Dynamics of the breakdown of the discharge gap at high overvoltage

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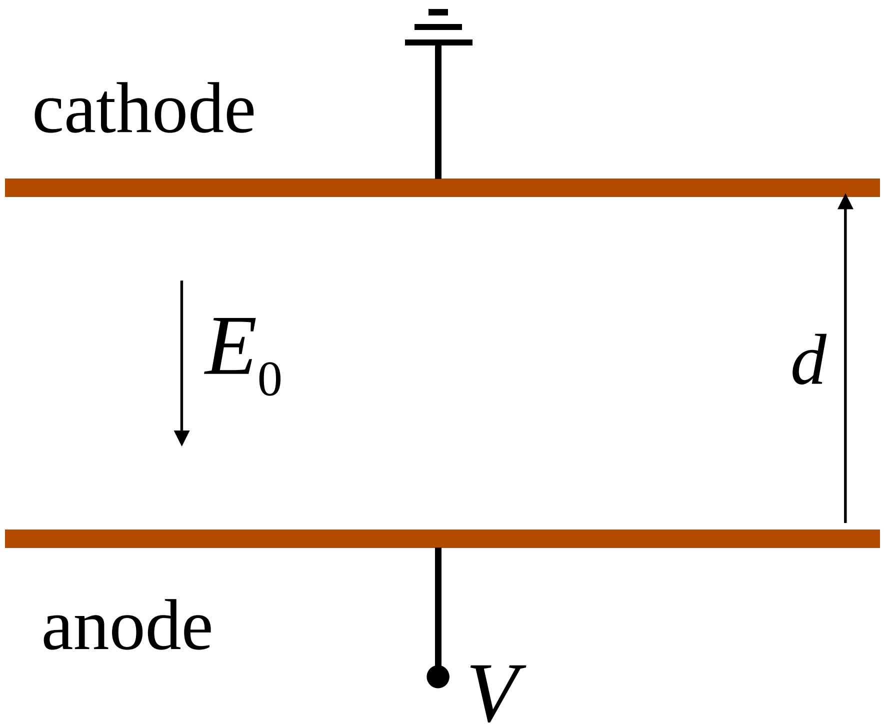
ABSTRACT

The dynamics of the breakdown of the discharge in a gap between two plane electrodes at high over-voltage is studied via 3D Monte Carlo/PIC kinetic simulations. In these simulations, the negative and positive macroparticles represent exactly their physical counterparts (which cannot in principle be attained in 1- or 2-D Monte-Carlo simulations, since macroparticles there are planes or rods rather than point particles). The breakdown is initiated by a single seed electron, and then an ionization region formed at the anode spreads toward the cathode. The velocity of this spreading (as well as the ionization region structure) at different voltages applied to the gap is compared with those predicted by the 1D analytical theory. Such realistic simulations allow the elucidation of the role of fluctuations in microdischarges, when the gap width is small and the number of particles is relatively low.

Geometry, parameters, and assumptions



- Pure Neon gas
- Pressure p=500 Torr
- Gap Length d=100–800 μm

  i.e. pd = 5–40Torr cm
- Initial voltage across the gap is much larger than the breakdown voltage

$$\alpha d >> \ln\left(\frac{1}{\gamma_{\text{ion}}}+1\right)$$

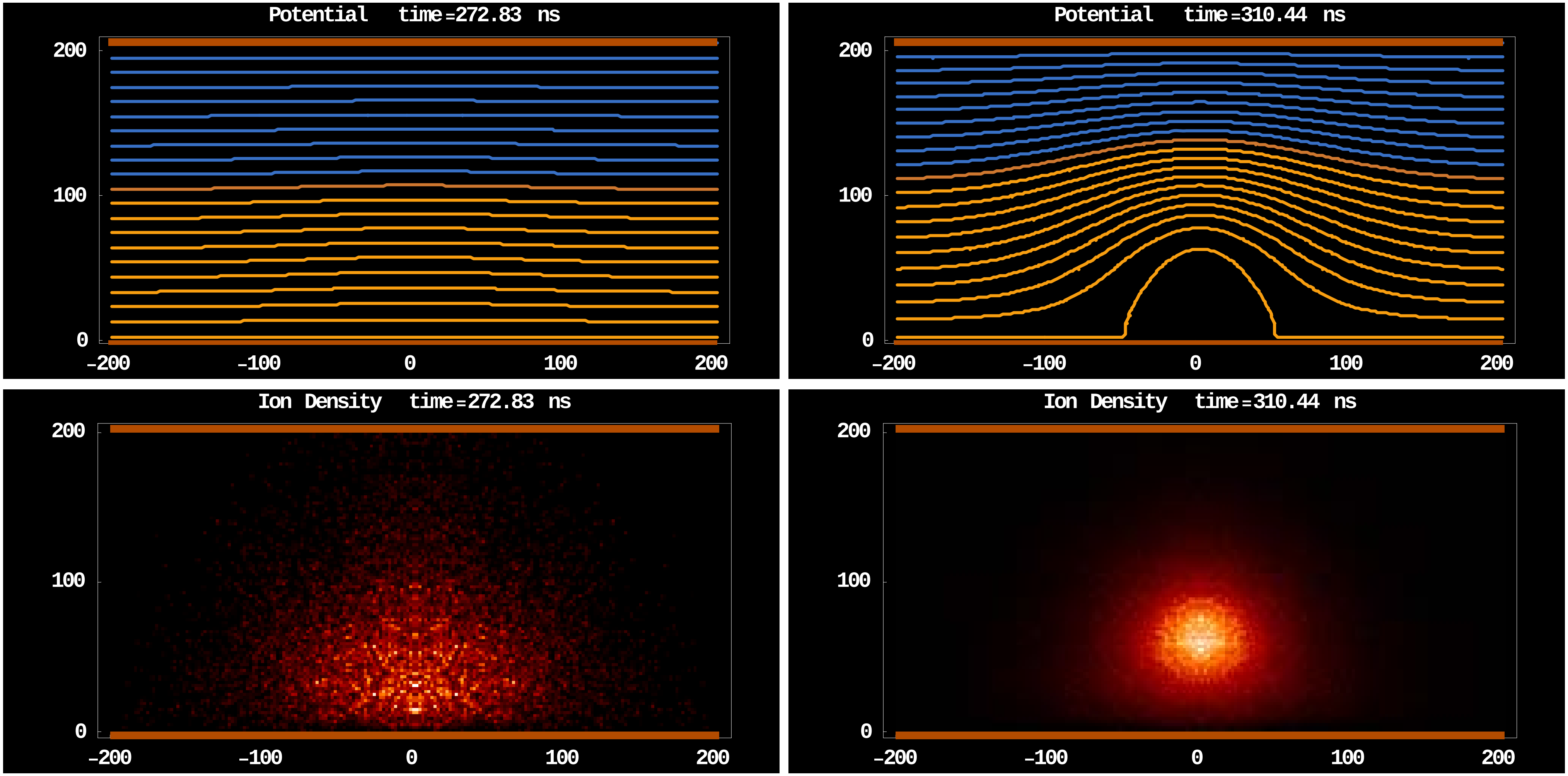
- Secondary electron emission coefficient due to ions γ_{ion} = 0.64
- No photoemission from the cathode

*Cross-sections were taken from SIGLO DataBase `http://www.siglo-kinema.com/database/xsect/siglo.sec'.

