X-RAY MEASUREMENTS REVEAL THE FINE DYNAMICS OF CURRENT MICRO-DISCHARGES IN A VACUUM HIGH VOLTAGE EXPERIMENT

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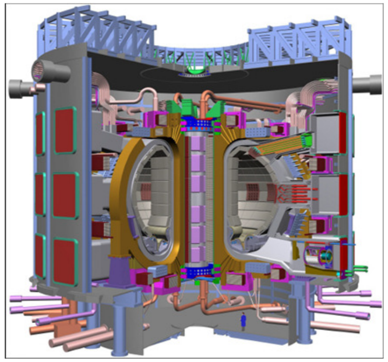
Outline

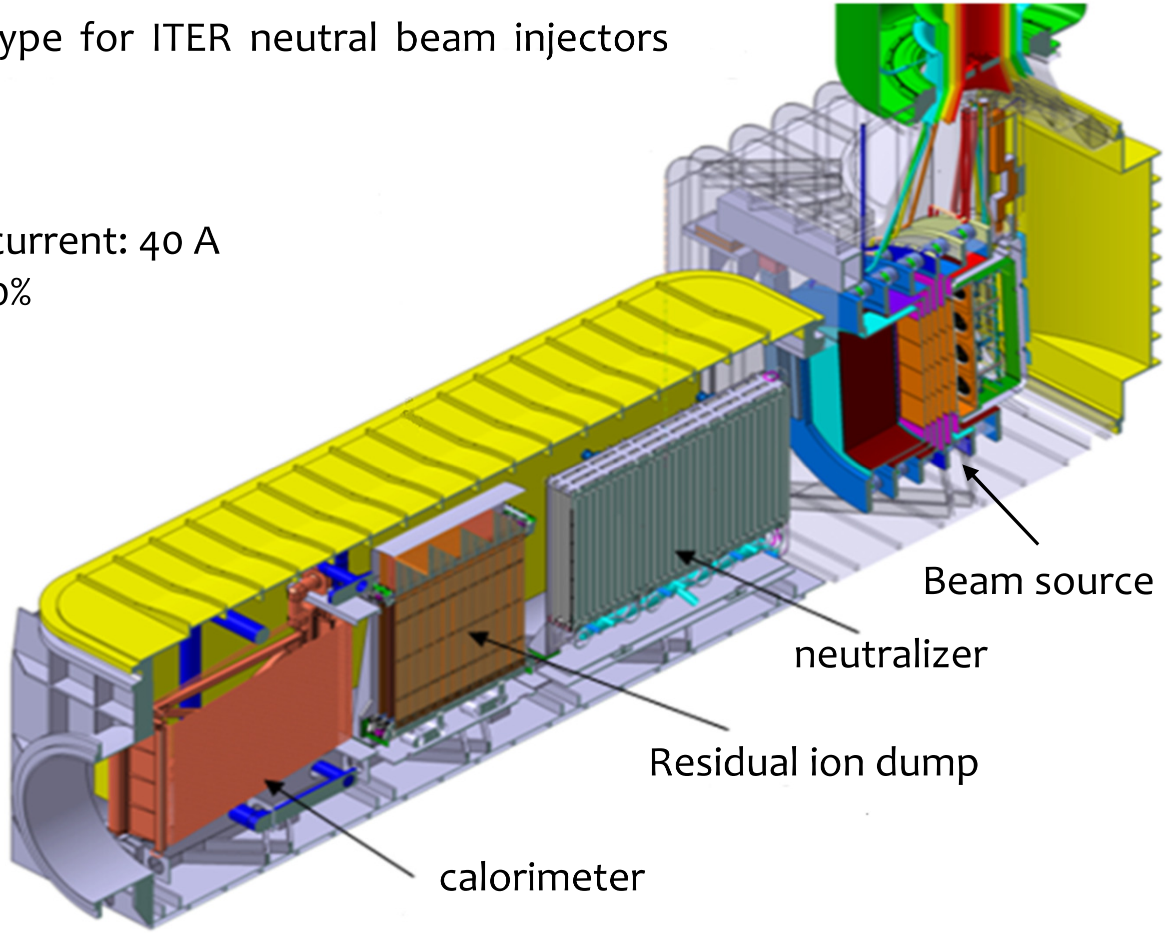
- Introduction
- Two experimental observations:
  - ➢Anode current increases during the conditioning
  - ➢MicroDischarge fine dynamics by X-rays measurements
- Tentative interpretation
- Summary

Megavolt ITER Injector and Concept Advancement

MITICA is a full-scale prototype for ITER neutral beam injectors (Padova, Italy)

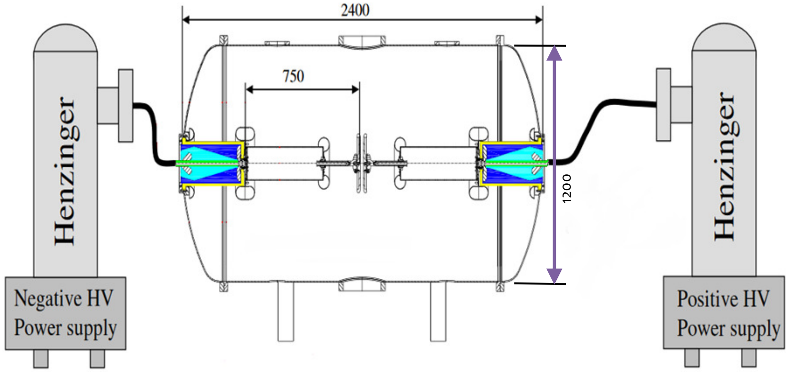
- Accelerating voltage: 1 MV
- Extracted and accelerated current: 40 A
- Neutralization efficiency: 60%
- Beam power: 17 MW
- Pulse length: 1 h
- Operating gas: H, D





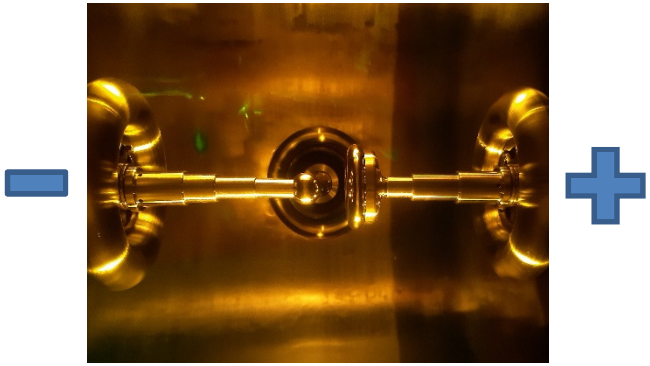
Open issue: voltage holding capability in the gap between the Ion Source and the Vessel in MITICA (conditioning pressure of 10^{-5} Pa, typical gap of 1 m)

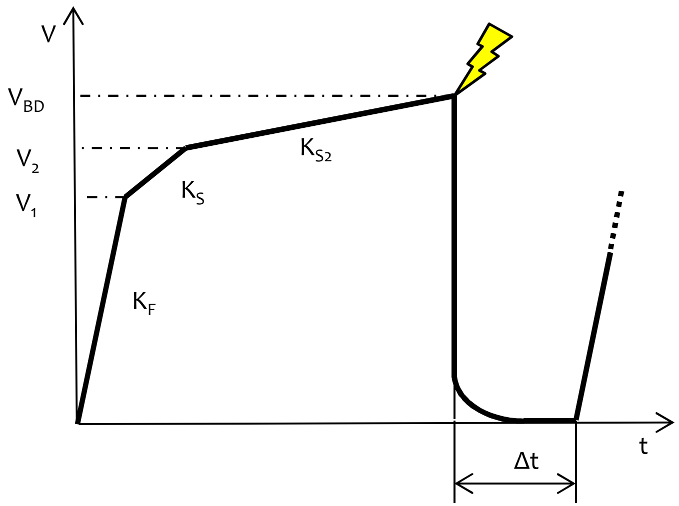
High Voltage Padova Test Facility – the device



- Stainless steel vacuum chamber (2.4 m, Ø=1.2 m)
- 2 Cockcrof-Walton power supplies (+400 kV, -400kV, 1mA dc)
- Vacuum pressure around 4.10^{-7}mbar
- Electrodes gap length 0-250 mm

Negative electrode: Sphere AISI304 Ø=40 mm
Positive electrode: Plate AISI304 Ø=108 mm
Gap between the electrodes: 30-33 mm





Voltage cycle

Voltage is regulated by an automatic procedure, simmetrically operating on both power supplies:

K_F=25kV/min, K_S=0.5kV/min, K_{S2}=0.25kV/min
$V_1=0.9V_{BD-1}$, $V_2=V_{BD-1}$
Δt=2 min

High Voltage Padova Test Facility – the diagnostics

• Applied **voltages,** V_+ and V_-, electrode **currents,** I_+ and I_- and **pressure** signals are sampled together at 100 Hz.

