2D Arc-PIC
Simulating arc ignition

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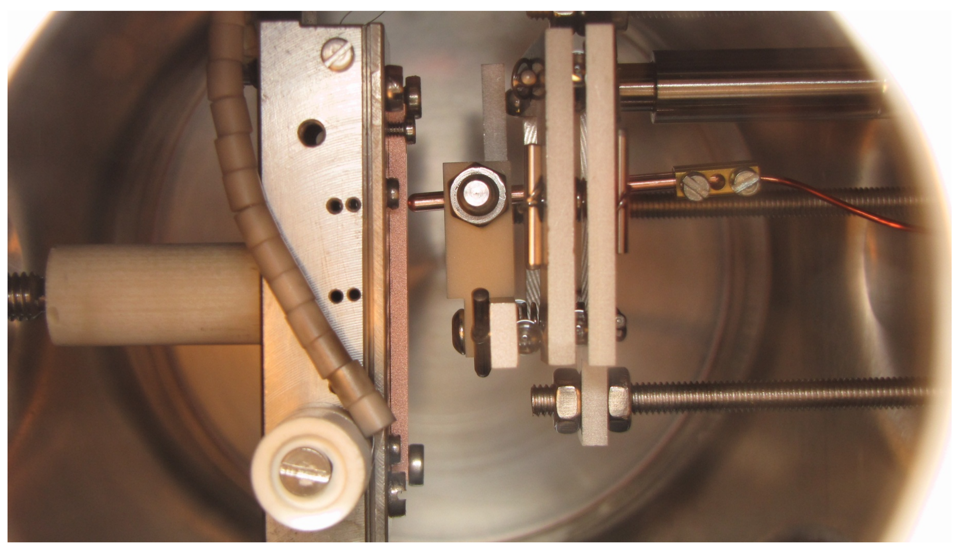
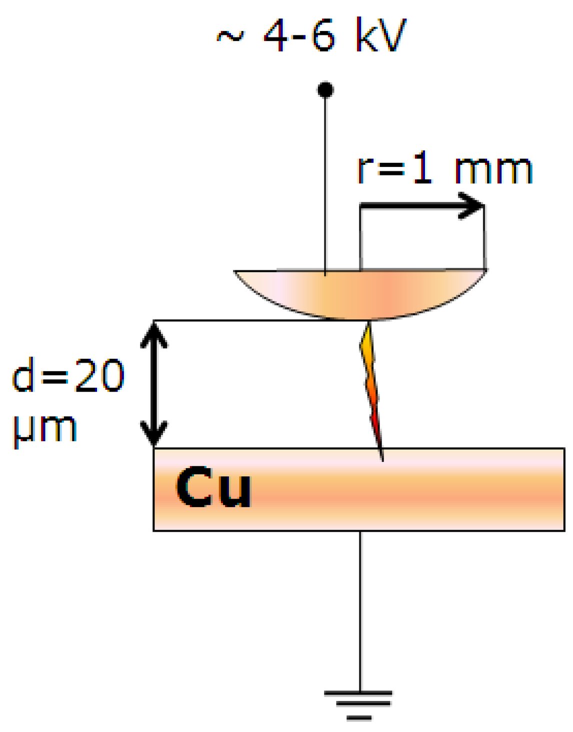
Introduction

Vacuum breakdowns significantly limit the achievable performance of future linear particle accelerators. Within the CLIC project we co-ordinate experimental and theoretical studies, in order to gain better insight into the physics of vacuum arcs.

The DC Spark experiments at CERN have been set up to closely mimic the conditions in RF accelerating structures, to provide a manageable platform for studying breakdown physics. With the 2D Arc-PIC code, we aim to model the breakdown process in the DC Spark experiments, the formation of plasma and the ignition of a vacuum arc, based on first principles.



The DC spark setup at CERN explores the properties of vacuum arcs in well-defined conditions.



