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PLASMA CLOUDS FROM VACUUM ARCS IN A LABORATORY EXPERIMENT - A POSSIBLE SIMULATION TOOL FOR IMPACT CLOUDS FROM HYPERVELOCITY DUST IMPACT?

K. Nilsen, Å. Fredriksen, I. Mann,
[1]*Dep. Physics and Techology, University of Tromsø - The arctic University of Norway, N-9037 Tromsø, Norway.*

Summary

The high velocity impacts of dust on an object in space generate an impact cloud of atoms, molecules and small dust fragments that is much larger than the mass of the impacting dust particles. These impact clouds influence the surface layer of solar system objects without atmosphere, like, e.g. the moon. They are directly measured in dust detectors and they possibly influence other particle and field measurements on a spacecraft. The impact process is studied at dust accelerators and typical dust speeds that are reached in these laboratory devices are up to around a few km/s. Most of these studies concentrate on measuring the charge production (amount of free charged generated) caused by the impacts.

It has been observed that similar plasma clouds form under arcing events in low-pressure plasmas. We report about laboratory experiments where we use arcs created between biased electrodes in vacuum in order to simulate the conditions of the impact cloud after its formation. This provides us with the opportunity to study the expansion of the impact cloud under various conditions of energy exchange between electrodes and discuss their relevance to plasma clouds from hypervelocity impact. In this poster, we present some first experimental results on electrons ejected from an arc discharge.

Introduction

Dust detection by antennas, employing sometimes the entire surface of the spacecraft as collecting area, are advantageous for measuring also low dust fluxes. The signal detection mechanisms are influenced by the surrounding plasma environment and evolve differently in the solar wind the Earth's ionospheres, or planetary magnetospheres. For many spacecraft, the electric field antenna detection technique will be the only way to make dust measurements.

The shock from an hypervelocity dust impact on the structure creates a plasma cloud expanding from the impact site.

Laboratory studies progressed the understanding of the hypervelocity impact process. Previously laboratories in the University of Kent were operated and the laboratory at the Max-Planck Institute in Heidelberg served as an example for new laboratories (University of Stuttgart and University of Colorado at Boulder). In laboratory studies [1], it was possible to simulate various aspects of impact-generated plasmas and the alternate pickup mechanisms responsible for the generation of electric signals on antennas. A recent experimental study demonstrated the different mechanisms of impact signal generation and their variation with antenna/spacecraft bias potentials [2, 3]. Laboratory capabilities have been developed recently to simulate the dust impact processes in well-defined conditions using a dust accelerator [1, 2, 3].

On the other hand, arc discharges in vacuum generate expanding plasma clouds. Spontaneous arcing in low-temperature, low-pressure plasmas is also a common phenomenon which affects in particular Langmuir probe measurements.

More specifically, Sheehan et al. demonstrated the detection by an antenna of a plasma cloud emerging from an arc discharge between a High Voltage (HV) pulsed electrode and a small-bore tube supplying a localized gas cloud [4]. In the present work, we investigate plasma clouds emerging from an arc between an anode at ~ 1 kV and a grounded cathode, at pressure in the range of 1 Pa, to accomodate breakdown at modest HV. We show preliminary characteristics of electron currents as detected by a movable Langmuir probe.

The experimental setup
in the Space Simulation Chamber (SSC).