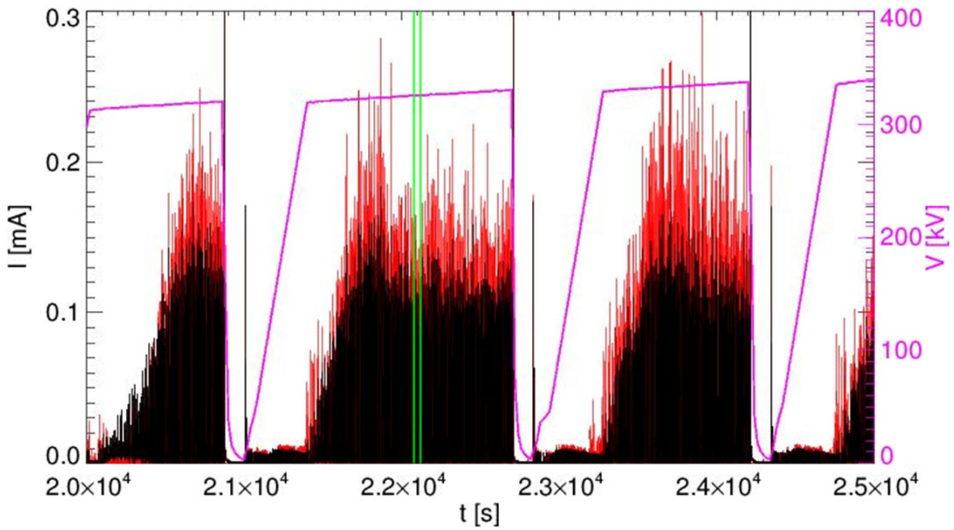
• A **Residual Gas Analyzer** (RGA), directly connected to the vacuum chamber, measures the composition of the gas desorbed from the internal surfaces.

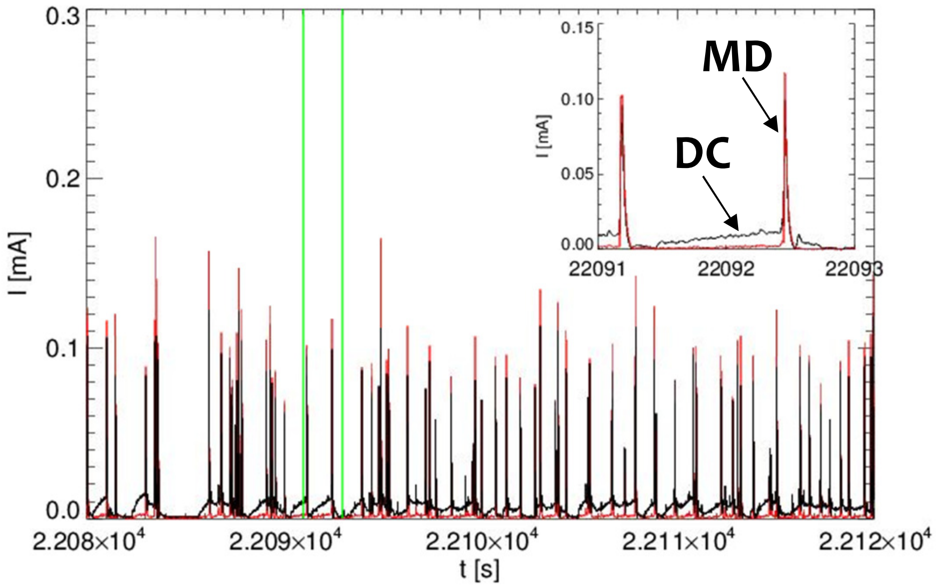
• **X-rays measurements**:

- a **LYSO**, is a small Cerium doped Lutetium based scintillation crystal (4mm x 4mm x 20 mm). It is characterized by a rather high average Z and high density, therefore the full-energy peaks have significant probabilities over the Compton continuum, thus really simplifying the spectra analysis. It is non-hygroscopic, with very fast scintillator pulses (the decay time is of about 40 ns) and the energy resolution is less than 9% (at 662 keV).
- the second scintillator is a Lanthanum Bromide (**$LaBr_3$:Ce**) crystal (Ø=25mm, 19mm long), able to stand very high rates (decay time of 16 ns) in single photon counting mode. Energy resolution is ~ 2.5% (at 662 keV).

Both crystals are coupled to a standard photomultiplier, and the signals are acquired by a CAEN DT5730 fast digitizer.

The current signals





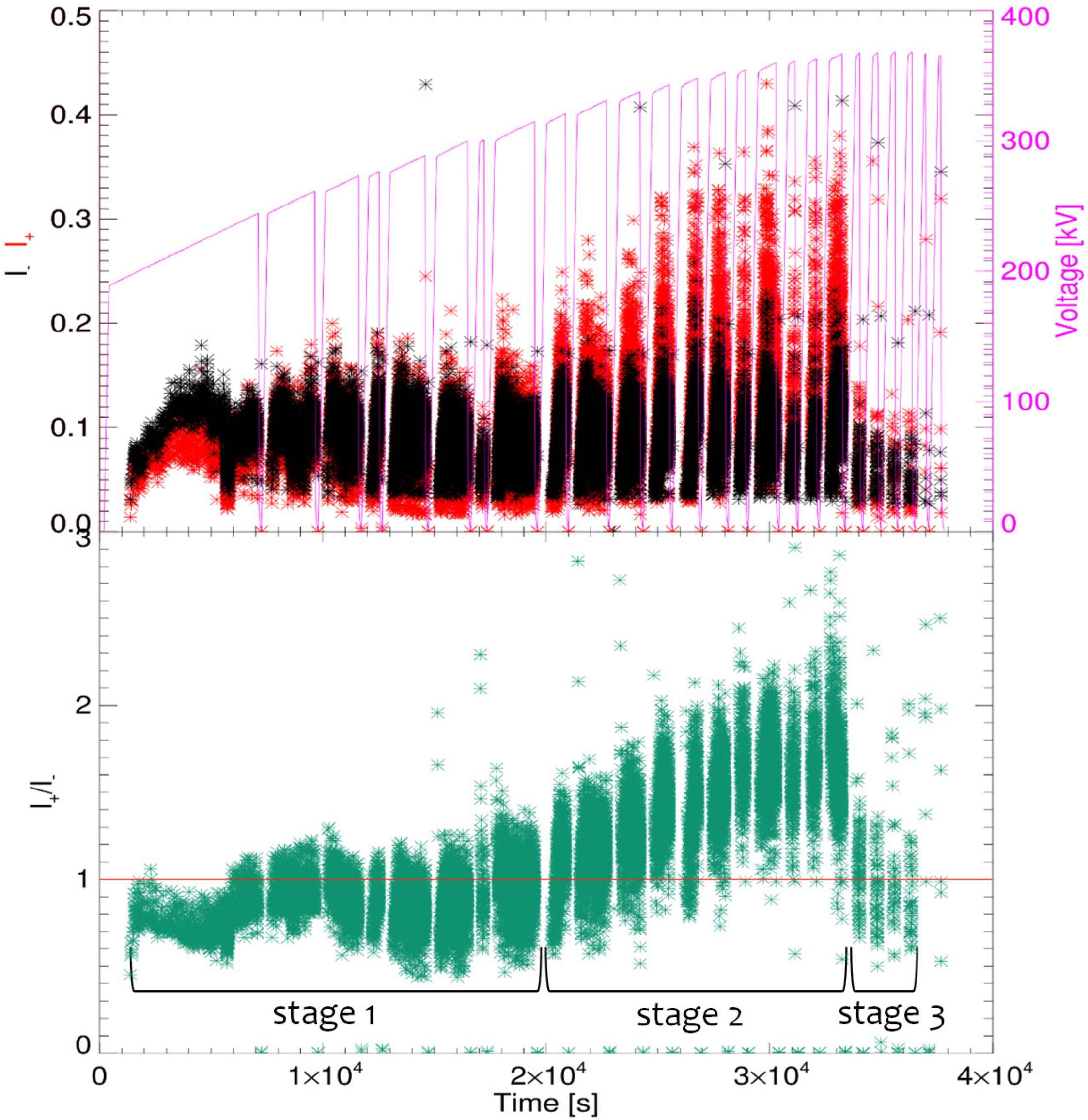
I_- → current on negative electrode
I_+ → current on positive electrode

- I_+ and I_- both exhibit the occurrence of spikes or **MicroDischarges (MD):** this interation mainly involves electrodes.

