Development of temperature-controlled DC spark measurement system

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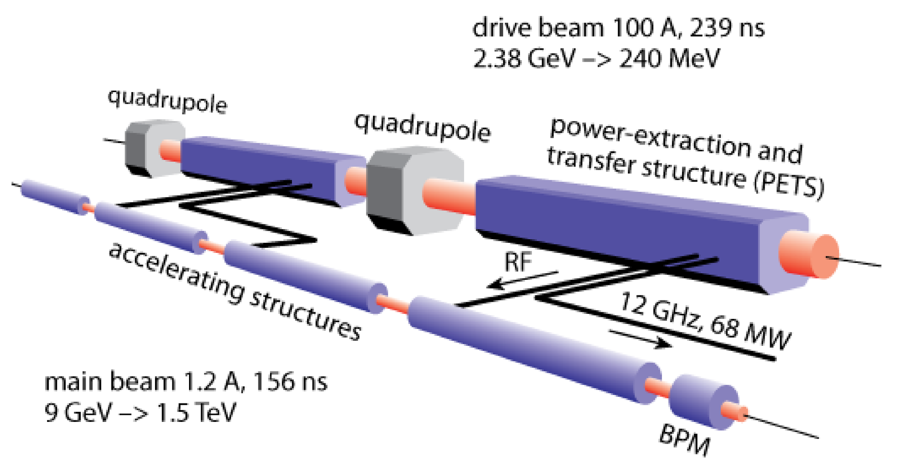
BREAKDOWNS IN CLIC

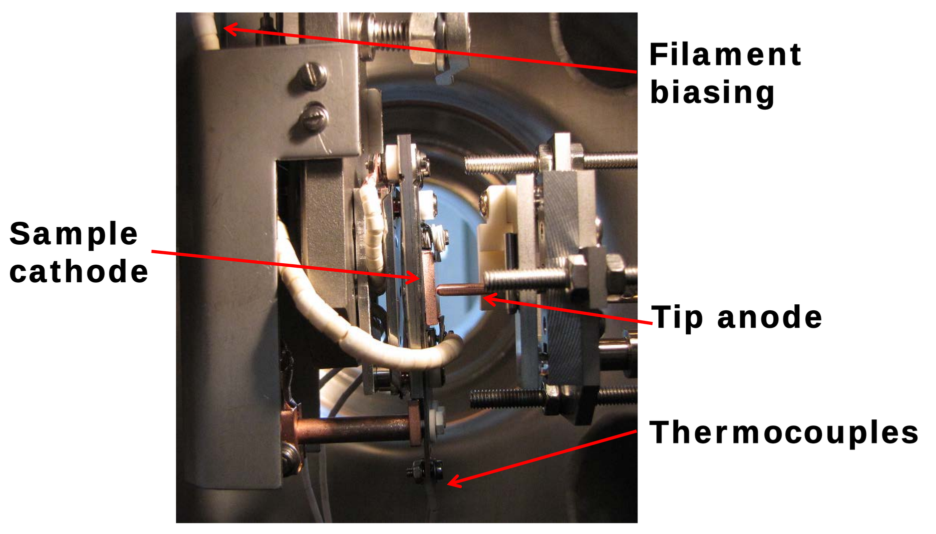
The design of the Compact Linear Collider (CLIC) is calling for a high accelerating gradient of 100 MV/m, raising the problem of RF vacuum breakdowns. For feasibility, the required breakdown probability is 10^{-7} 1/m.



CLIC is a study for a future electron-positron room temperature linear collider. Its unique feature is the two-beam acceleration method.

COMPARING RF AND DC

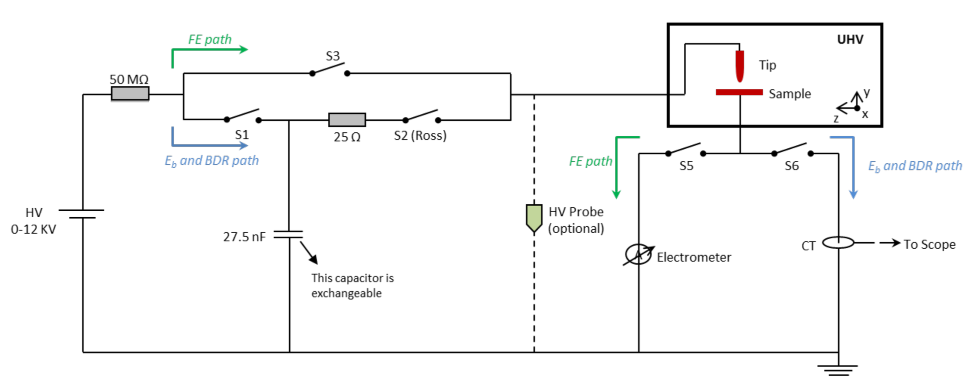
Supporting RF tests, two DC spark setups at CERN provide a effective and less expensive alternative for breakdown studies. They allow testing of several materials, surface treatments and breakdown conditions (field, energy, temperature etc.).