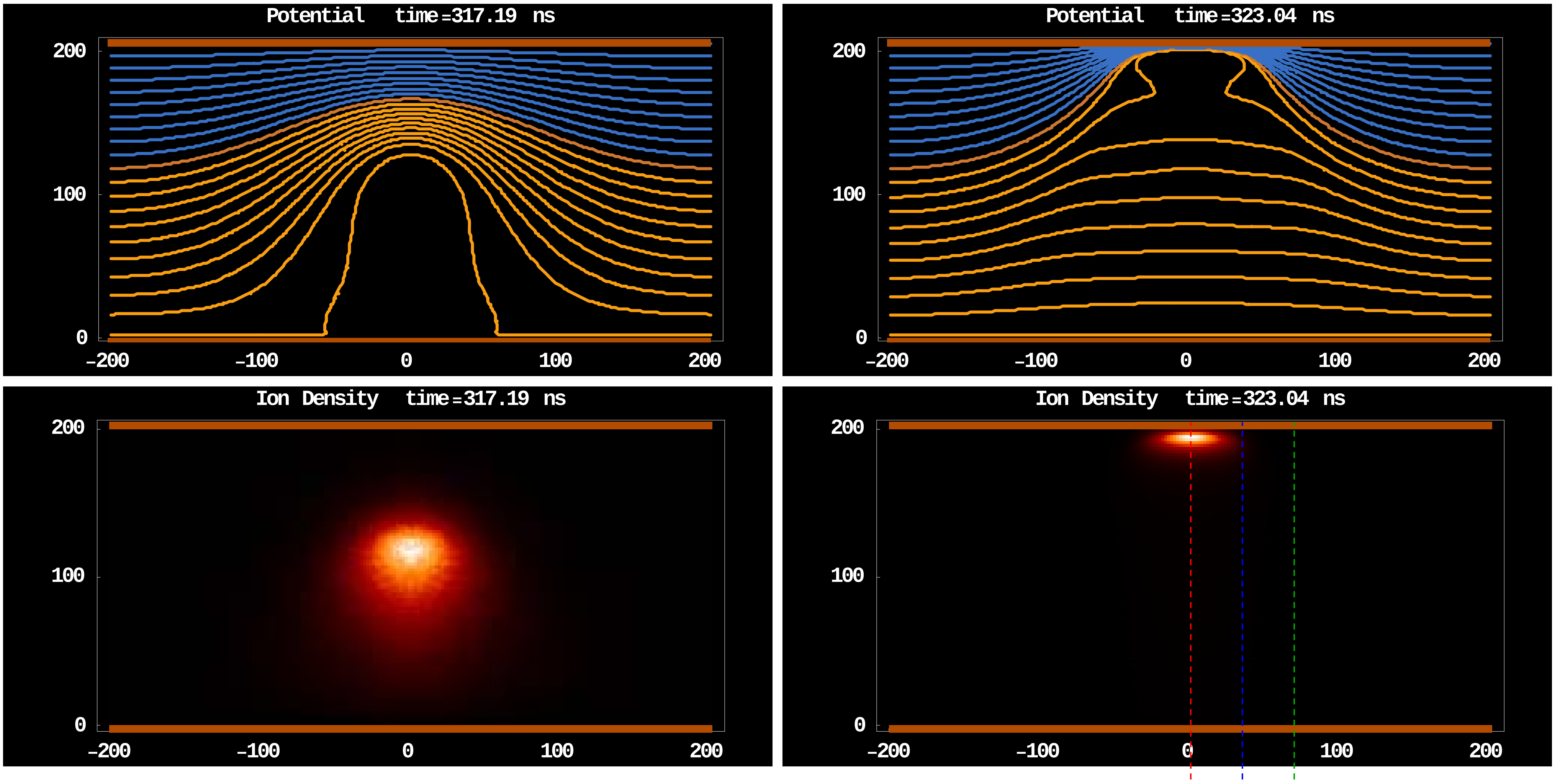
Features of MC/PIC code

- One ion/electron is represented by just ONE macroparticle!
- Total of up to 250 million of ions and electrons are tracked on a up to 64 processors (on Linux clusters at the Ohio Supercomputer Center)
- Up to 150x150x150 meshes are used
- FFT method is used for solution of Poisson equation

