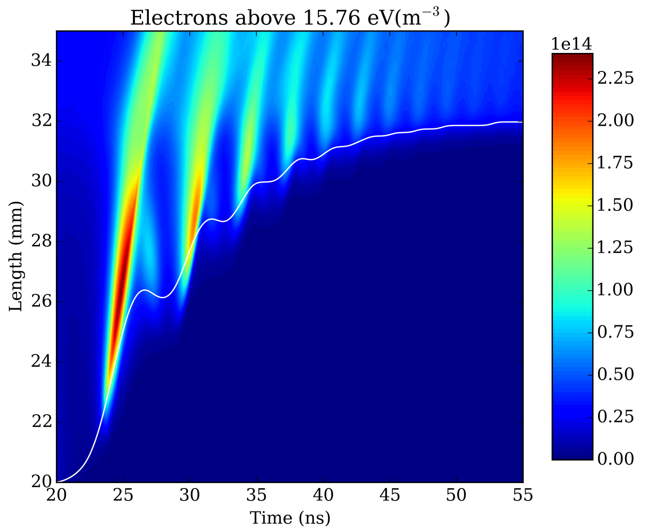
current source: 100 A/m^2

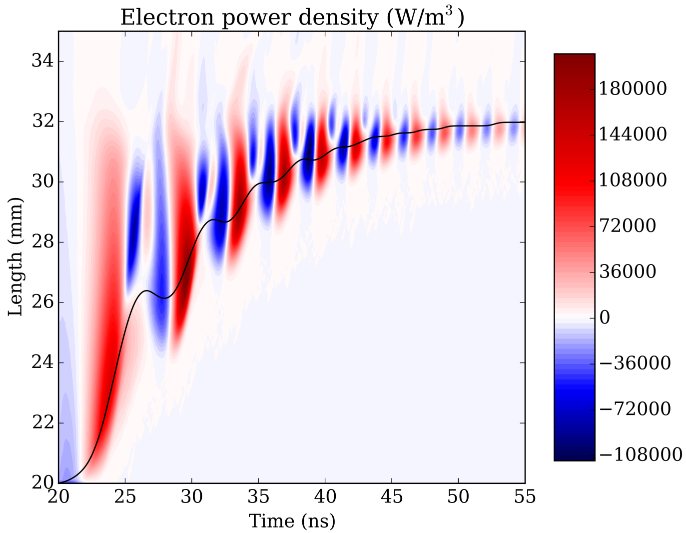




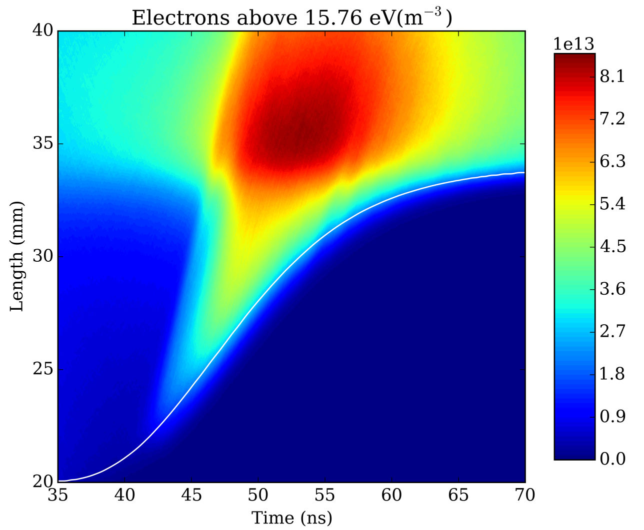
Fast electrons above 15.76 eV

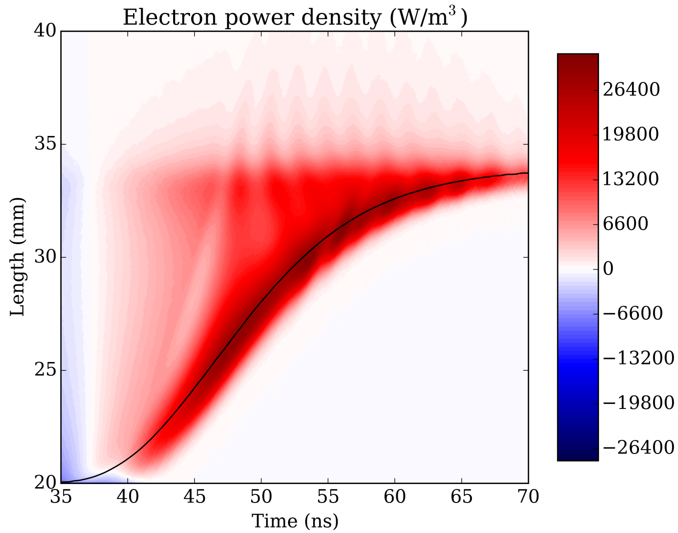
voltage source: 700 V





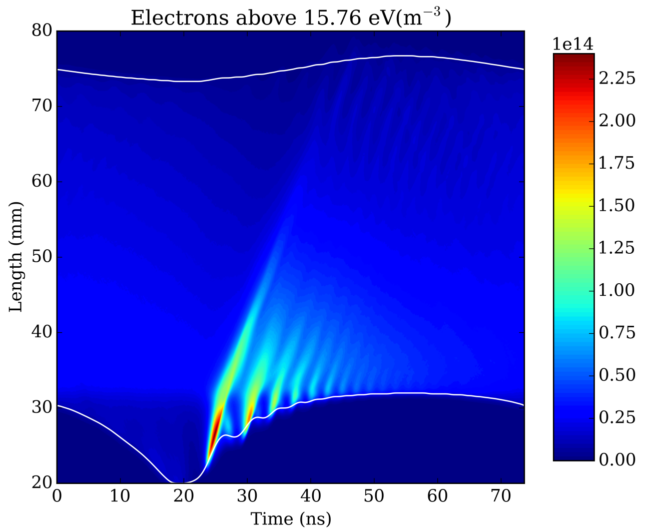
current source: 100 A/m^2