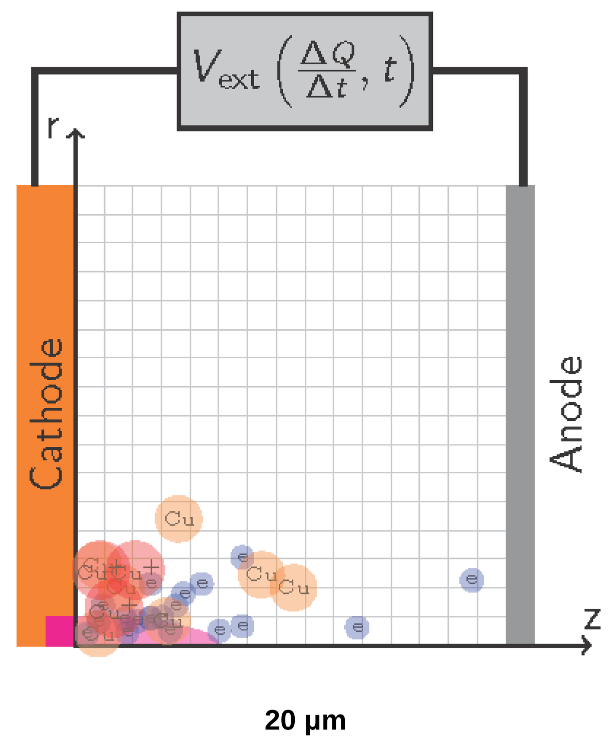
Breakdown simulations

Our simulation tool is a 2d3v electrostatic PIC code, originally developed by Helga Timkó, with implemented Monte Carlo collisions. We simulate the early stage of plasma build-up in a DC discharge between two planar copper electrodes. Three particle species are taken into account: e^-, Cu, and Cu^+.

Electrons are injected into the vacuum according to the Fowler-Nordheim model of field emission, from an emitter area on the cathode with an electric field enhancement factor β. Copper atoms are injected from the same area, as a fraction of the electron emission. In addition, sputtering and heat spike sputtering by high-energy copper atoms and ions releases Cu from both anode and cathode. Ions are produced only through impact:

$e^- + Cu \rightarrow 2\, e^- + Cu^+$.

The system is coupled to an external current circuit. The potential is stored in a capacitor, whose charge is drained by the arc current during the simulation.



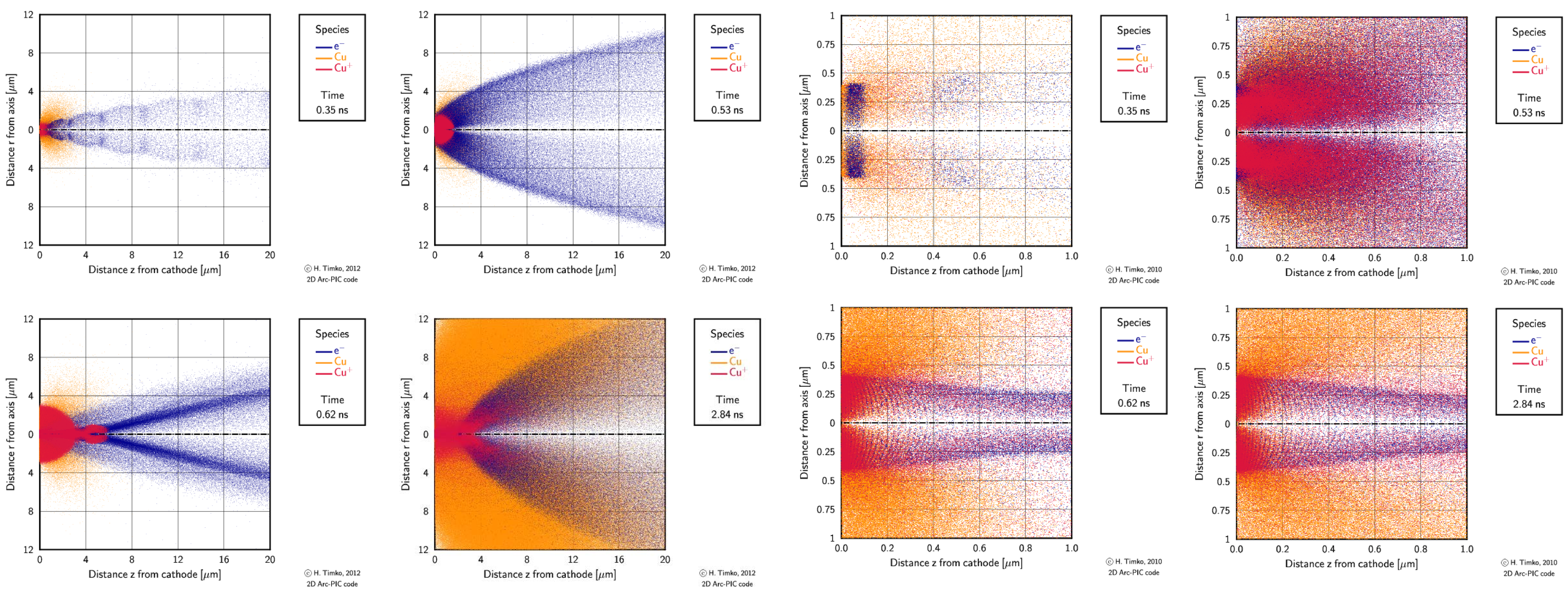
The 2D Arc-PIC code simulates the build-up of plasma in the DC Spark setup.