- I_- signal measures an almost continuous current, named **Direct Current (DC),** of about 0.01 mA, not corresponded by a symmetric I_+. The cathode interacts with the vessel.

We will focus on MD phenomenon

Microdischarges



Cathode current

Anode current

R parameter $\mathbf{R} = \frac{\mathbf{I_+}}{\mathbf{I_-}}$

During the conditioning process

Stage 1: $R \leq 1, I_- \geq I_+$

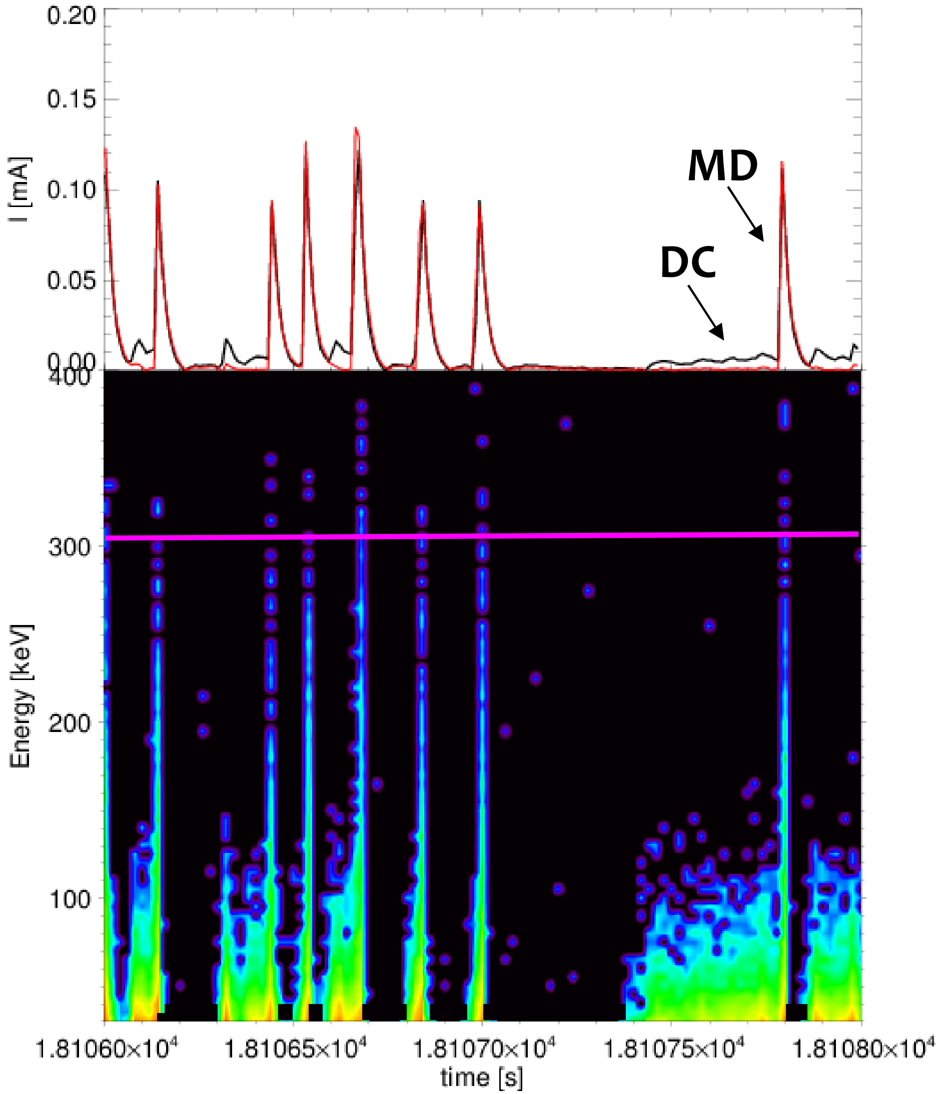
Stage 2: $R > 1, I_- < I_+$

Stage 3: $R = 1, I_- = I_+$

At stage 2, I_+ increases with respect to I_- → WHY?

$1 < R < 1.8$

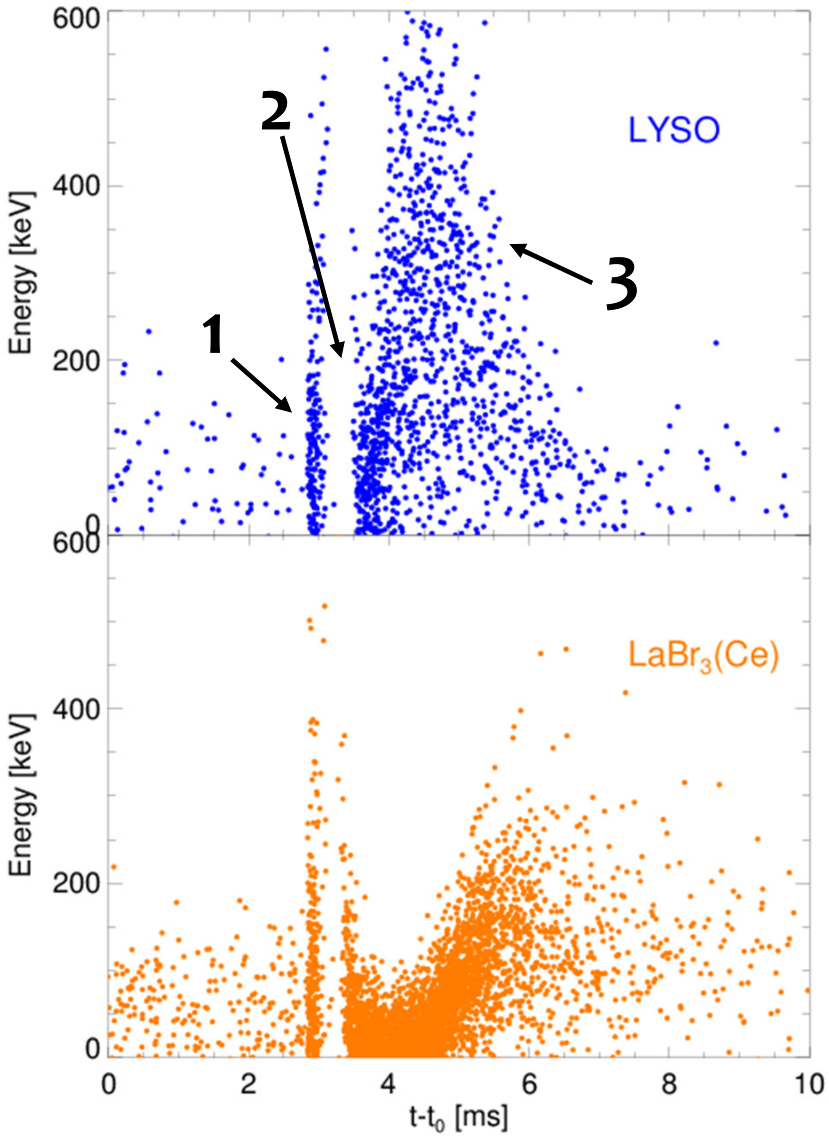
X-rays



There is a clear relation between I_- current and X-ray signals:

- MD are associated to **high energy** (full energy) events → from the electrodes.
- DC is due to electrons from the cathode to the vessel (half energy)