Gap Length 200μm, Voltage 400V

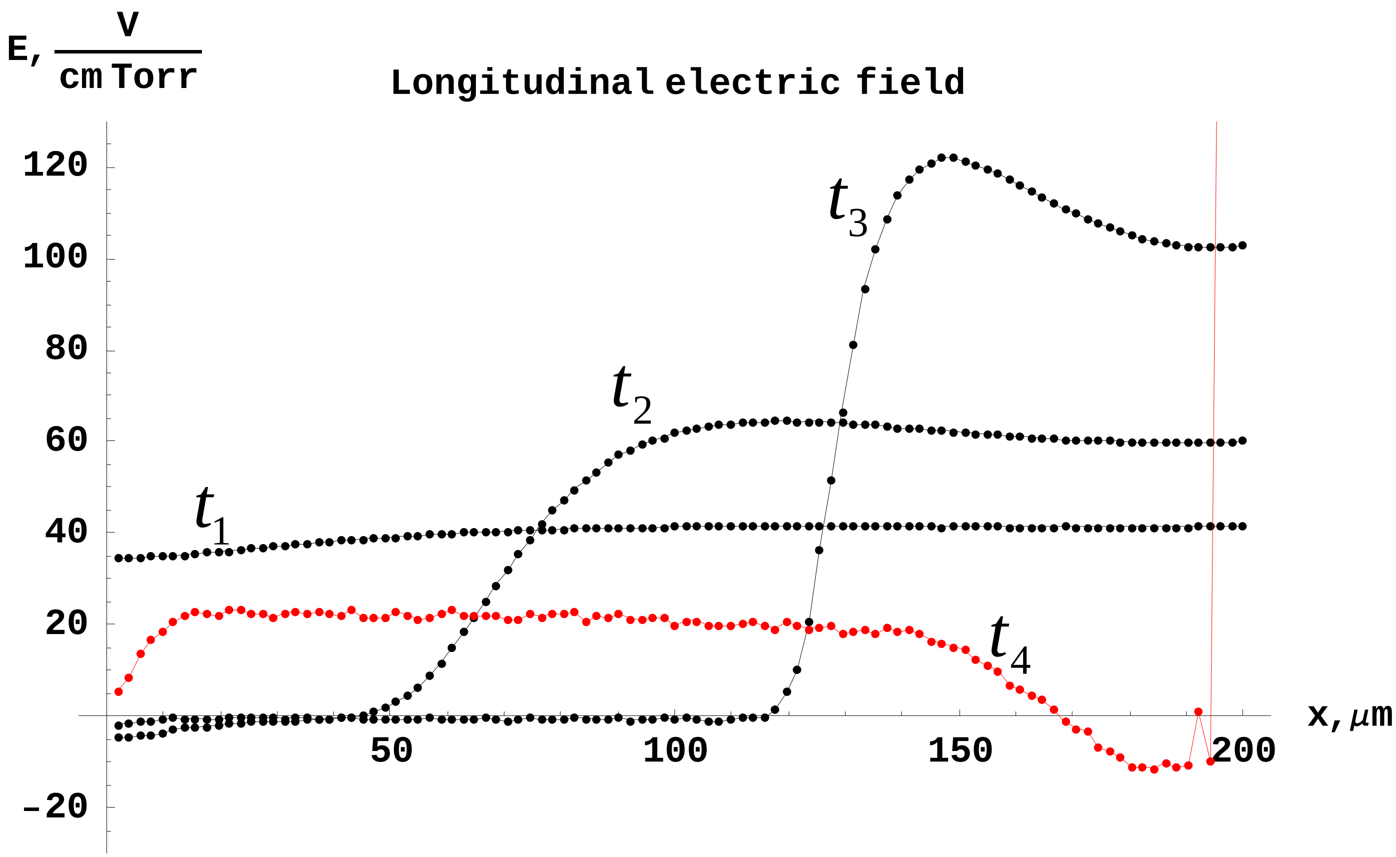


Gap Length 200μm, Voltage 400V



Longitudinal uniformization of plasma trail

When ionizing wave approaches the cathode and the cathode fall starts to form, the electric field in the plasma trail becomes uniform

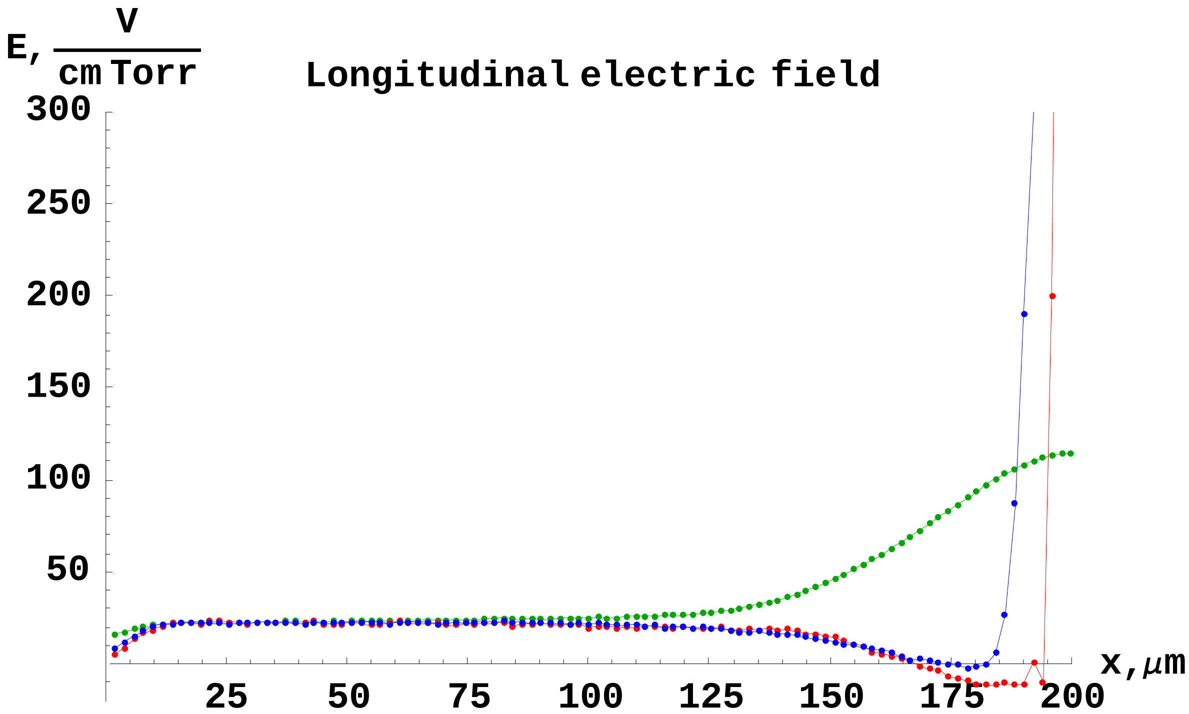


Longitudinal electric field along the midline of the discharge at time moments

t_1=272.83ns, t_2=310.44ns, t_3=317.19ns, t_4=323.04ns

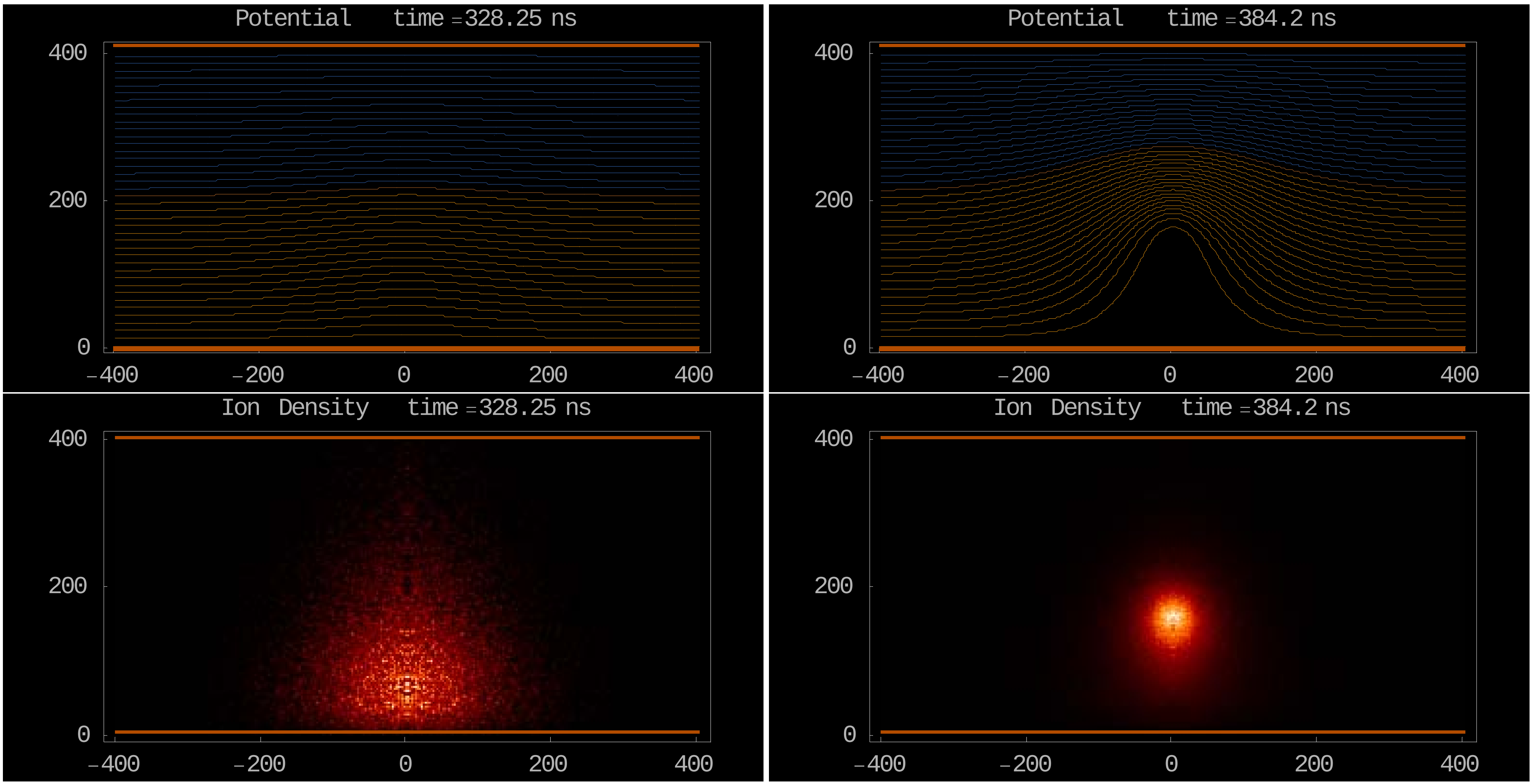
Transverse uniformization of plasma trail