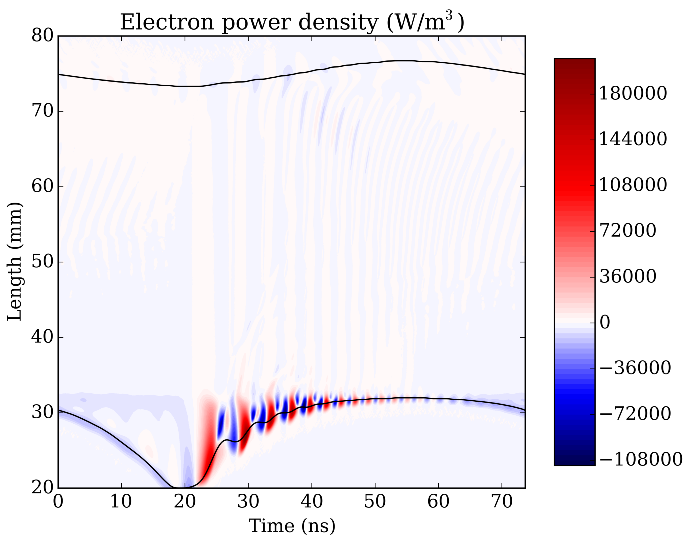




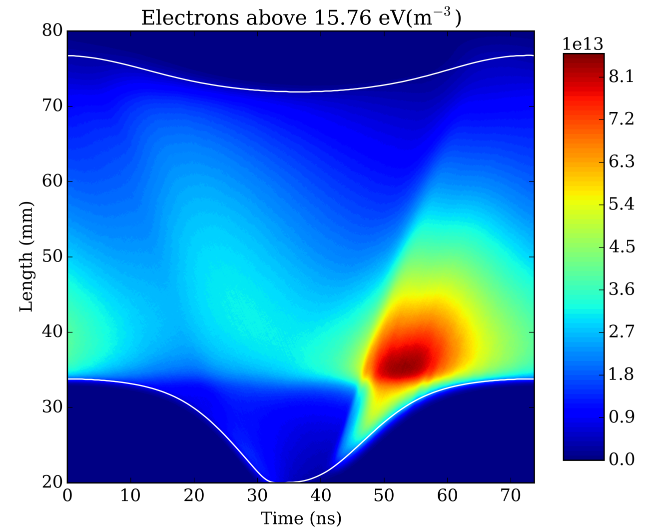
Fast electrons above 15.76 eV

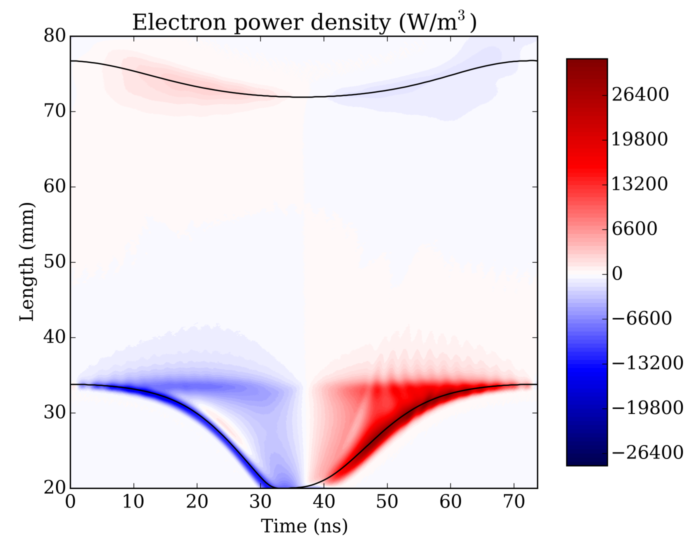
voltage source: 700 V





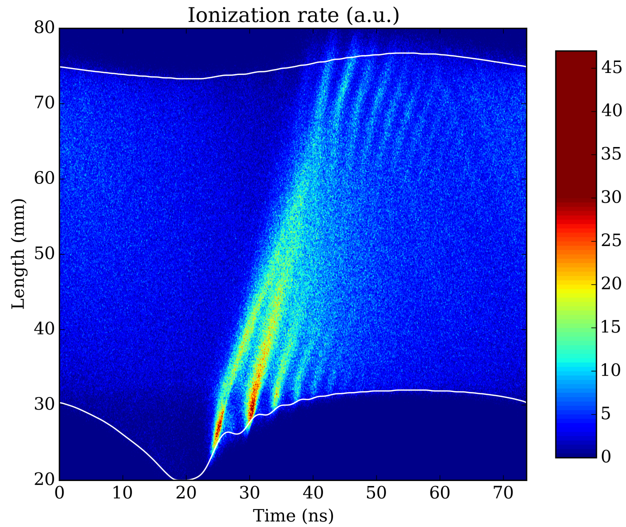
current source: 100 A/m^2

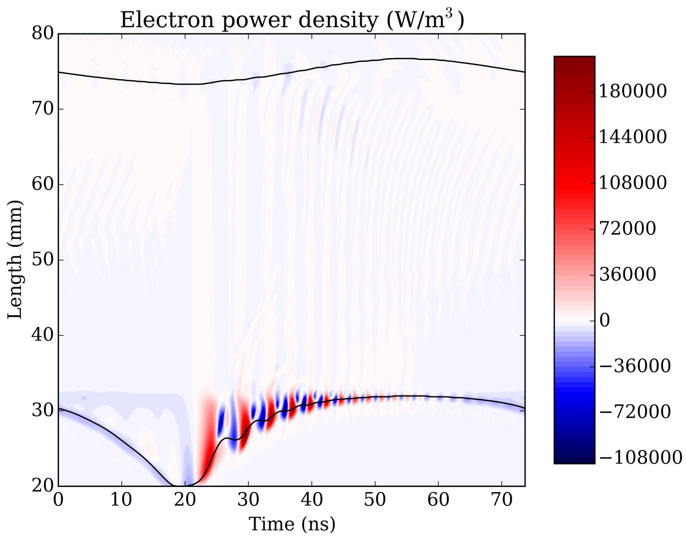




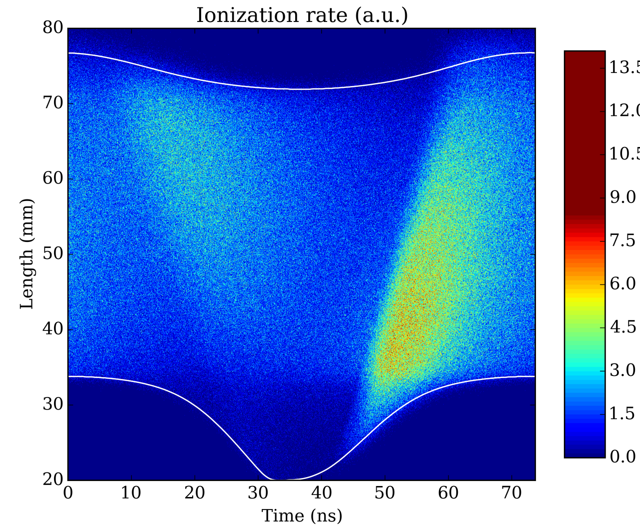
Ionization rate