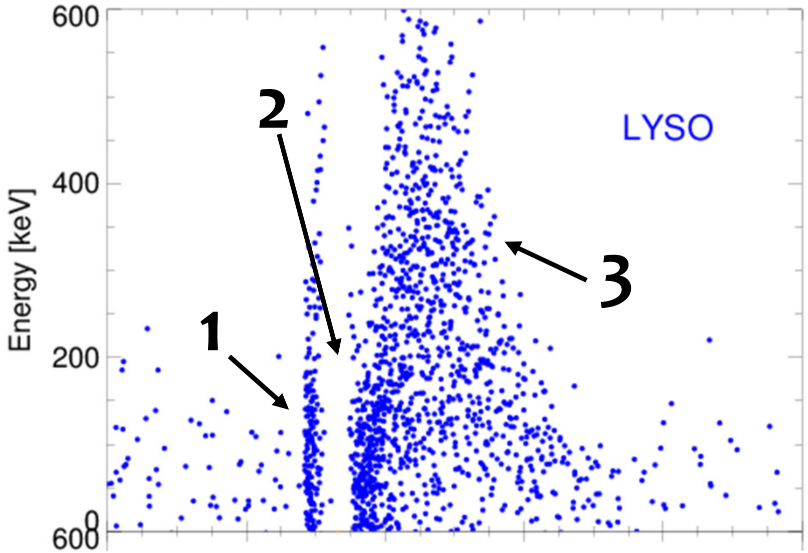
X-rays measurements: MD fine dynamics

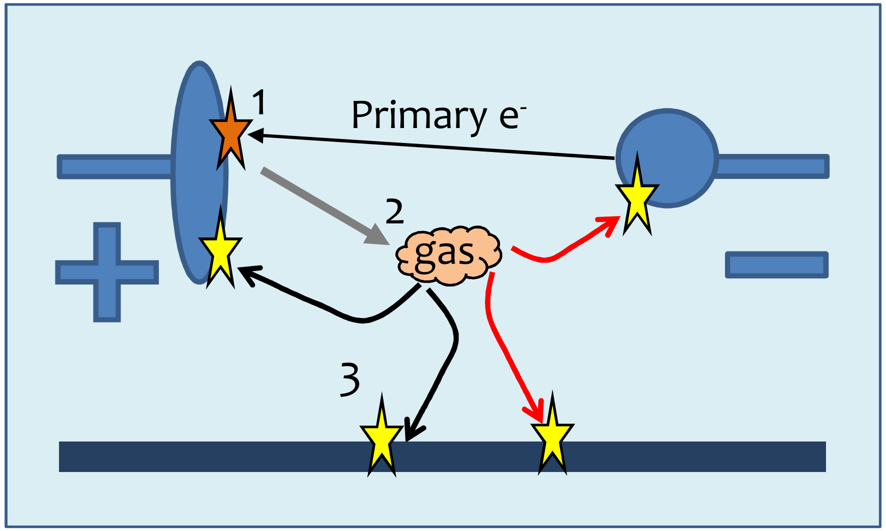


Both the scintillators reveal 3 main phases in a single MD event :

1. X-rays of different energies are generated, up to the maximum value provided by the accelerating voltage (Δt = 0.1 - 0.2 ms).
2. X events are very rarefied (Δt = 0.4 - 0.5 ms);
3. a strong X-rays production is measured (Δt = 3 - 4 ms). The energy distribution of the events looks very different in the two detectors.

MD fine dynamics: tentative interpretation





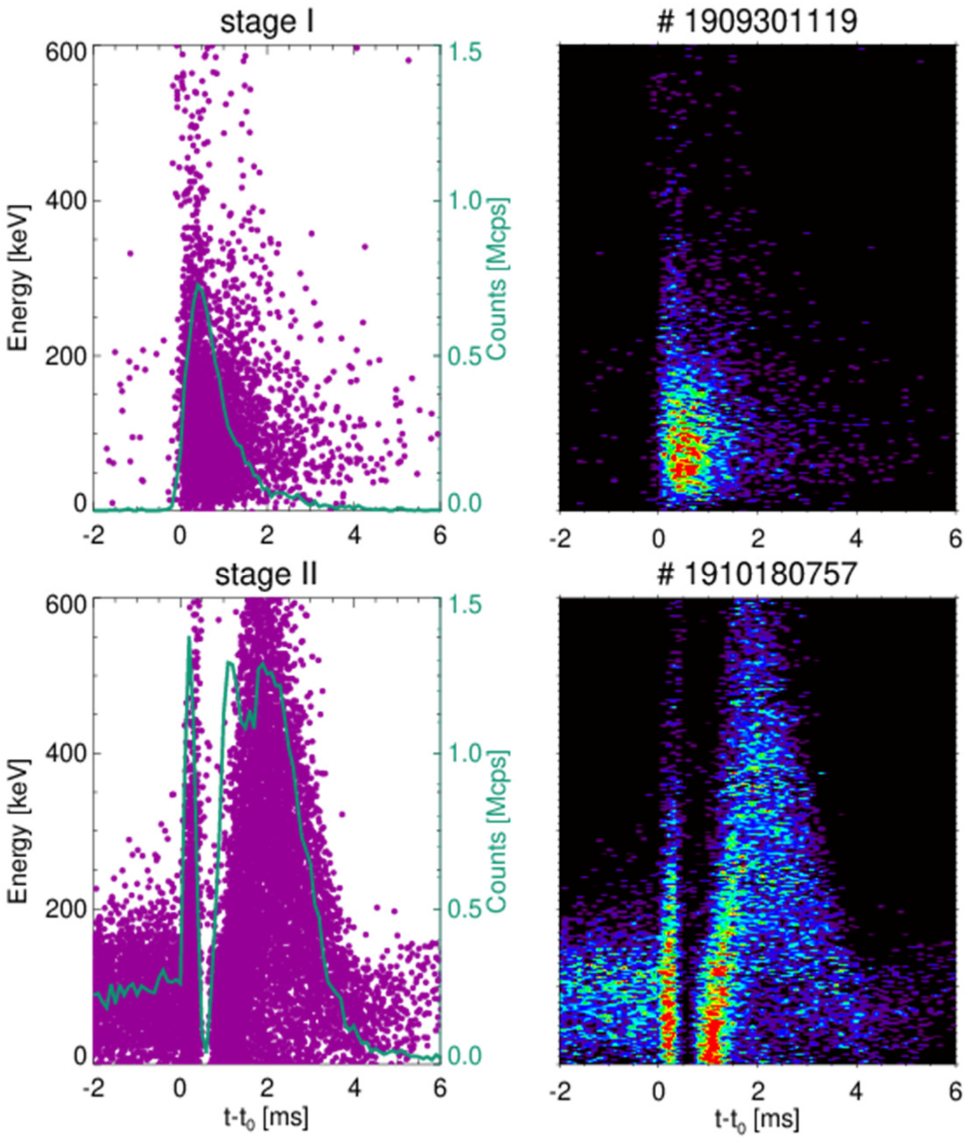
PHASE 1: the first train of X events is generated by the primary electrons emitted by the cathode hitting the anode;

PHASE 2: from the impact, gas* is emitted by the anode (and ionized): it could create collisional conditions reducing the X-rays component;

PHASE 3: X-rays are generated by the electrons produced by the ionized gas and by secondary electrons, hitting the chamber, the electrodes and their metallic supports.

* Gas emission (in particular H_2 and CO_2) was measured in correspondence of MD occurrence

X-rays measurements during the conditioning

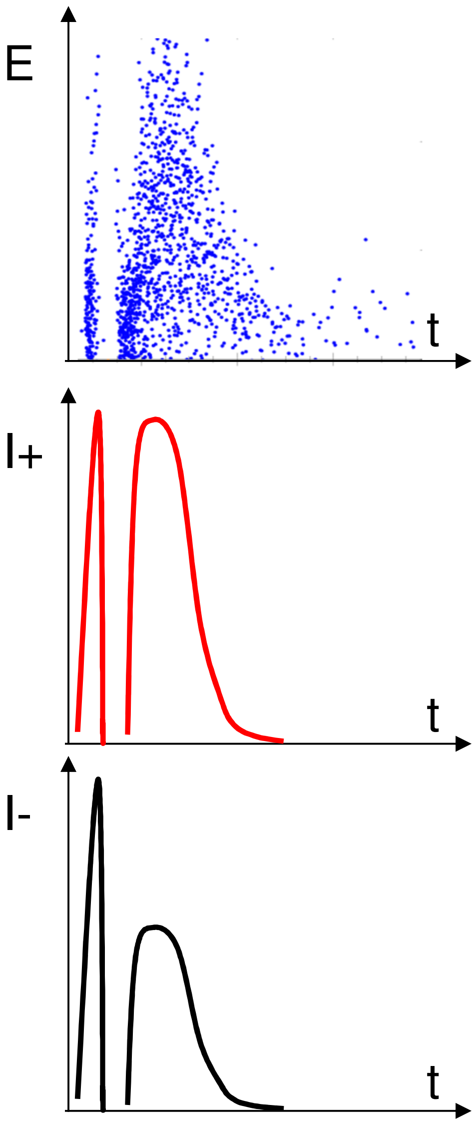


Stage I: high energy X-rays produced by the primary electrons are observed, followed by those produced from secondary electrons emission.