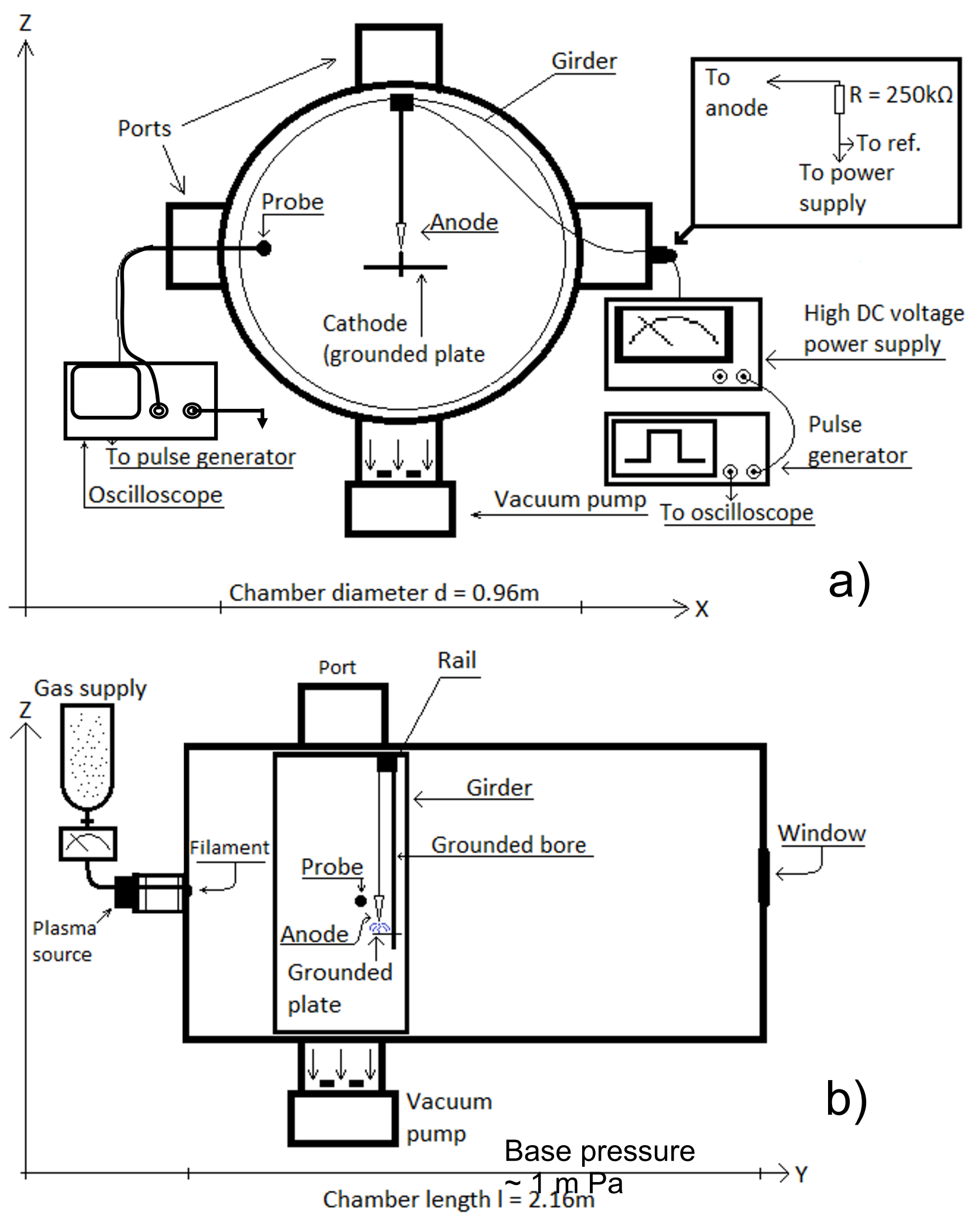

Figure 1. Axial view of the SSC chamber (not to scale) with the electrical circuitry indicated. The anode is 1 mm wide, 1.5 cm long, made of brass, and placed 7 mm above the 100 x 100 mm^2 aluminium cathode (a). In (b), a side view showing the gas feed and the axial positioning of the cathode and anode supports fixed to a rail at the top. The radial probe was placed at an axial distance
z = 100 mm away from the electrodes.

Gas pressure: ~ 2 Pa argon.
→ Neutral gas density: 5×10^{20} m^{-3},

average mean free path electrons $\lambda_{mfp,e}$ ~ 0.1 m

Pulsed, HV DC power source (1500 V) ramped up by pulse generator until breakdown. Discharge current limited by 120 kΩ resistor.

Output monitored by HV probe, used for reference.
Electron and ion saturation currents monitored by movable Langmuir probe.