Insight into the vacuum chamber of the DC setup: Cathode (planar, left) and anode (cylindrical with spherical tip, right).

DC SPARK SETUP

The typical operation voltage ranges from 2 to 12 kV. In order to reach electric fields in the range from 100 to 800 MV/m, the discharge gap is limited to around 20 μm. By switching between two different modes, we can measure field emission currents in the pA-range and discharge currents of 100 A during arcing.



Schematic drawing of the electric circuit. In field emission mode, S1 is closed, while in discharge mode first S2, then S3 are closed.

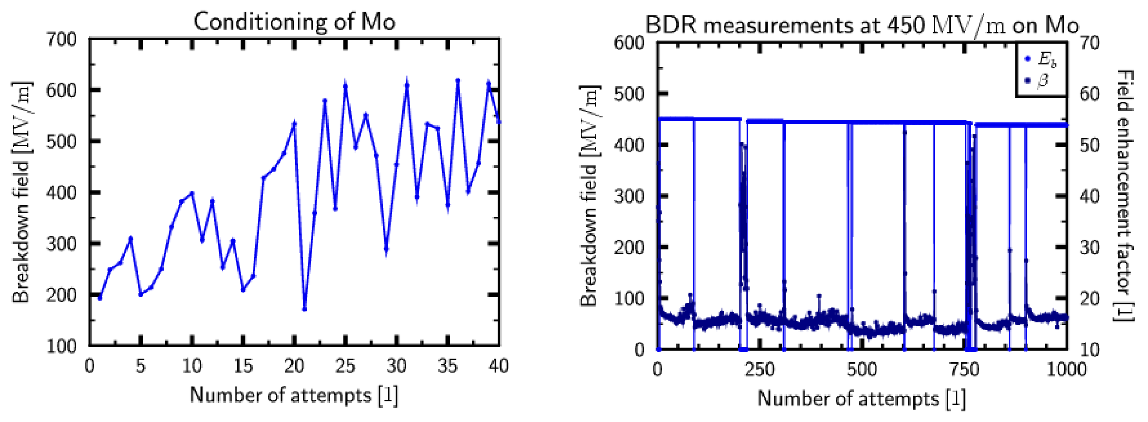
IN-SITU MEASUREMENTS

1. From the **field emission mode** we can extract the so-called field enhancement factor β, defined by the Fowler-Nordheim eq.

$$j_{FE} = \frac{1.54\cdot 10^6 (\beta\cdot E)^2}{\phi}\exp(10.41\cdot\phi^{-1/2})\exp\left(\frac{-6.53\cdot 10^3 \phi^{3/2}}{\beta E}\right)$$

Here [j] = A/m², [E] = MV/m and [ϕ] = eV. The fit of β is performed in a linear regime between $2\cdot 10^{-11}$ and 10^{-9} A.

