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Ricerca Formazione Innovazione

Current signals and X-ray spectra analysis for a vacuum high voltage holding experiment

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Megavolt ITER Injector and Concept Advancement

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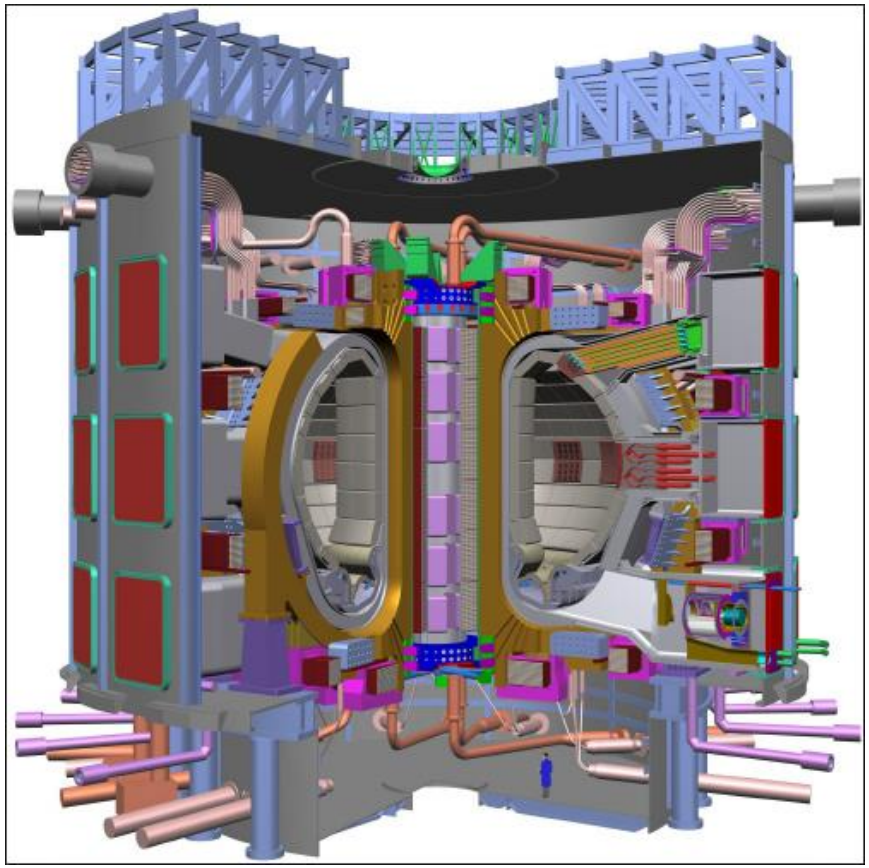
ITER is an international experimental facility (Cadarache, France) aiming to demonstrate the technological and scientific feasibility of **thermonuclear fusion** as an energy source. It requires additional heating by two **neutral beam injectors**.