Electric field in the plasma trail becomes uniform also in the transverse direction

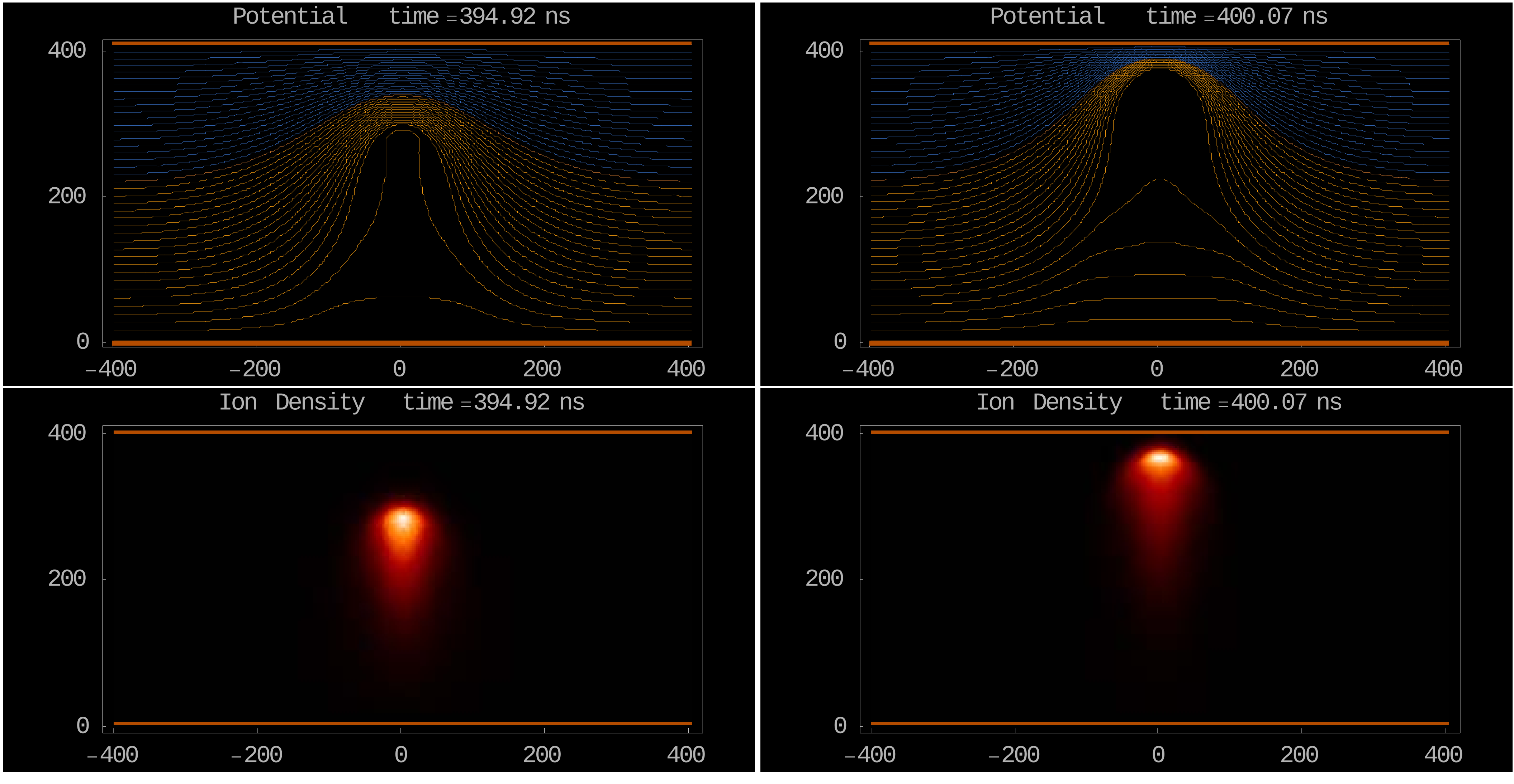


Longitudinal electric field along the midline (red), 40um (blue) off the midline , and 80um (green) off the midline