The transition from field emission to a developed arc

Starting from electron field emission and neutral evaporation, through impact ionization a plasma builds up in the vicinity of the field emitter on the cathode.

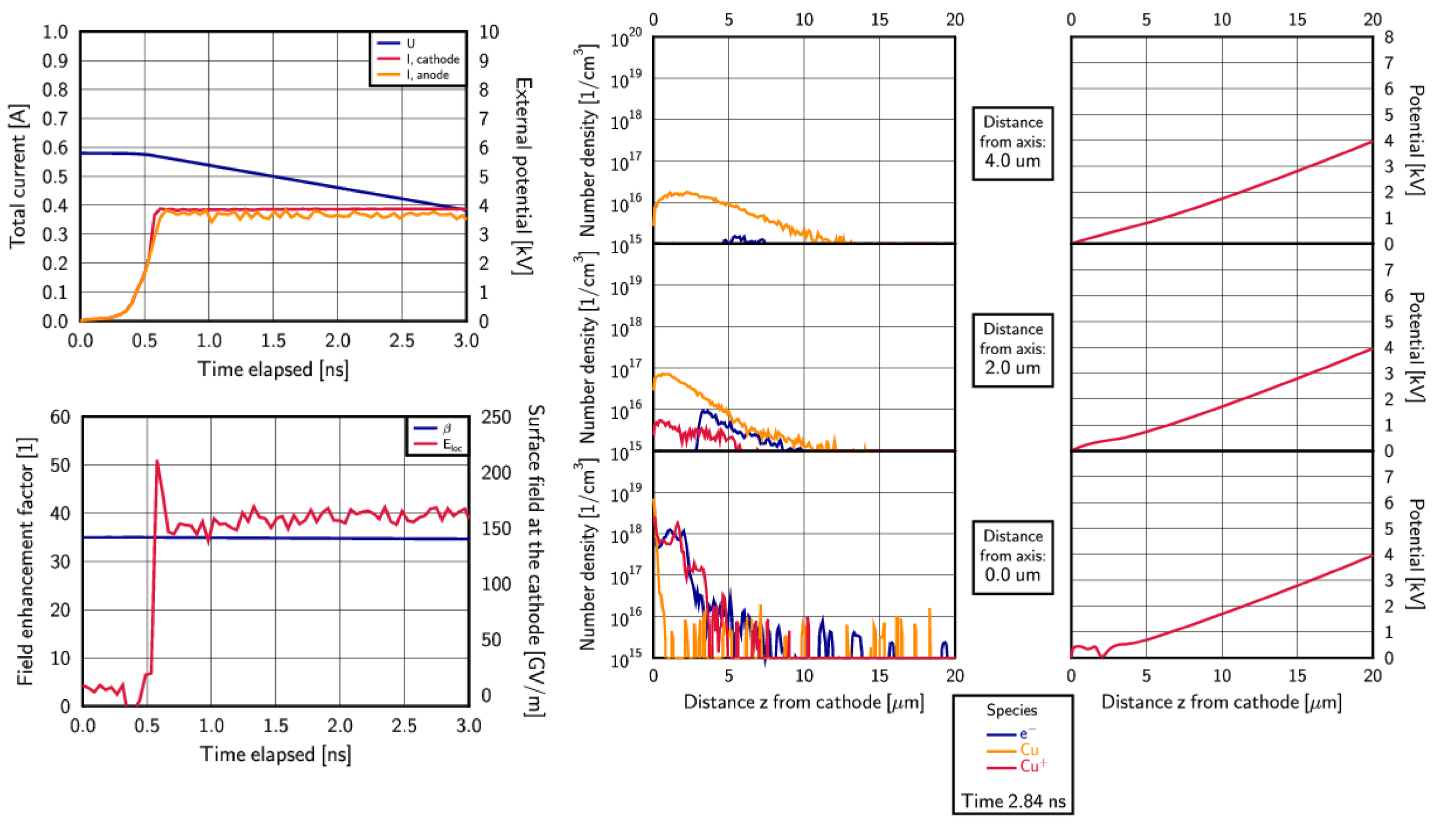
For a breakdown to take place, two criteria are required: **(i)** a high enough *initial local field* at the field emitter to ensure a growing FE current, and **(ii)** reaching a *critical neutral density* to induce an ionisation avalanche, determined by the ionisation cross section and the number of particles within a simulation cell (i.e. grid spacing).