Stage II: the 3 phases can be distinguished → high energy electrons extract a (growing) gas amount from the anode.

We wonder if the two experimental observations (i.e. the modification of the MD fine dynamics and the anode current increase during the electrodes conditioning) are related.

Tentative interpretation: a simple model



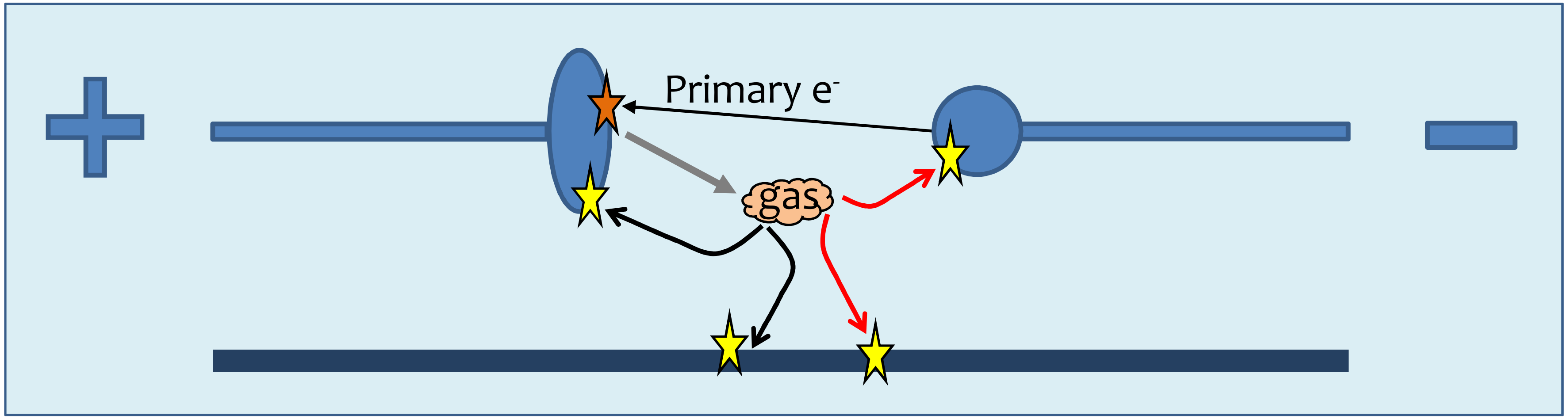
According with our idea, the current signals could have a fine dynamics we cannot measure at present (100 Hz sampling time)

- PHASE 1 corresponds to the electrons flowing from cathode to anode → symmetric current
- PHASE 3 corresponds to all the interactions caused by the ionized gas interacting with the electrodes and the vacuum chamber → the current asymmetry could lie here

We focus on PHASE 3

Tentative interpretation: a simple model

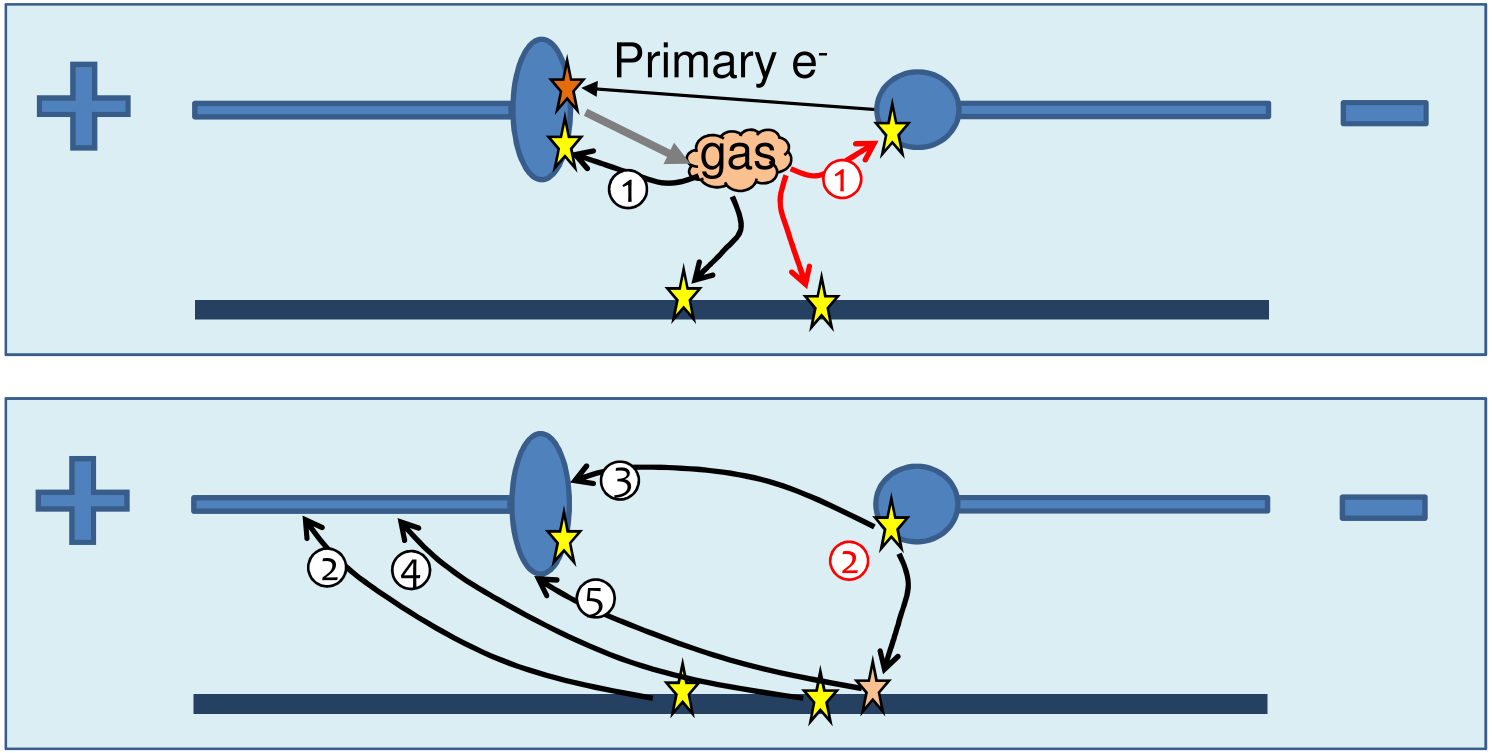
We wonder which is the mechanism behind the current asymmetry: why there is a surplus of anodic current?
→ the anode collects **secondary electrons from the vacuum chamber**



We evaluate the R parameter (from exp 1.0 < R < 1.8) by the current contributions

- Electron-ion pairs produced from the ionized gas
- SEY(e^-) ≈ 0.1 [0.01; 0.51]
- SEY(i^+) ≈ 2.5 [0.5; 4.0]
- Fraction of particles interacting with electrodes, EIF ≈ 0.4 [0; 1]
- Fraction of particles interacting with the chamber, CIF =1 - EIF ≈ 0.6 [0; 1]
- Fraction of particles from the chamber to the electrodes, CEF ≈ 0.8 [0; 1]