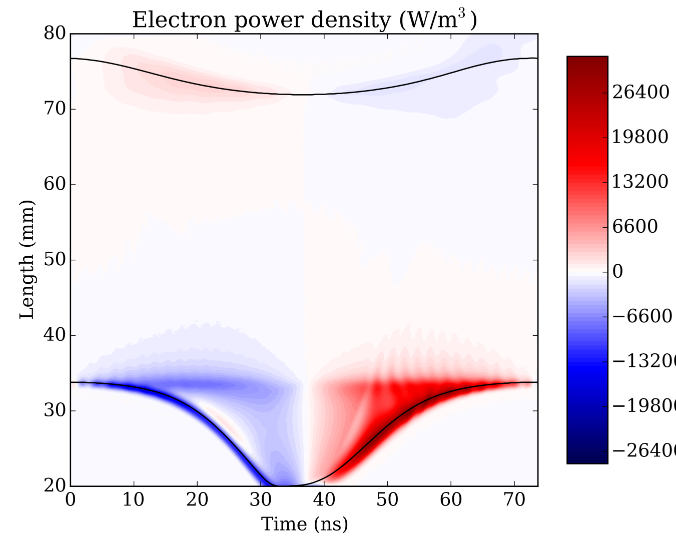
voltage source: 700 V





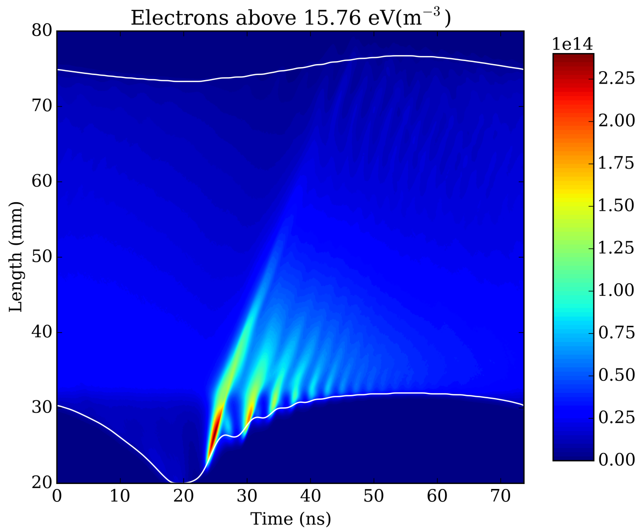
current source: 100 A/m^2

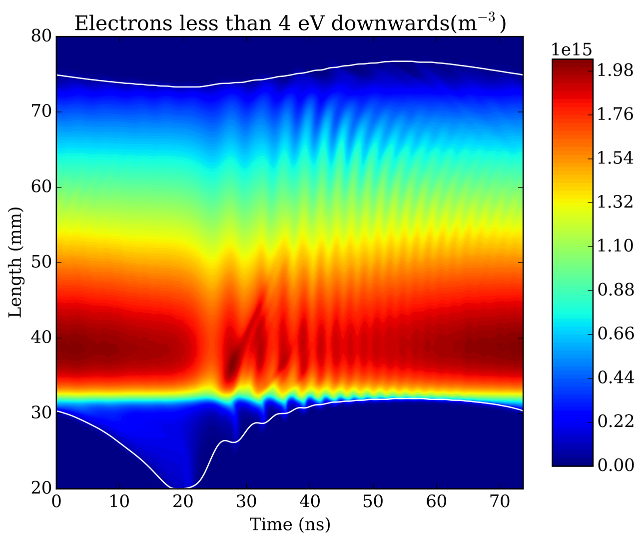




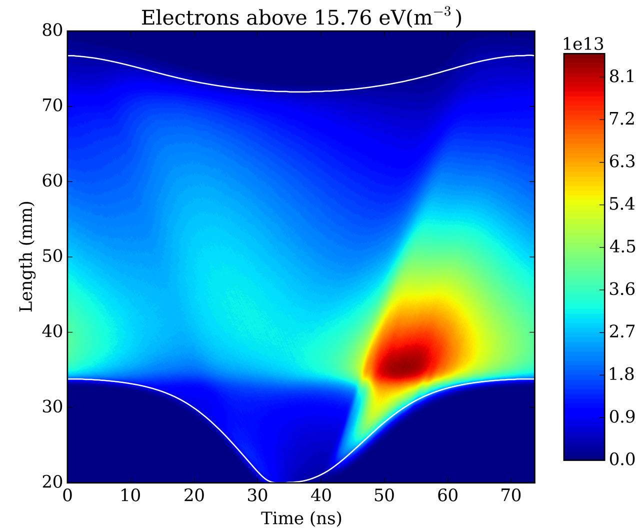
Beam electrons vs. bulk electrons

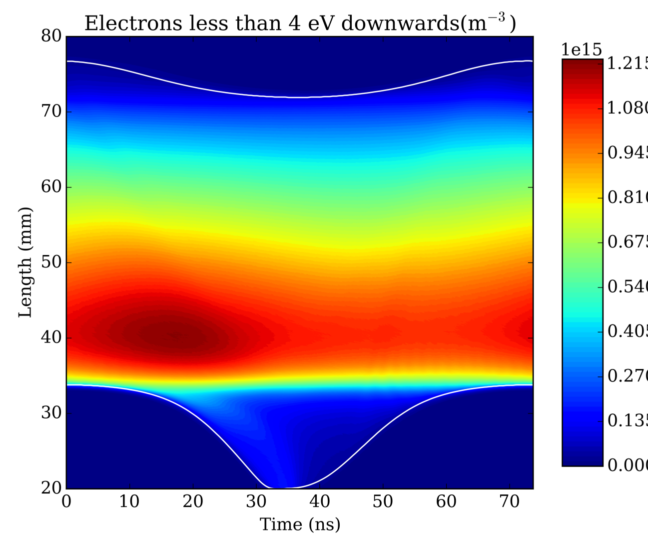
voltage source: 700 V