Anatomy of HV pulse with breakdown

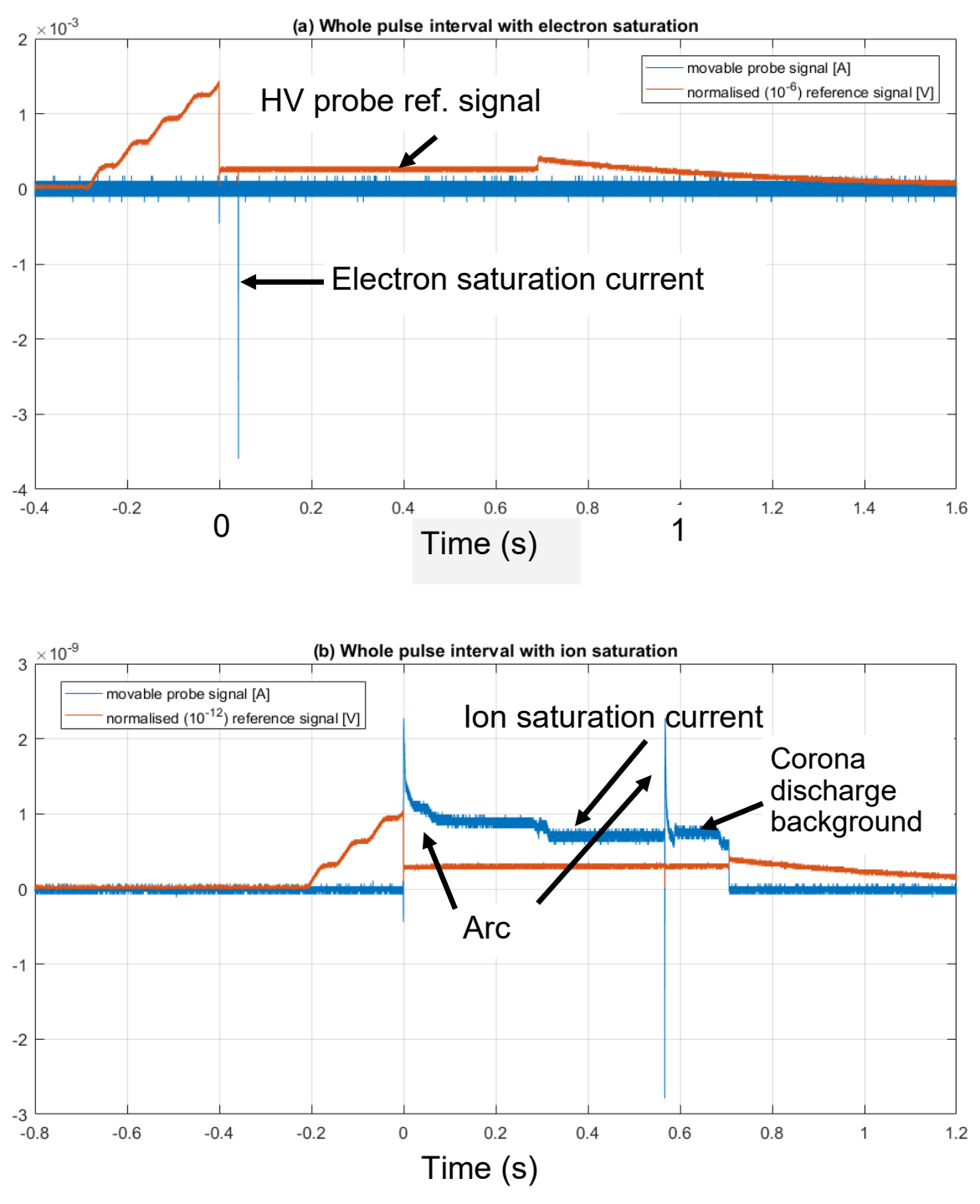

Figure 2. The voltage is ramped up until an arc occur and it collapses to a small value. An ion signal peak forms and fade towards a corona discharge. In some cases, a 2nd arc occurs too. Electron current peaks occur on a time scal too short too bee visible on this time scale.