Tentative interpretation: a simple model



<u>Anode current contributions (I+):</u>

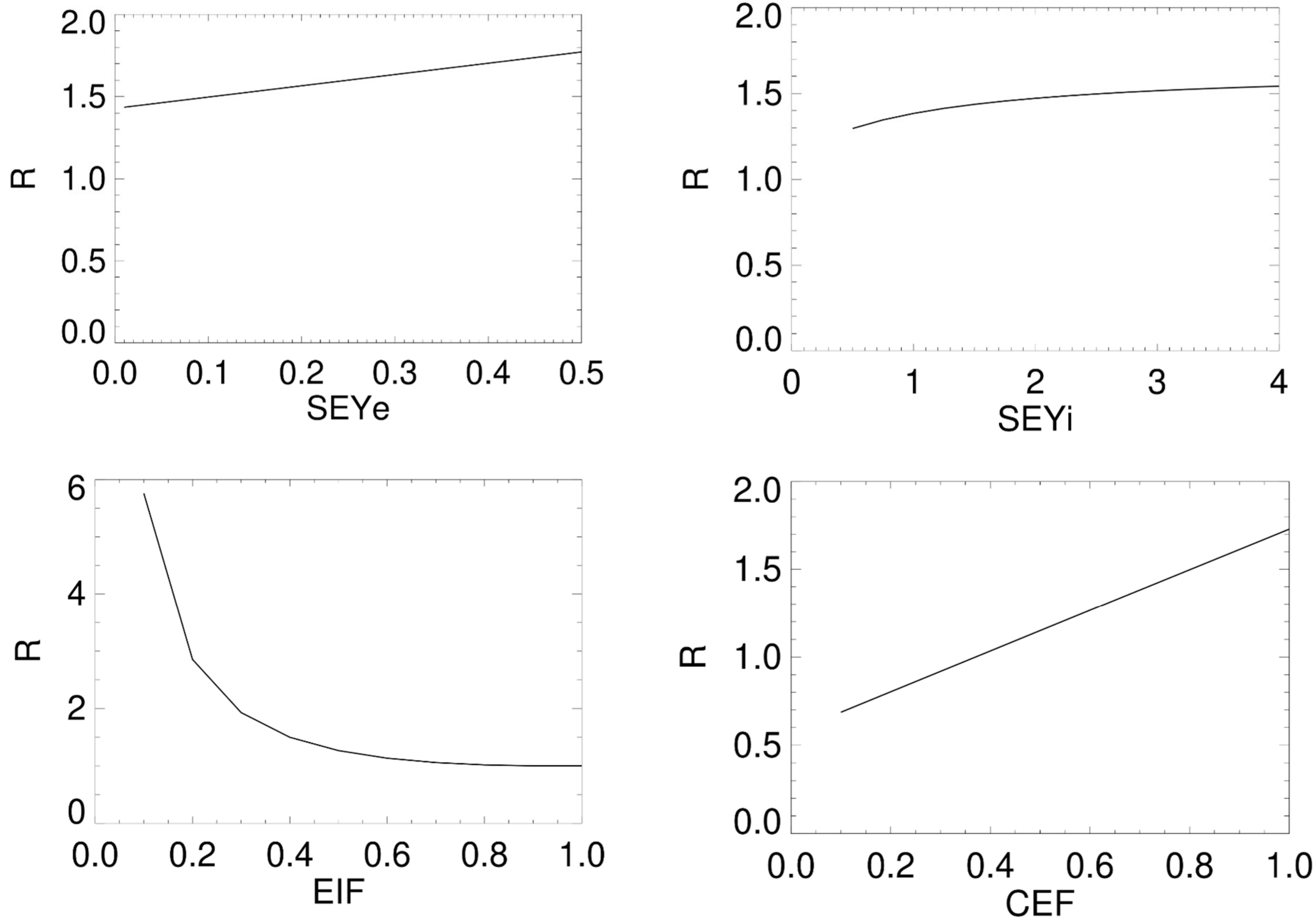
1. Gas electrons on anode
2. SE from electrons impacting the camera
3. SE from ions impacting the cathode
4. SE from ions impacting the camera
5. SE from cathode SE impacting the camera

<u>Cathode current contributions (I-):</u>

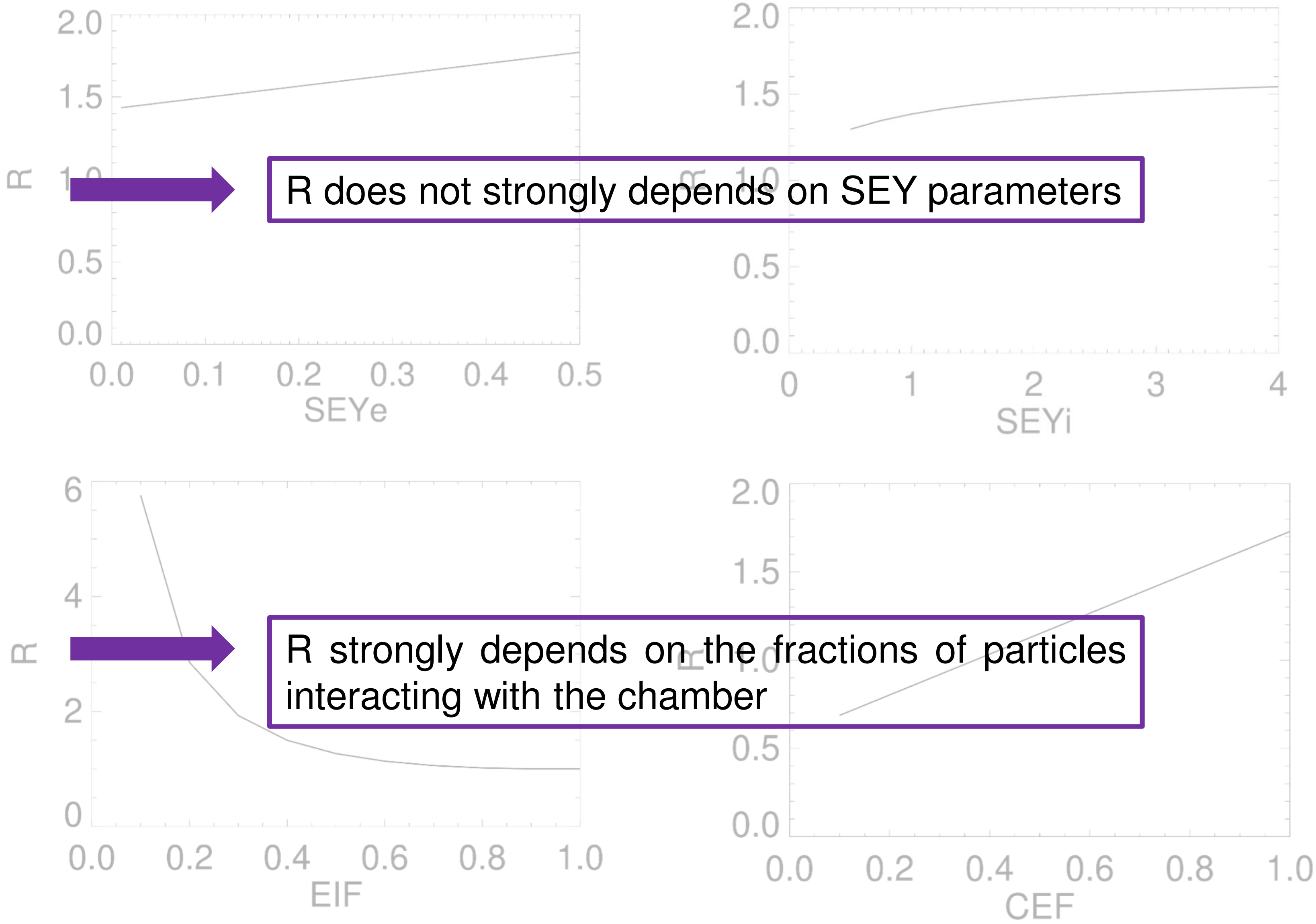
1. Gas ions on cathode
2. SE leaving the cathode for gas ions impact

Tentative interpretation: the R parameter

$$R = \frac{I_+}{I_-}$$



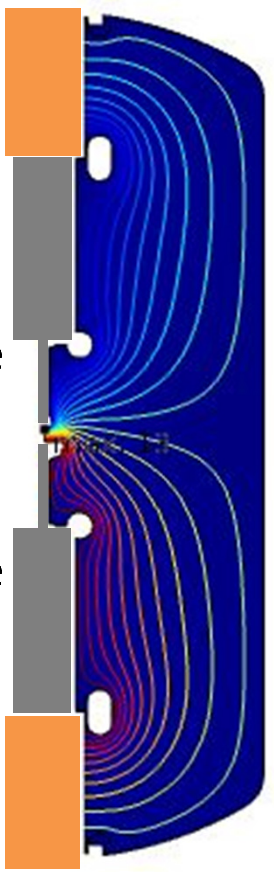
Tentative interpretation: the R parameter