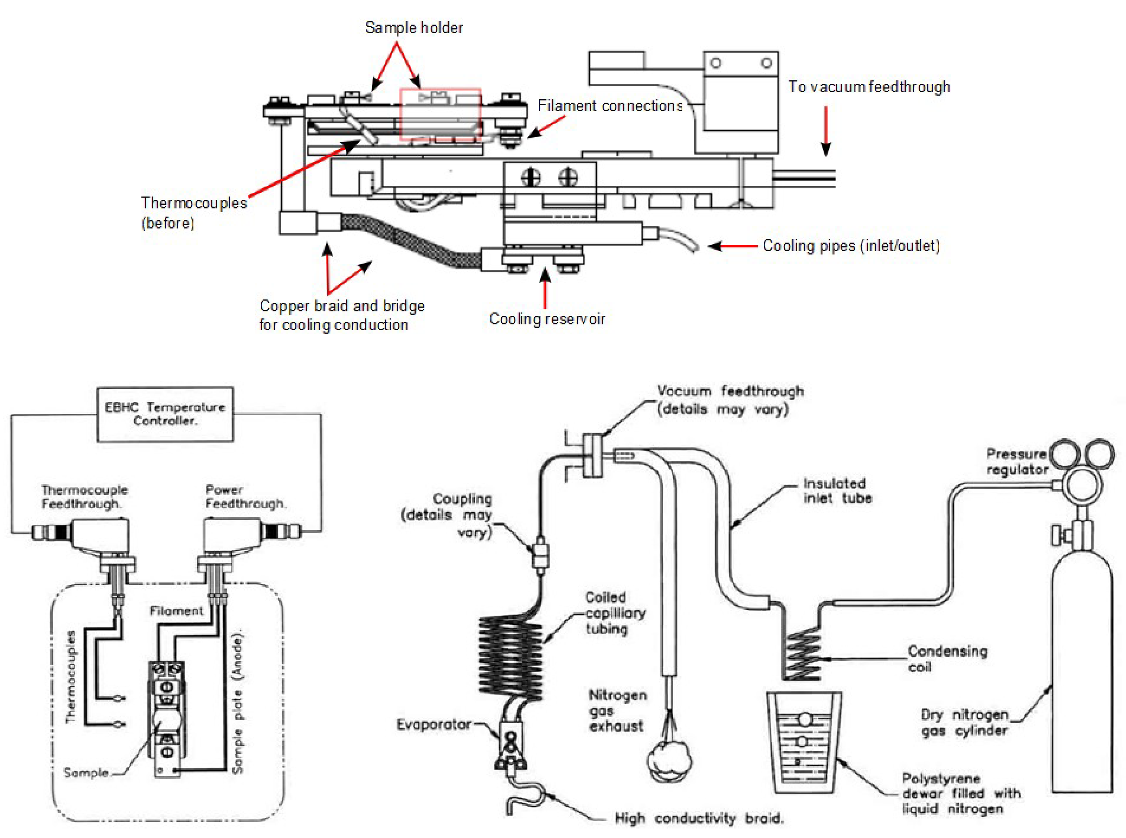
2. In **discharge mode** two types of information can be extracted: (i) breakdown probability in *breakdown rate mode* (BDR) and (ii) saturated field in *conditioning mode*.



Most of the materials exhibit conditioning (left): After consecutive sparks, a given saturated field is reached. By applying a fixed field, breakdown probability (right) is determined.

Temperature-controlled system

For all measurements, a temperature-controlled sample holder is available in one of the setups. Ranging from elevated (up to ~1000 °C) down to cryogenic (-200 °C) temperatures, the cooling is done through liquid Nitrogen whereas the heating process is by electron bombardment.



Illustrative diagram of the temperature-controlled connections in the sample holder (top), heating system (bottom left) and cooling system (bottom right).

Both heating and cooling have been tested in one of the setups. The highest and the lowest temperature achieved in our system was 874°C and -130°C, respectively. It was found that the gap distance between two electrodes were significantly affected by temperature due to thermal expansion of materials. Keeping gap distances during measurements is one of the key issues of field-dependent electron emission and discharge measurements.

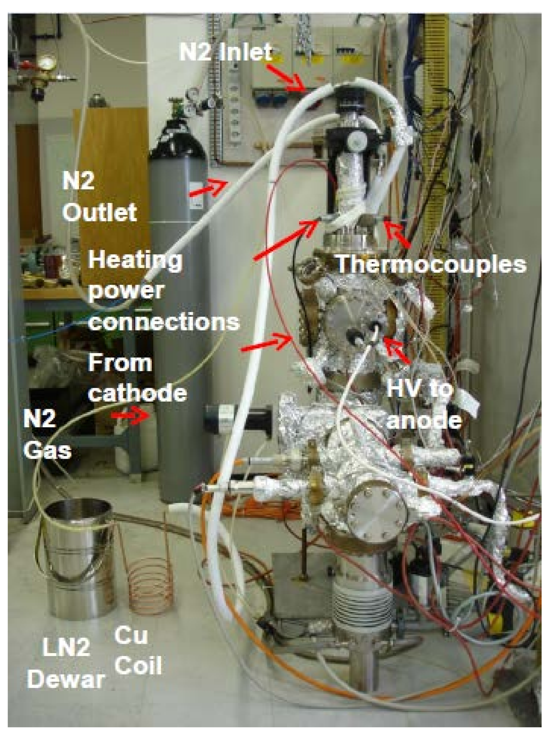


Photo of cooling system connection to the vacuum chamber of the DC setup: The condensing coil is to be inside the dewar with liquid nitrogen.