current source: 100 A/m^2

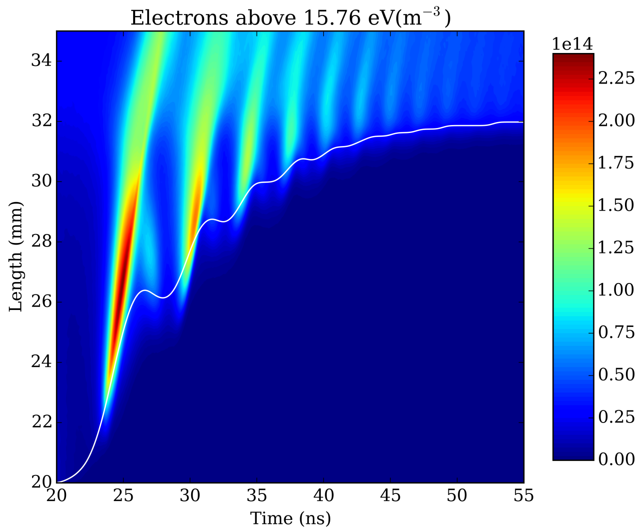


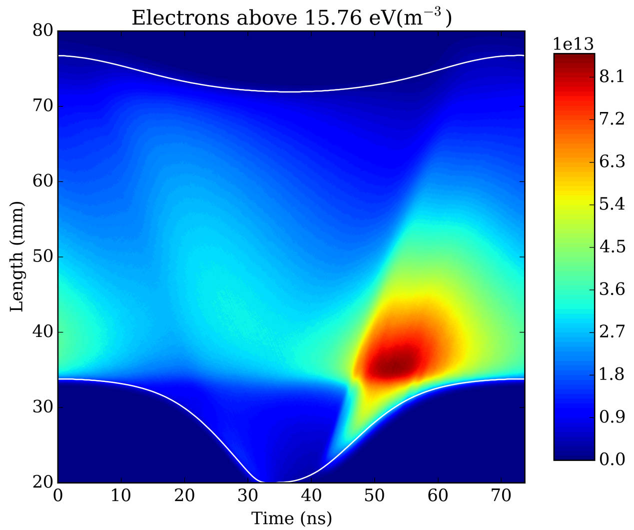


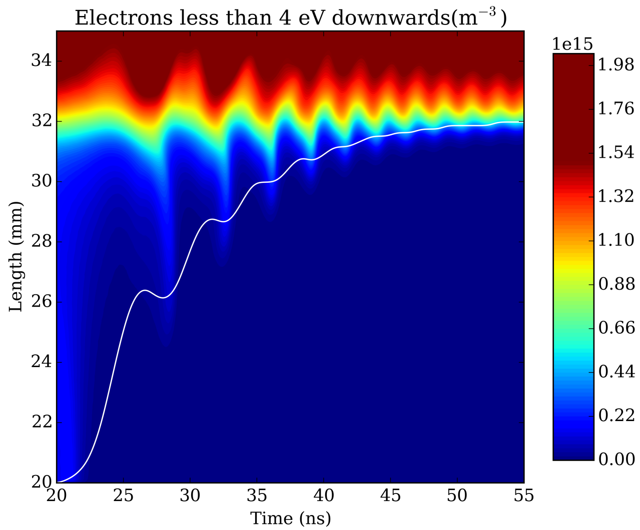
Beam electrons vs. bulk electrons

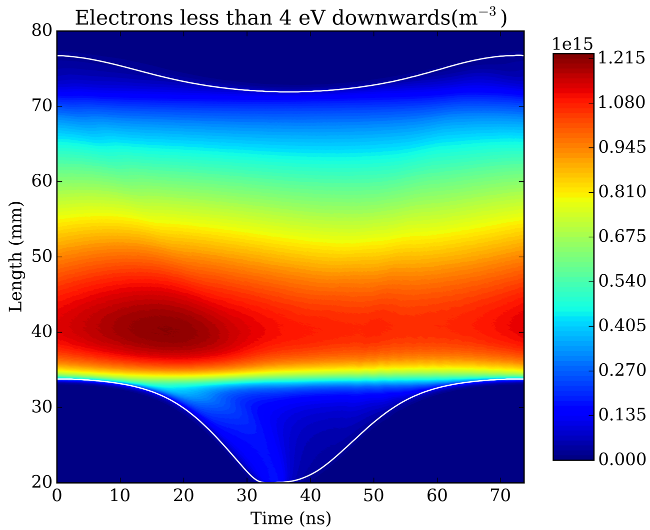
voltage source: 700 V

current source: 100 A/m^2









Conclusion

- significant differences of current and voltage driven discharges
- different power distribution of the absorbed electron and ion power
- voltage sources represent the correct physics of asymmetric ccrf discharges
- nonlinear electron resonance heating plays a crucial role for the ionization process in voltage driven systems
- electron beam excites the bulk electrons which are attracted back to the sheath[2]
- nonlinear interaction with the plasma sheath leads to multiple electron beams and the generation of harmonics in the current

Outlook:

- even in symmetric discharges significant differences occur, especially at low pressures ($\approx$1 Pa)

[2] Wilczek et al., Phys. Plasmas. 23, 063514 (2016)