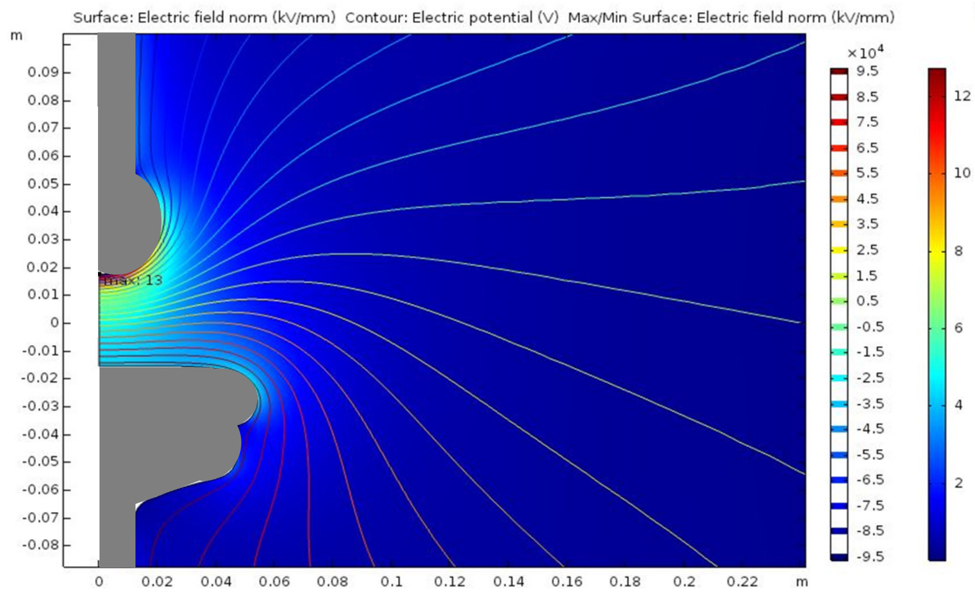


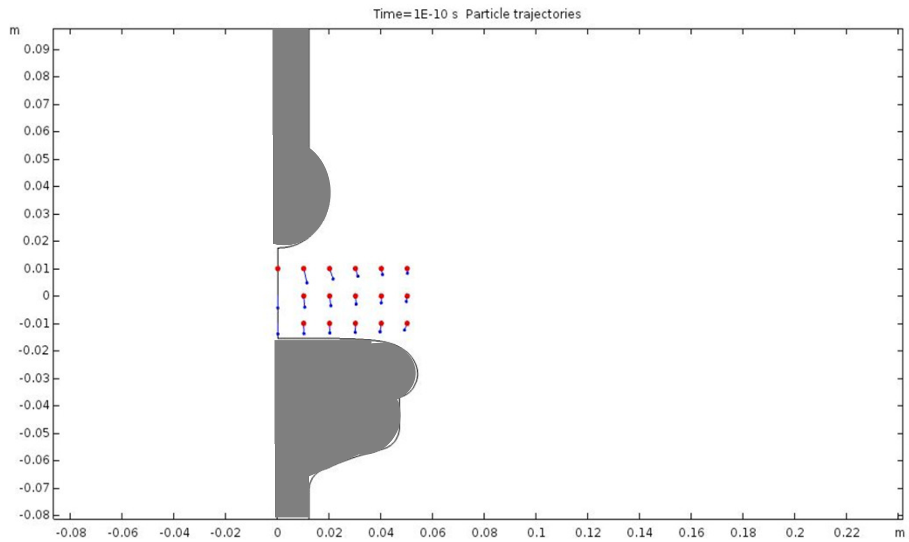
R does not strongly depends on SEY parameters