Non-contact gap control

Currently the gap distance is measured by moving the anode into electrical contact with the cathode and then recording the distance it is retracted. Contacting two electrodes may affect local surface properties and possibly results in initial condition variations. Non-contact gap control is necessary to be developed to study the effect of surface treatments and their link with fabrication (machining, preferential etching at dislocations, influence of H_2 bonding, faceting, smoothening etc.)

Capacitance measurement

It is known that the capacitance between two electrodes depends on the gap distance and on its surfaces. Our non-contact gap control method is based on a accurate capacitance measurement.

Principle of the method:

*1. The **capacitance** between the anode and the cathode is **measured** at various points and the **relative distance** between them is recorded.*

*2. The **absolute distance is** calculated by taking the **relative distance plus** the **distance offset** and adding them together.*

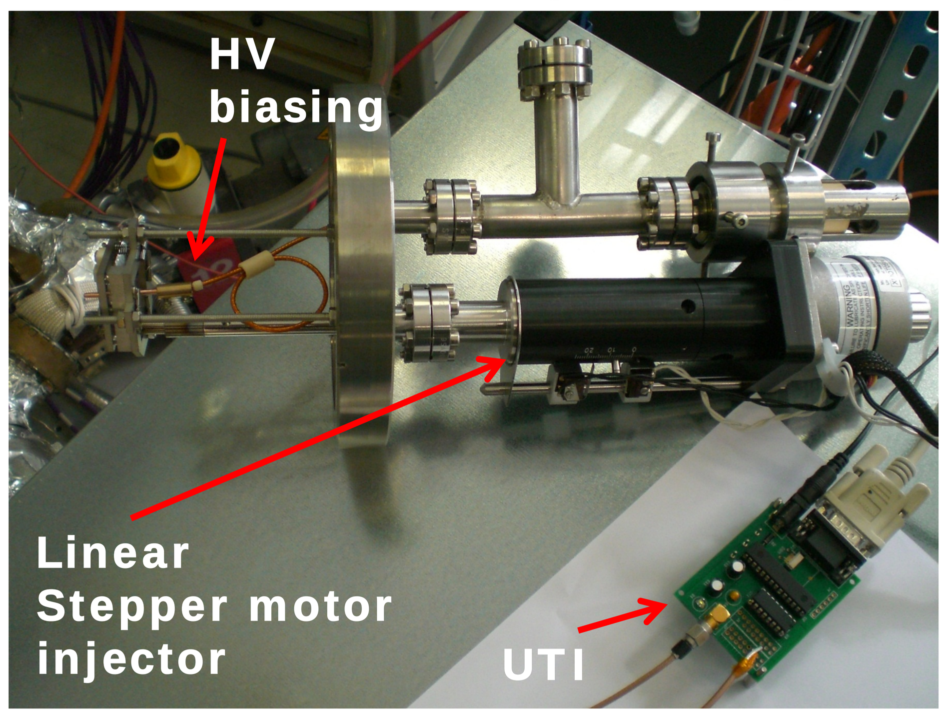
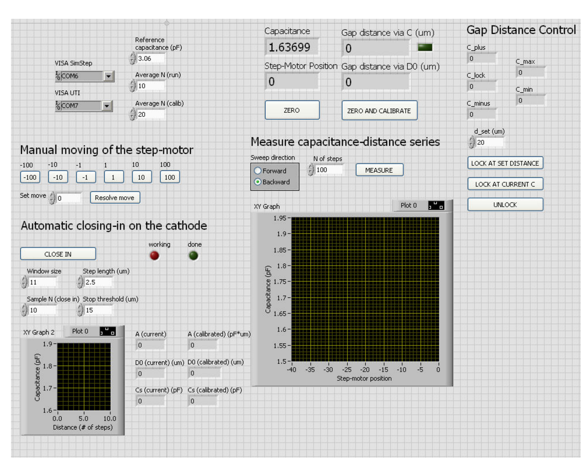


Photo of anode injection system with UTI for capacitance measurement: coaxial cables from UTI are connected to cathode and anode via feedthrough.

The capacitances are very small ~pFs. Various tests were carried out to see whether we could accurately measure them. The capacitance is measured using a “Smartec Universal Transducer Interface” or UTI.

Feedback gap control

In order to keep the gap distance with changes in temperature, a development of a feedback gap control system is in progress as well. The effect of thermal expansion on the gap distance could be measured as a function of time.



Courtesy of A. Korsback

The front panel of the feedback gap control system. The program is capable of moving the step-motor manually, measuring series of capacitance as a function of step-motor position, measuring the absolute size of the gap between the electrodes, and controlling it via negative feedback.