Gap Length 400μm, Voltage 600V



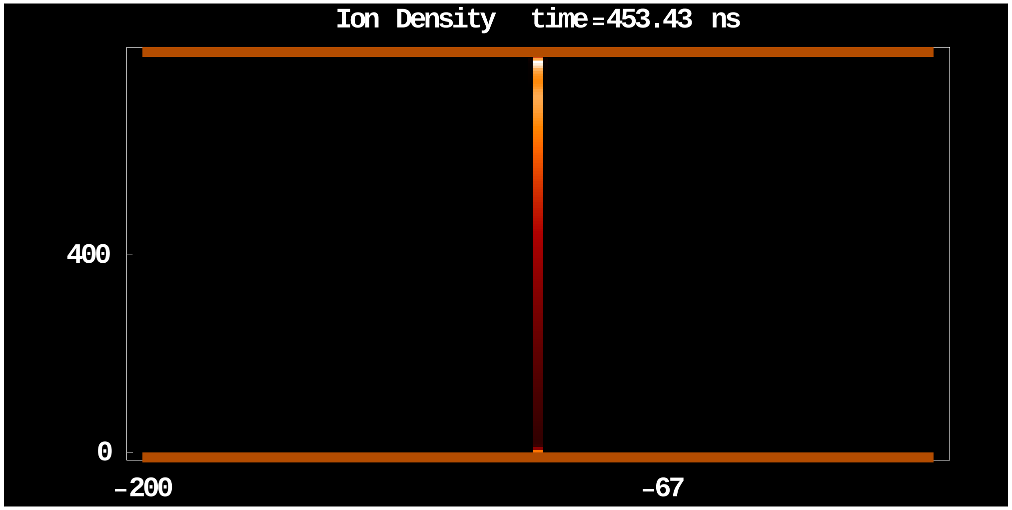
Gap Length 400μm, Voltage 600V

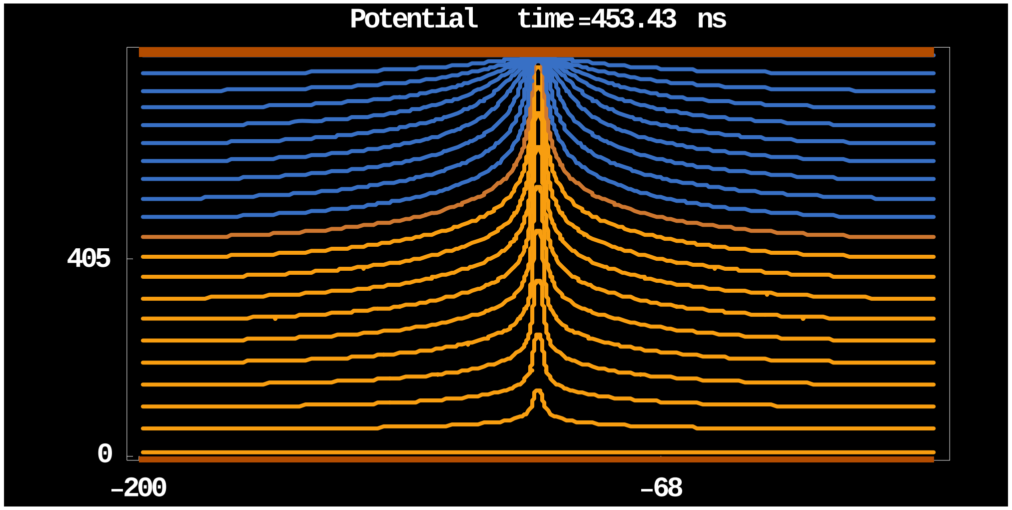


Size of Ionizing Wave

•Longitudinal size of the ionizing wave is determined by the ionization coefficient

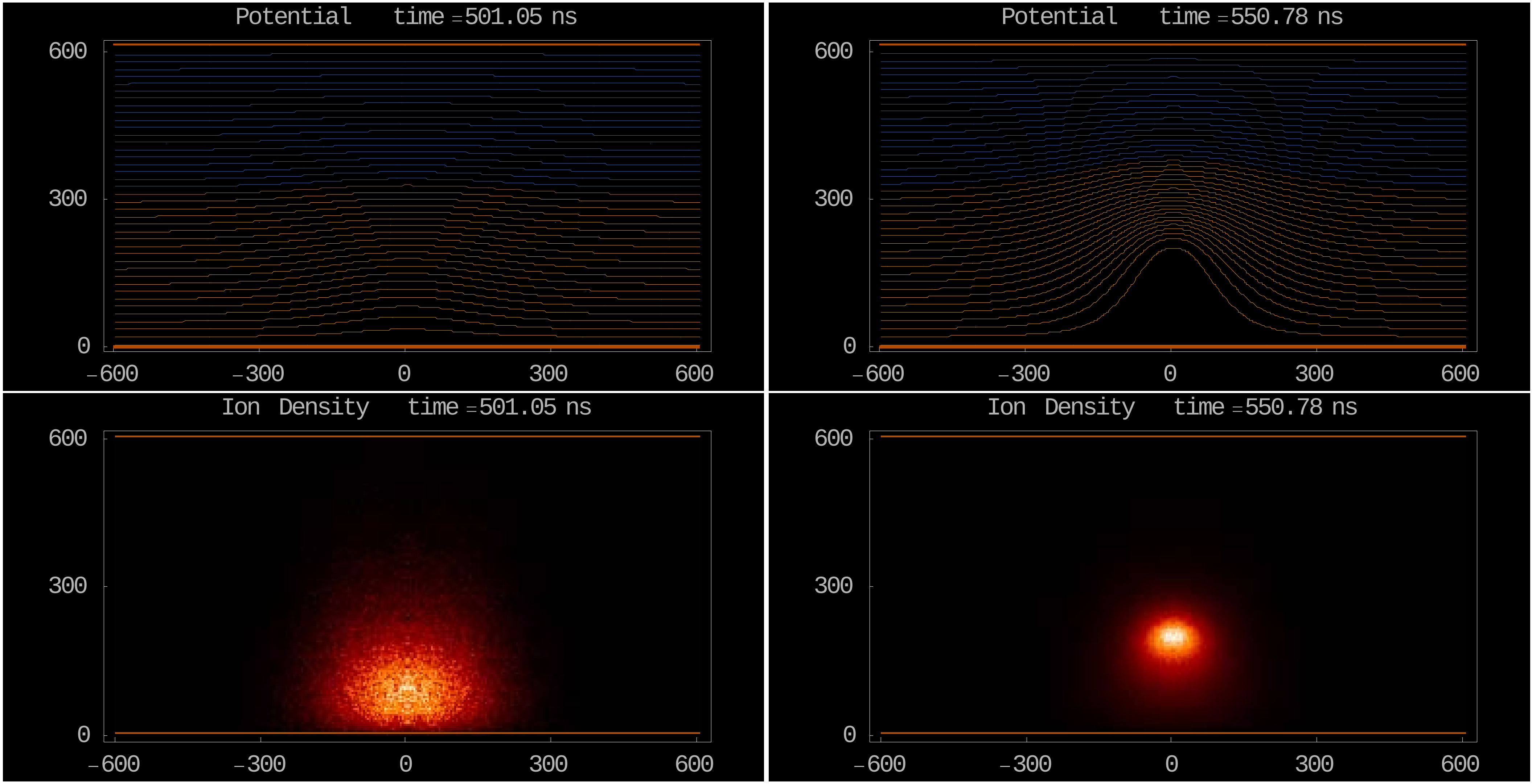
• Transversal size is controlled by the electron diffusion, since in the case of zero electron diffusion coefficient the transversal wave size reduces to zero (as seen from the presented figures)