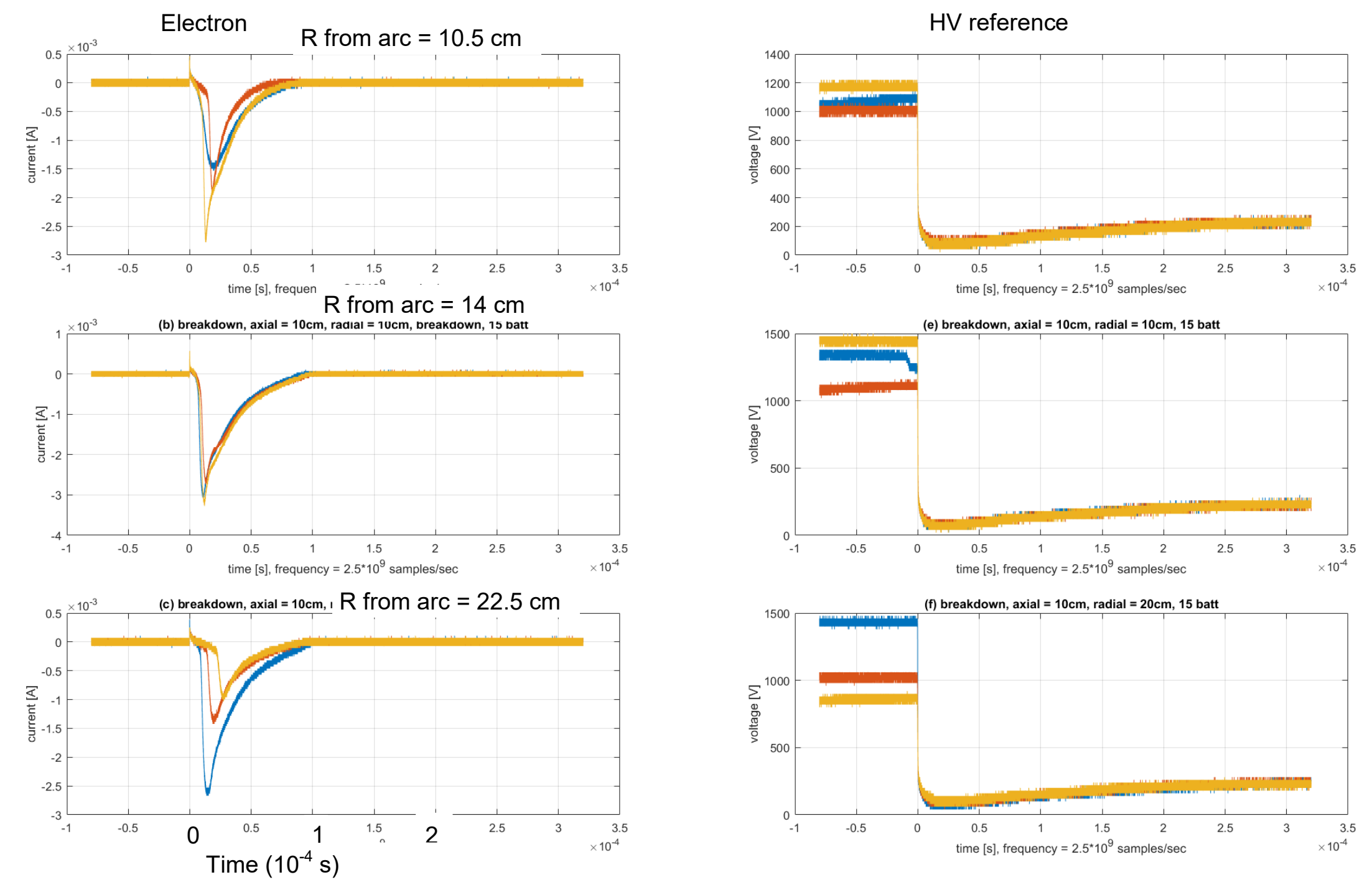

Figure 3. In high time resolution (2.5 GHz sampling rate) the electron current signal is resolved as negative current peak with amplitude apparently proportional to the voltage prior to collapse.

Averaging current signals.

To obtain an average representation of the current pulse and its delay before hitting the probe, the method of ***conditional averaging*** was applied:

1. Pick out a specific *event (condition)* in the (many) reference signals. Here, *event* = the collapse of the HV when an arc occurs.
2. Select a time window around the event, long enough to cover events also on the movable probe.
3. Average the current signals on the movable probe with time window of data centered on condition in the reference signal.