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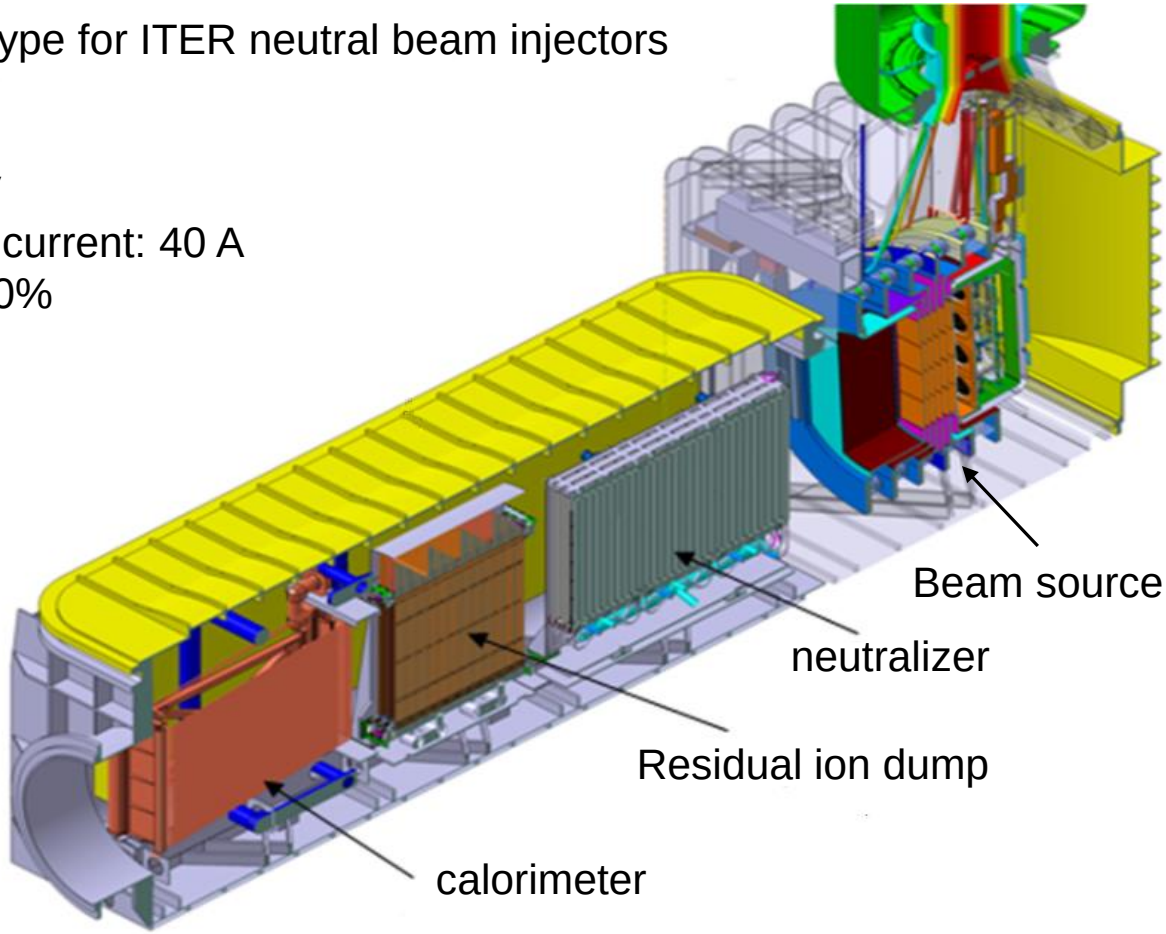
MITICA is a full-scale prototype for ITER neutral beam injectors (Padova, Italy)

- 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



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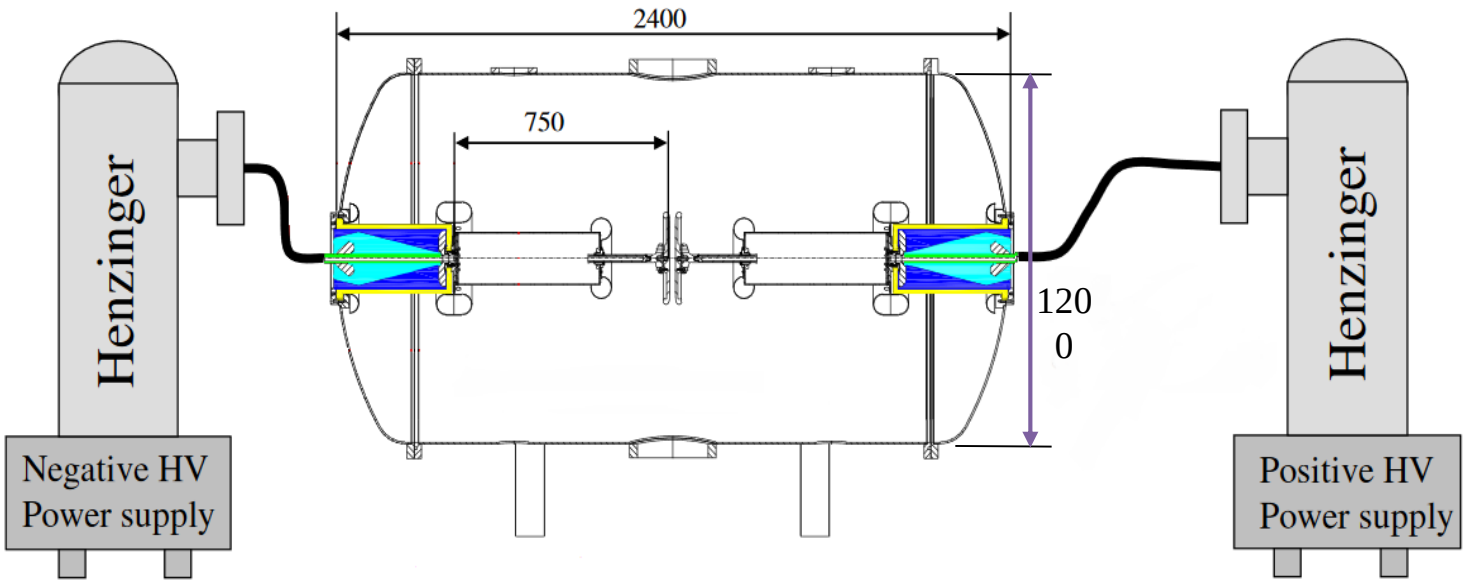
Open issue: voltage holding capability in the gap between the Ion Source and the Vessel in MITICA (conditioning pressure of 10^{-5} Pa, typical gap of 1 m)