Once the ionization has set in, a plasma sheath is formed along the emitter region with a quasi-neutral plasma region above it. The plasma remains self-maintaining for as long as energy is available.



The development of the vacuum arc from initial field emission seen through snapshots of the different particle species at different stages of the simulation.

The pictures on the left show the entire simulation domain (the upper half plane; the lower half is a reflection). On the right are zoomed-in pictures of the field emission area.

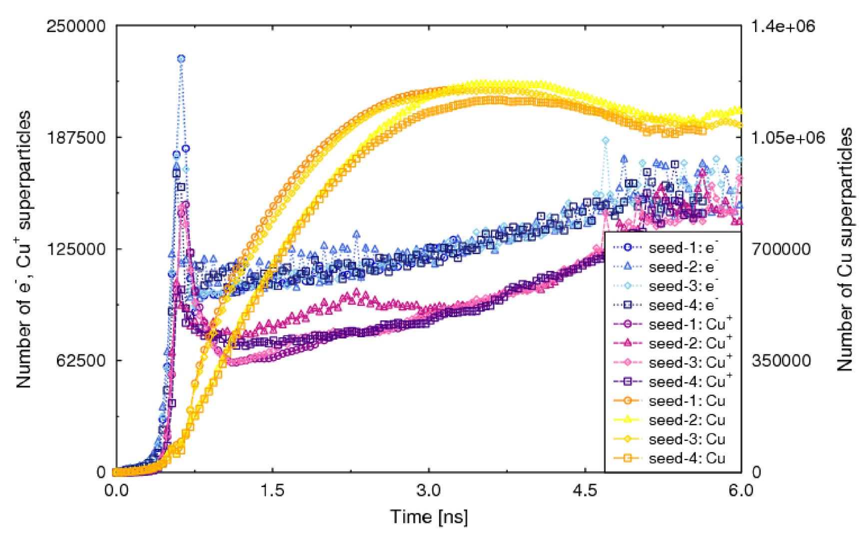


The transition from field emission to arc onset is evident in the current measured at each electrode. During the current rise, as the plasma sheath forms, the local field at the emitter rises rapidly. On the right, the plasma sheath and quasi-neutral plasma over the emitter region, and the consequent drop and plateau in the potential can be seen.

Discussion

Our simulations show the development of field emission from a single emitter to a burning arc. Despite limitations in orders of magnitude, we can see the principles of plasma formation and cathode spot expansion; when the sheath is formed and the current rises, the cathode spot expands, until the maximum current is reached.

The simulations are very sensitive to statistical fluctuations. Nevertheless, the same input physics seem to converge to the same "steady state". This is due to the fact that the properties of the arc, e.g. currents and particle densities, are fully determined by the physics model we employ. For example the electron emission is currently a simplified model, ignoring any thermal effects. Work is on-going to improve this and other aspects of the simulations.



Despite sensitivity to initial conditions, different simulations with the same input, reproduce the same steady state burning arc.