Result, based on collapse events only:

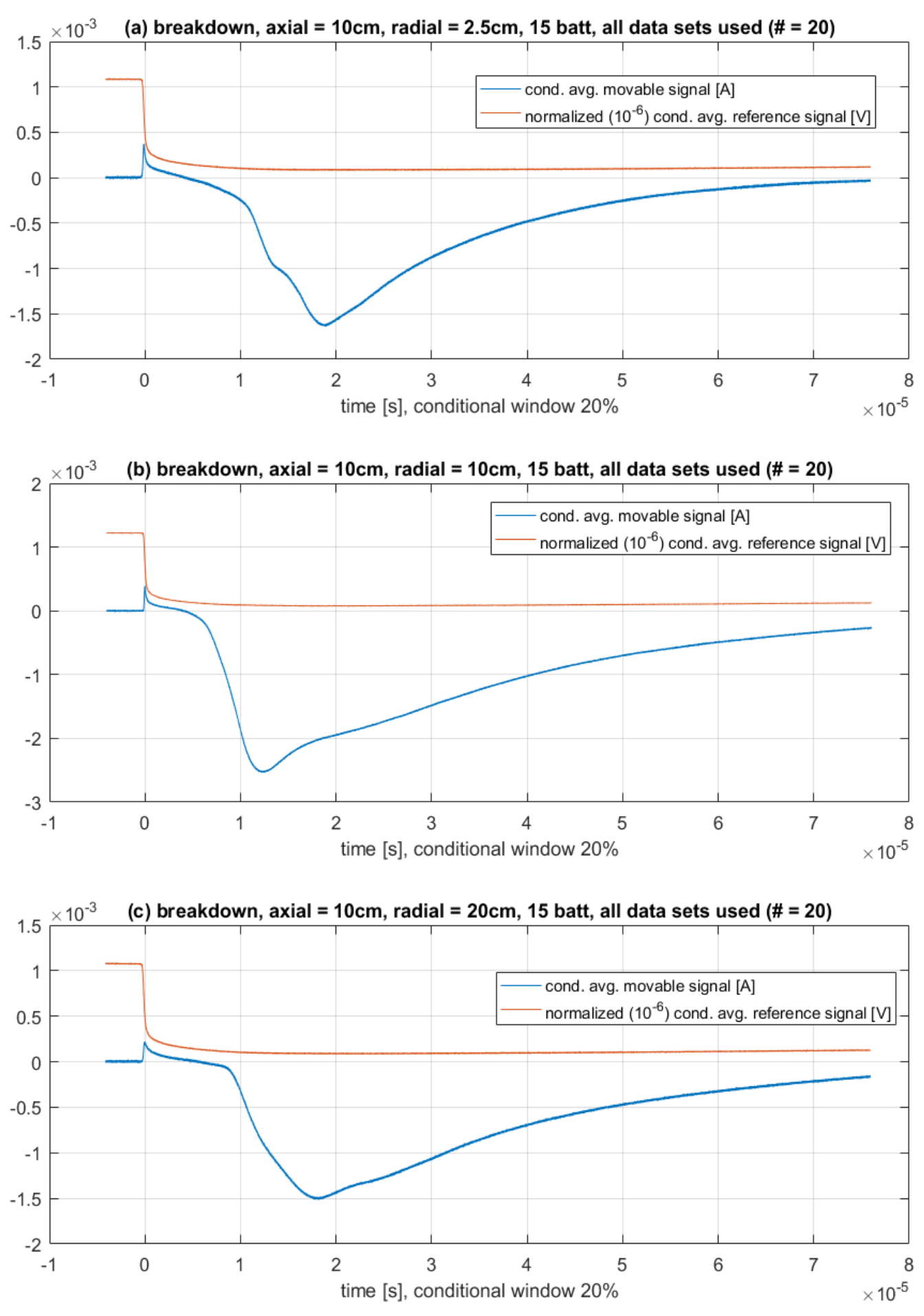

Figure 4. Conditionally averaged electron pulses, based on HV-collapse event only, at the same distances from the arcs as in Figure 3. Pulses are distorted from their actual shapes as seen in the raw data, in particular, in the flanks. No systematic arrival times can be deduced.

⇨ Another condition needs to be selected.