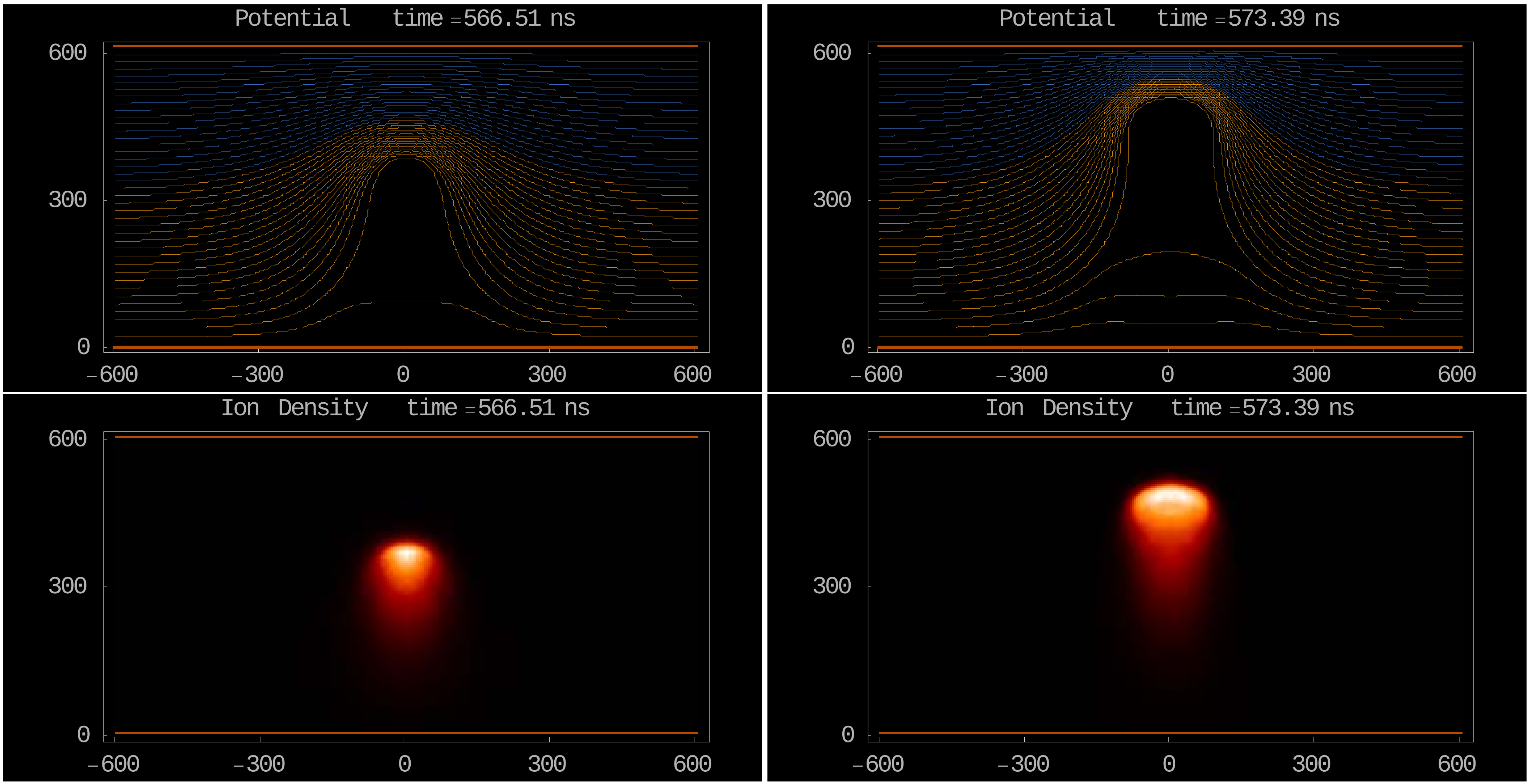


Case Te=0

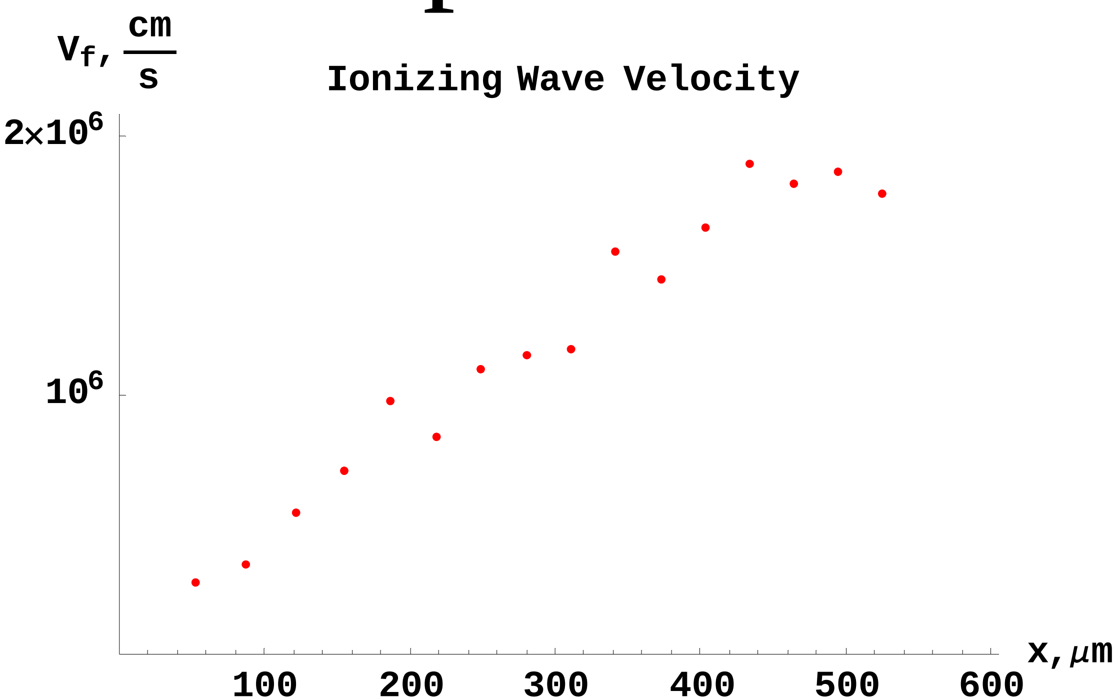
Gap Length 600μm, Voltage 800V



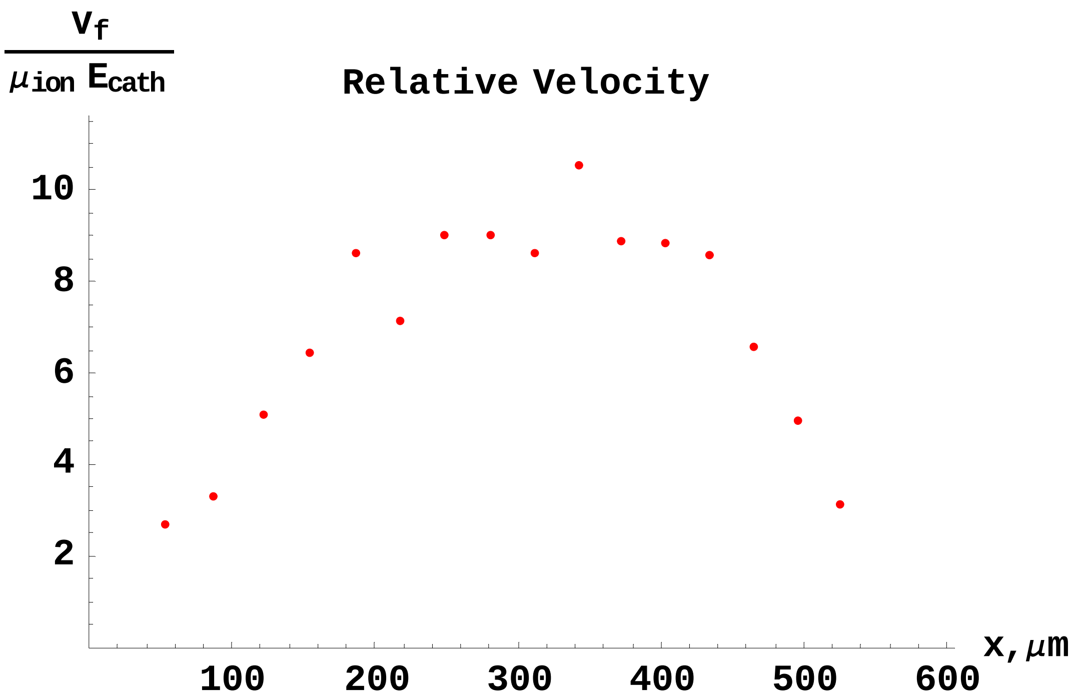
Gap Length 600μm, Voltage 800V



Speed of Ionizing Wave

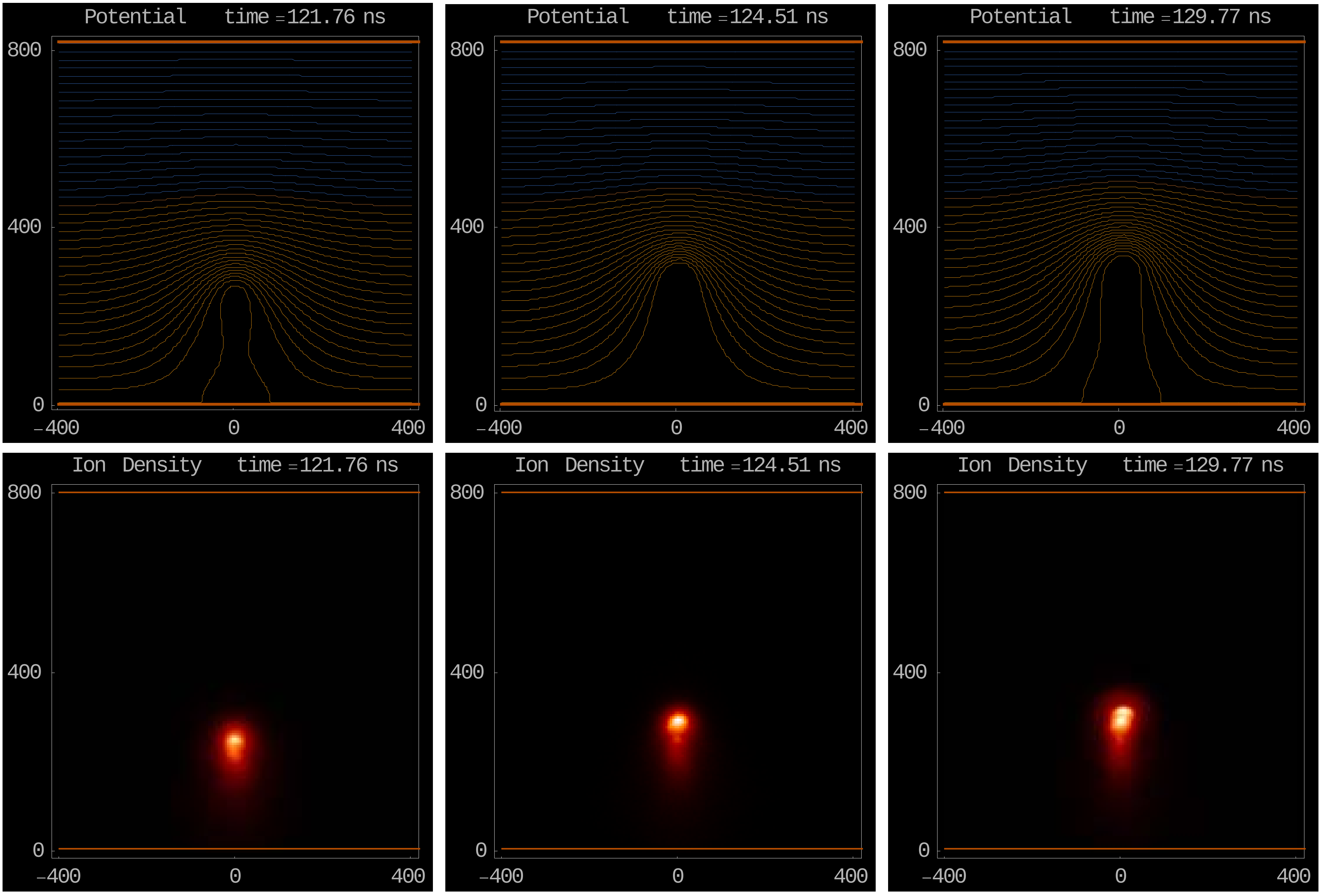


Wave velocity increases as it moves toward the cathode

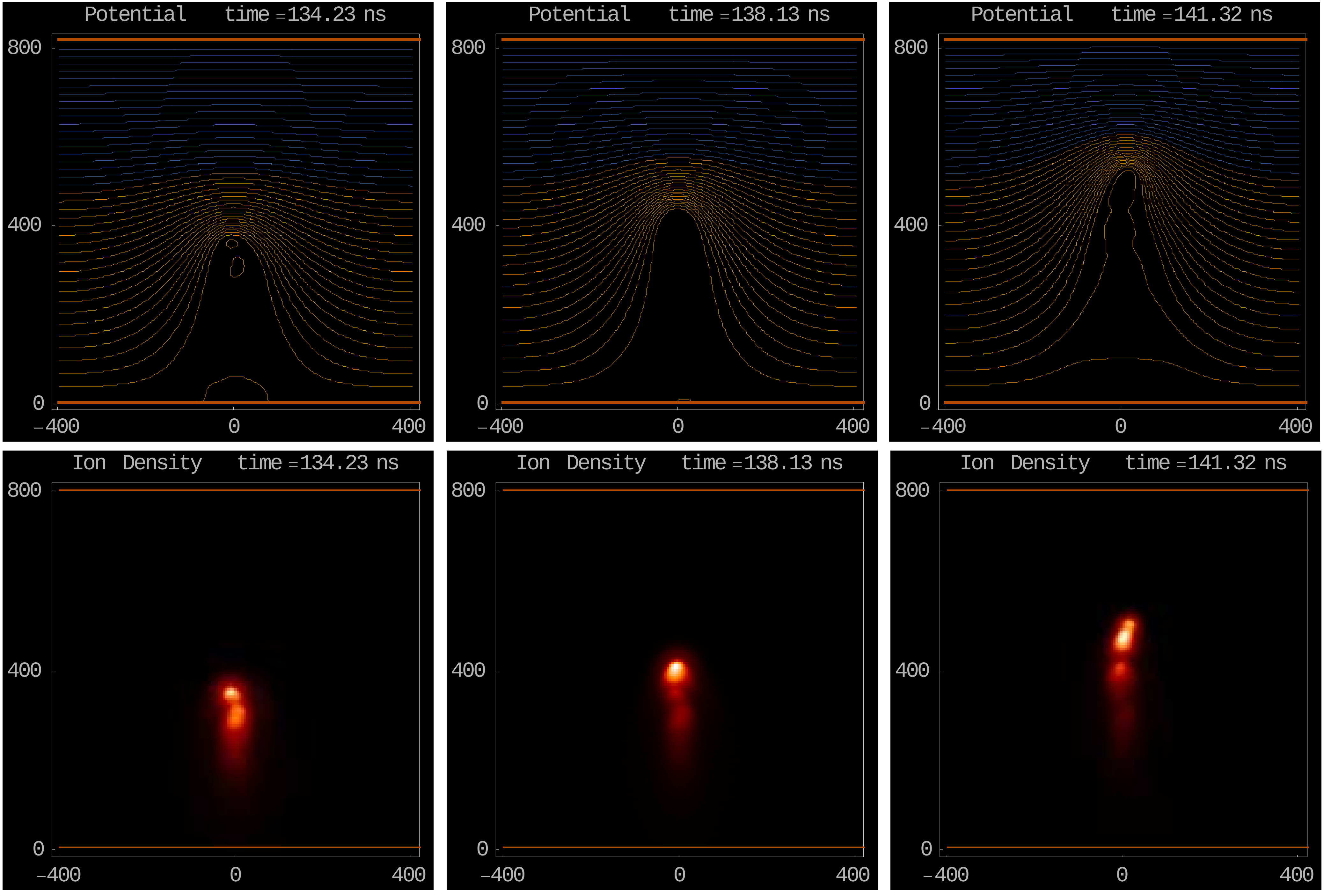


Relative wave velocity normalized to the ion velocity at the cathode goes through a maximum

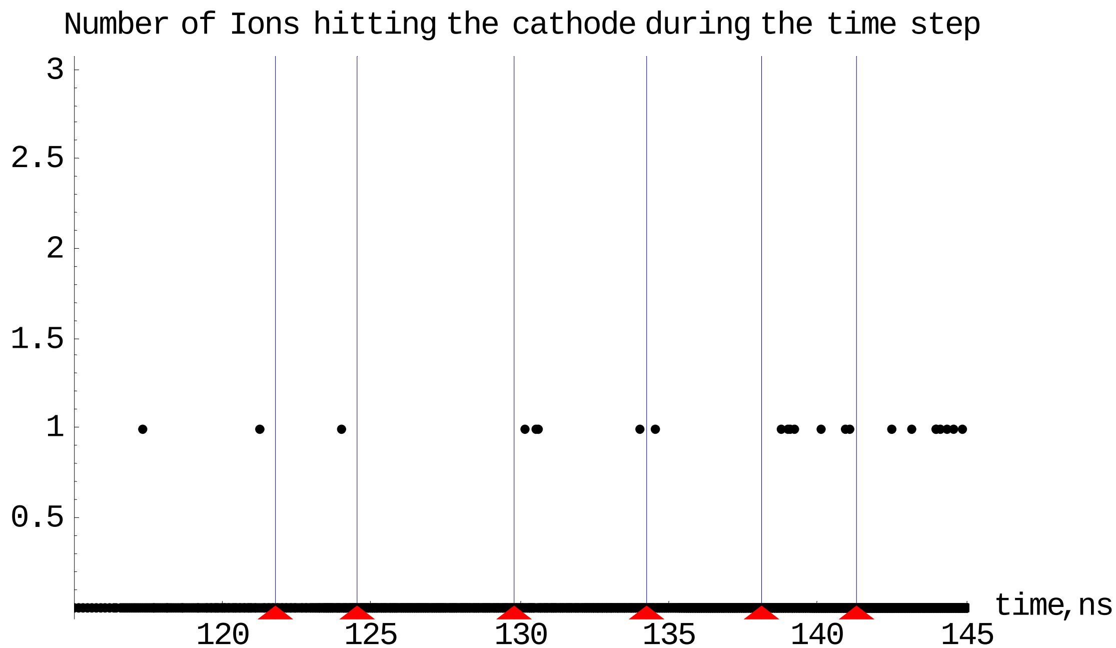