R strongly depends on the fractions of particles interacting with the chamber

Tentative interpretation by simulation

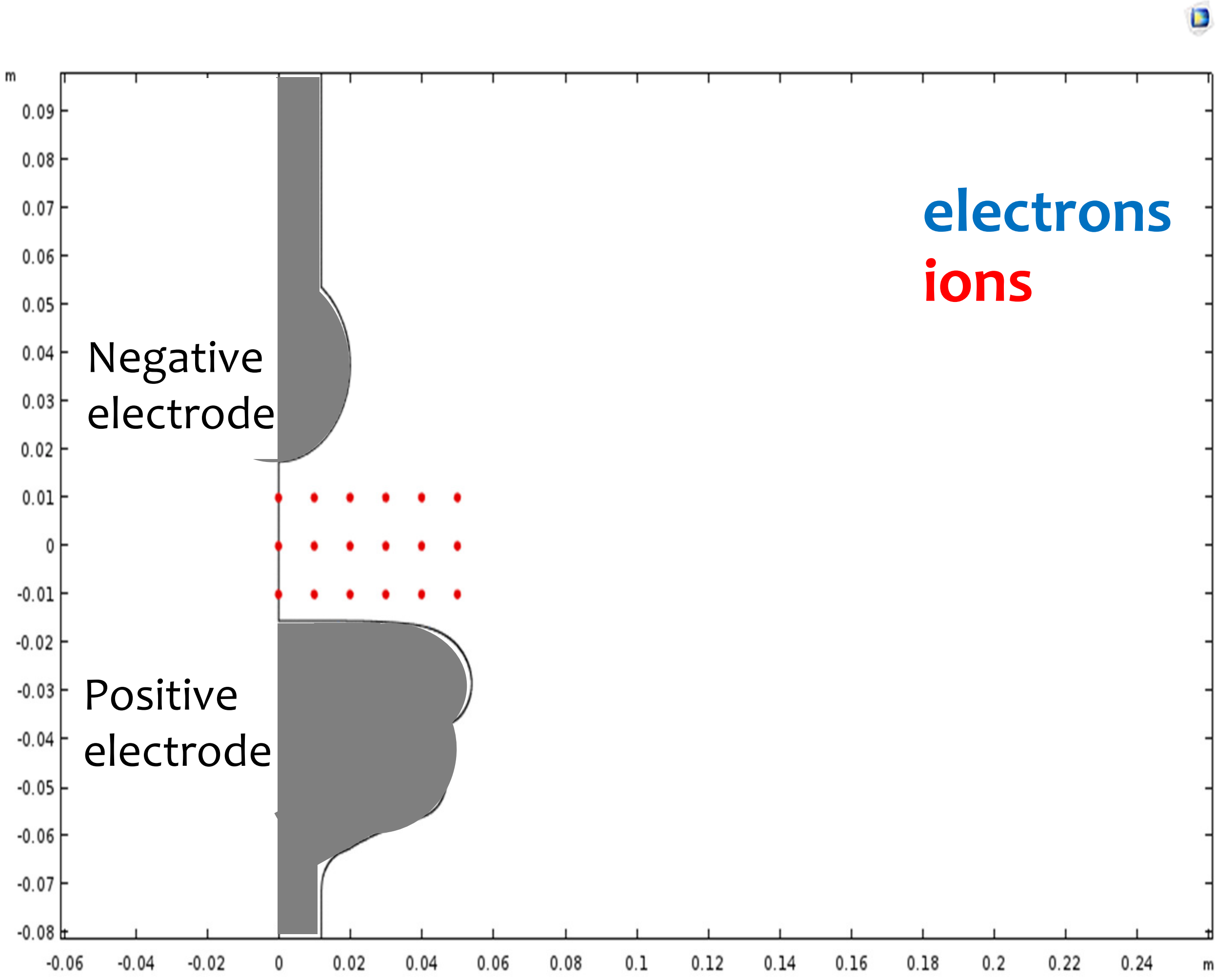




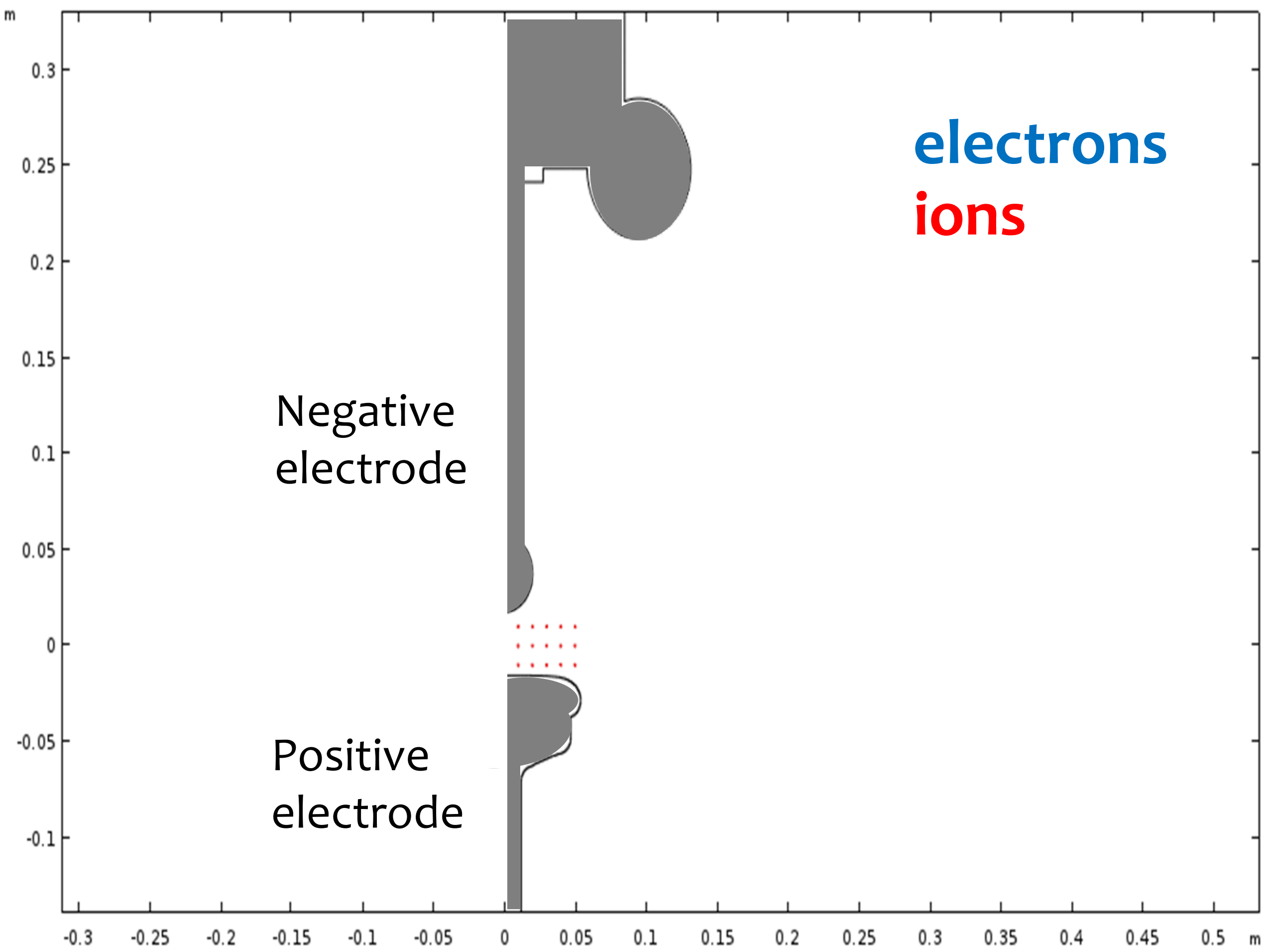


- Axisymmetric geometry of the chamber
- Electrode = electrode itself + its metallic support
- Ion/electron pairs matrix between the electrodes (v=0), miming the ionized gas

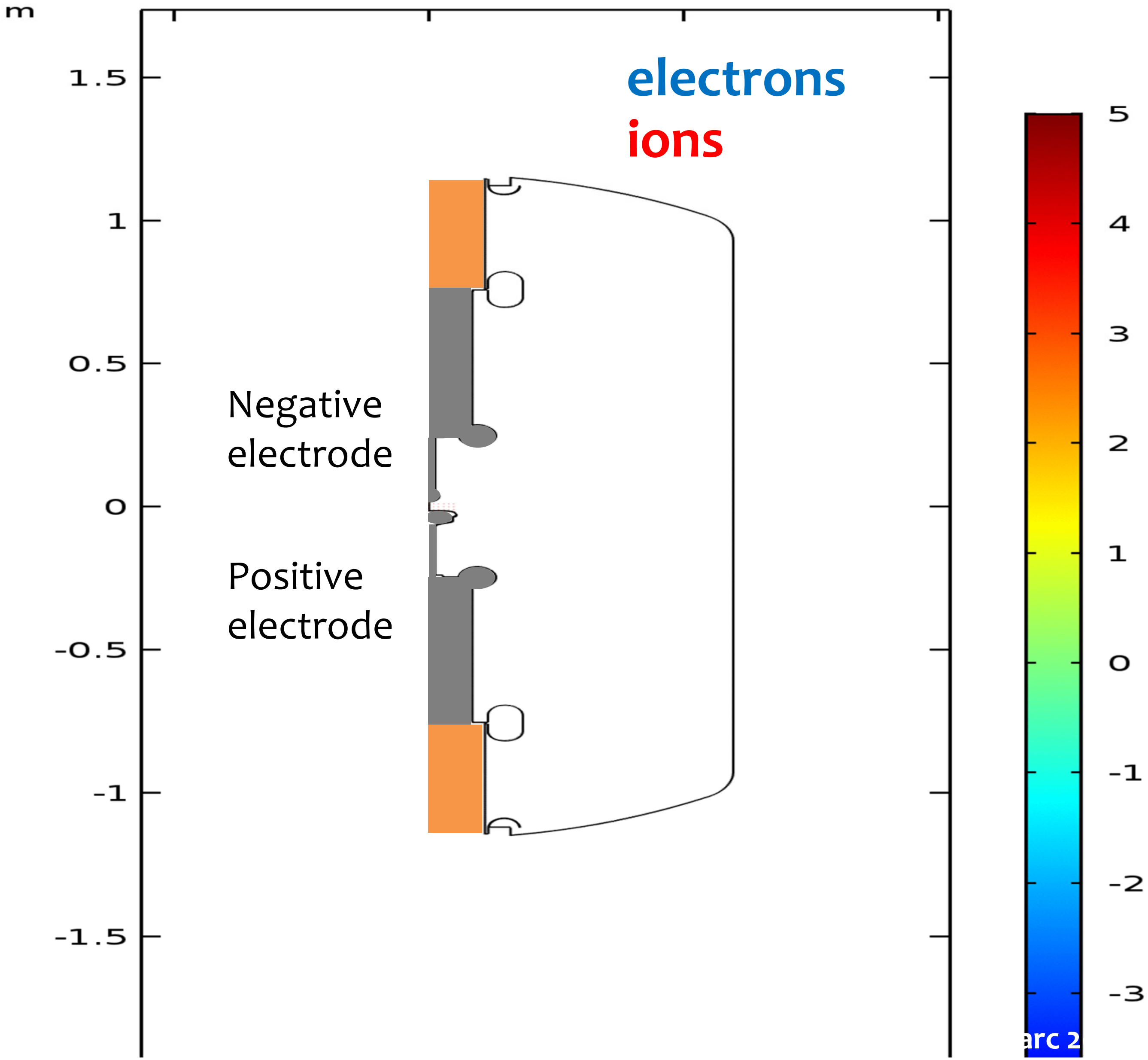
Tentative interpretation by simulation



Tentative interpretation by simulation



Tentative interpretation by simulation



Summary

- LYSO and LaBr scintillators revealed a MicroDischarge fine dynamics.
- Anode current increases during the condition process.
- The MD dynamics changes during the conditioning process: from 1 to 3 phases observed by X detectors.
- Tentative interpretation of the 3-phases MD:
  1) cathode emits electrons hitting the anode,
  2) gas is released by the anode and ionized,
  3) ionized particles generate secondary electrodes hitting electrodes and chamber.
- The 3rd phase could explain the current asymmetry: a (growing) amount of secondary electrons are collected by the anode.
- A simple study of the current contributions collected by anode and cathode suggests that the fraction of gas particle interacting with the electrode, EIF, is a crucial parameter to evaluate R.
- First steps in charged particle tracing simulation.

THANK YOU