Further signal selection

Noting the proportionality between current amplitude and voltage drop, scatter plots of current amplitude vs voltage drop were made.
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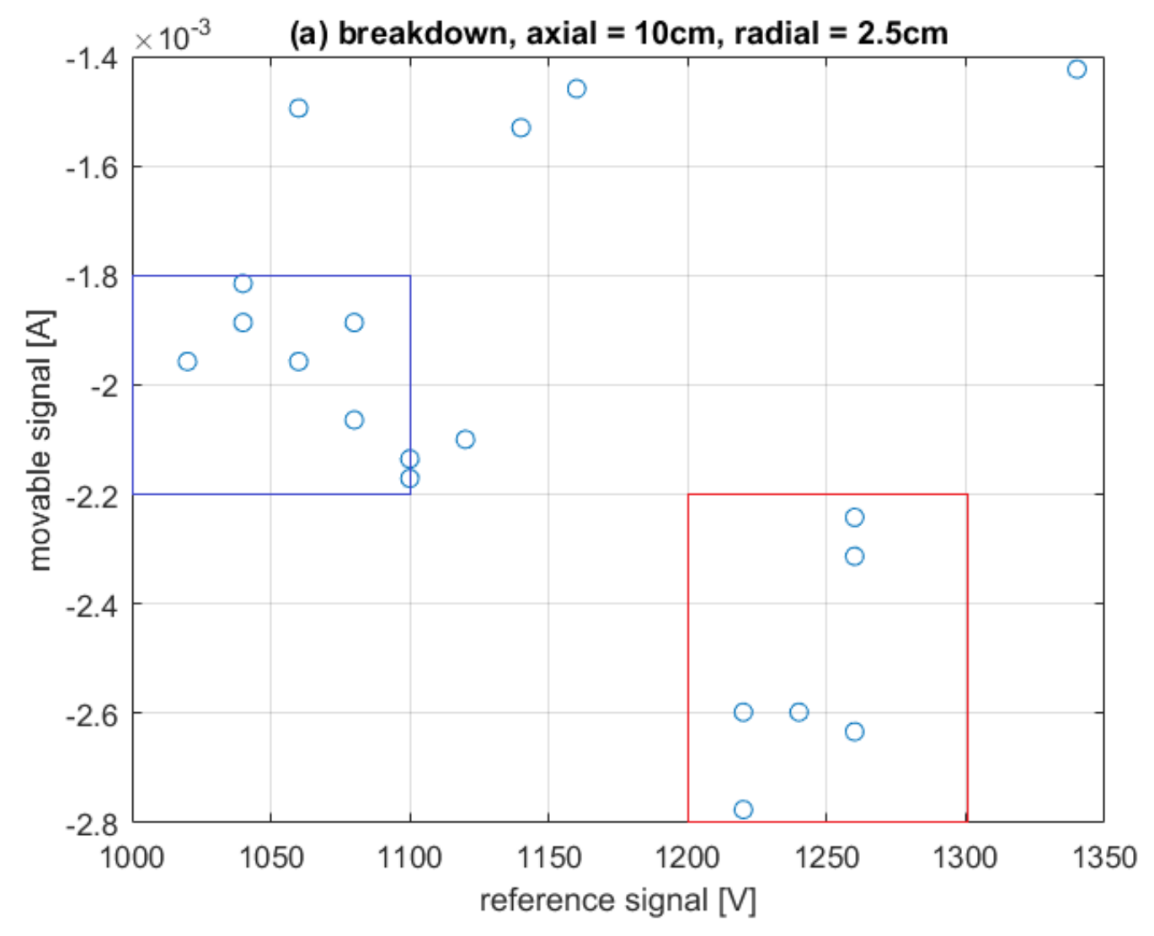

Figure 5. A scatter plot of current amplitude (= minimum in current signal) versus HV bias at voltage collapse, reveals that current signals may cluster in certain regions of cathode bias. In this example, clusters of similar amplitude are found at low voltage drops (≦1100 V), and one cluster (with larger amplitude variance) at higher voltage drops (1200 V—1300 V).