Gap Length 800mm, Voltage 1200V

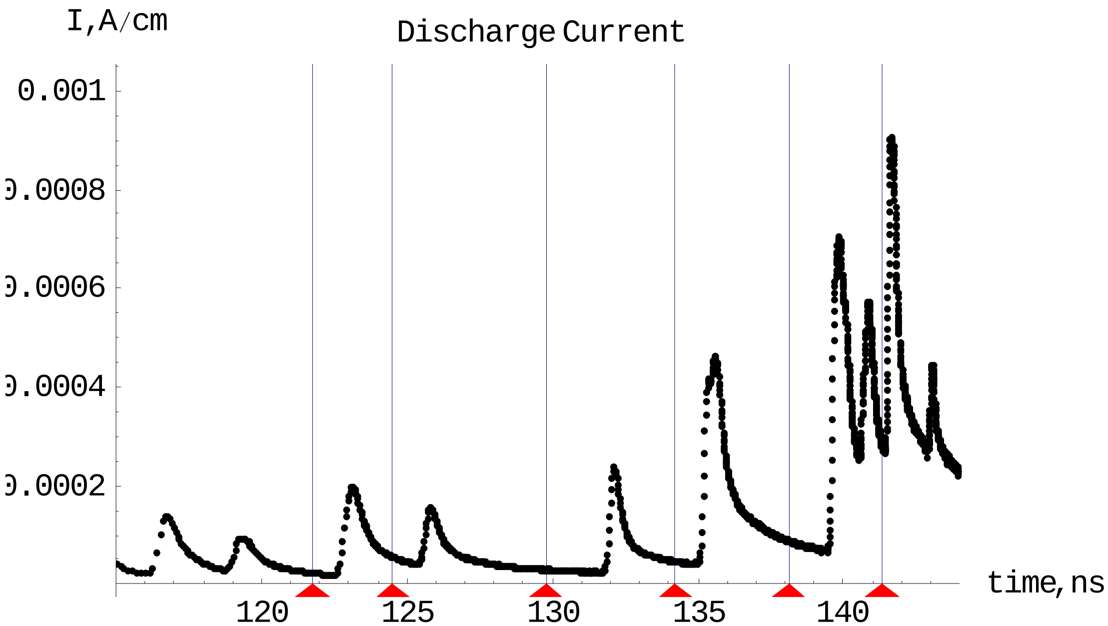


Gap Length 800mm, Voltage 1200V



Erratic ionizing wave movement at high avalanche multiplication





- Erratic movement of the ionizing wave corresponds to individual ions hitting the cathode

CONCLUSION

- Uniformization of the plasma trail is similar to 1D case
- Longitudinal size of the ionizing wave is controlled by the ionization coefficient and is proportional to α^{-1},while the transverse size is controlled by the electron diffusion
- While the ionizing wave moves toward the cathode, its velocity increases. The relative velocity (to the ion velocity at the cathode) may experience maximum if the initial electric field in the gap corresponds to the right branch of the Paschen curve
- When the charge charge produced by an avalanche originated by just a single electron emitted from the cathode is comparable with the charge at the tip of the ionizing wave, its front moves erratically