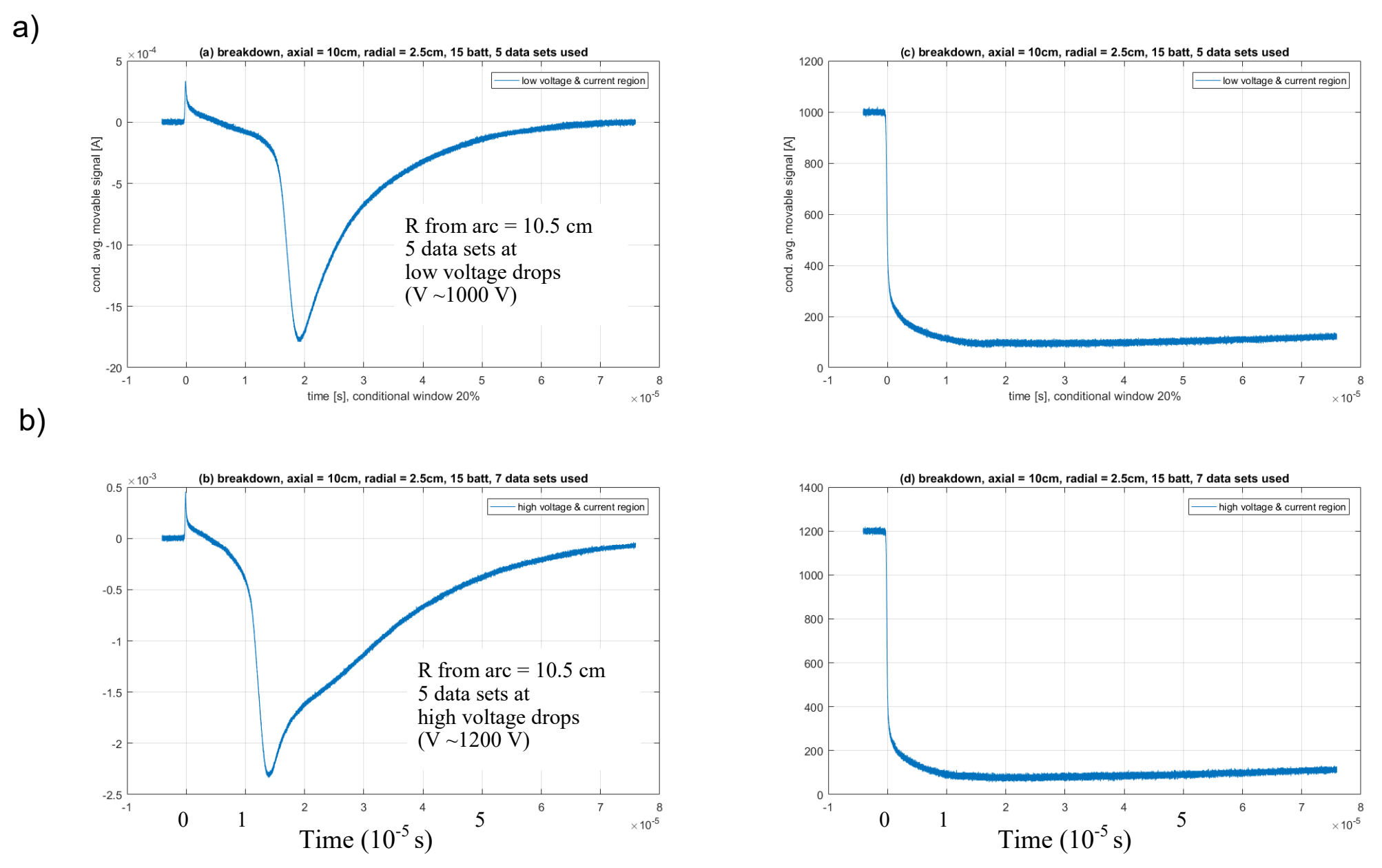

Figure 6. Conditionally averaged electron currents, with current pulses selected at low (a) and high (b) voltage drops. Both pulses are observed at a distance 10.5 cm from the arc. A significant longer delay time is observed for the electrons arriving at the probe from less voltage drops. The delay time for the current peaks to arrive is about 19 μsec (a) and 14 μsec (b), respectively. At the given distance, these delays imply speeds of about 5500 ms^{-1} (a) and 7500 ms^{-1}(b), which is of the order of thermal speeds of 1 eV electrons in case (a) and about 1.8 eV electrons in case (b).

Conclusions

- To analyze current pulse, signals had to be selected according to amplitude of voltage drop at HV collapse to obtain uniformly shaped pulses for averaging.
- For electrons, larger voltage drops results in faster electrons, i.e. electron pulses of large amplitude reach the probe faster than the pulses with smaller amplitudes typical of small voltage drops. The speeds estimated from the delay times in these two cases, are of the order of thermal speeds of ~1—1.8 eV electrons.

References

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