High Voltage Padova Test Facility

HVPTF aims:
- to support MITICA design and operation
- to test MITICA components (e.g. high voltage insulators)
- to investigate the voltage holding in vacuum as a physical phenomenon (e.g. diagnostics, large gaps)

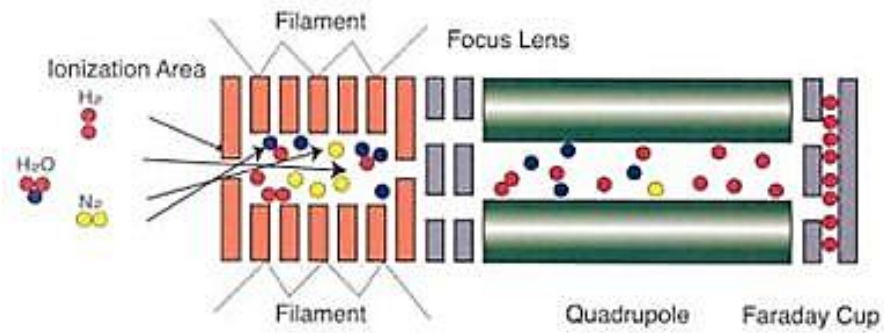


- Stainless steel vacuum chamber (2.4 m long, Ø=1.2 m)
- 2 Cockcrof-Walton power supplies, +400 kV, -400kV, 1mA dc
- Vacuum pressure around 4.10^{-7}mbar
- Electrodes gap length 0-250 mm

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.

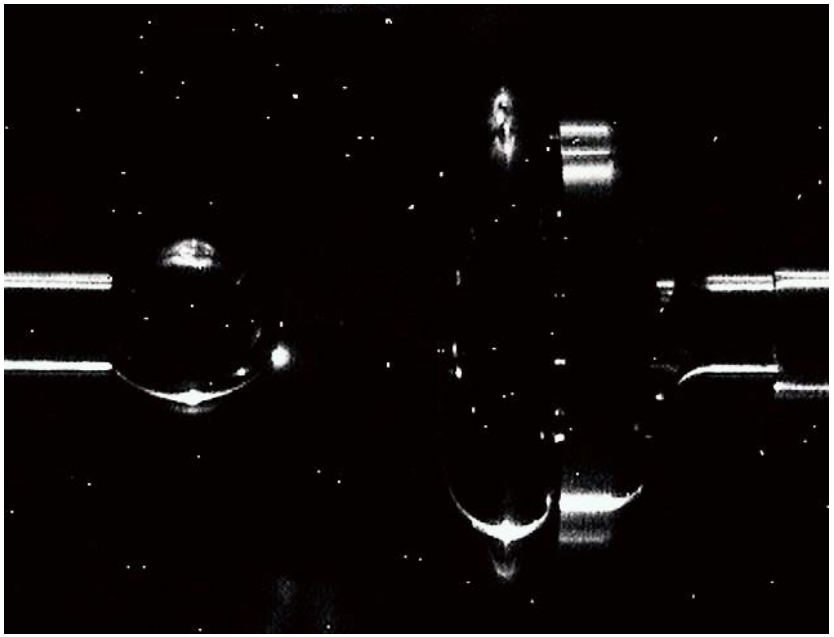


•X-rays are measured by a EJ-228 organic scintillator in polyvinyl toluene (PVT), positioned outside the vacuum chamber, at 1 meter far from a glass window. It is connected to a multichannel digitizer, recording energy and time of each single photon detected up to a maximum rate of 350 kHz.

•An Infra-Red Camera is devoted to the monitoring of the temperature inside the vessel. Thermal sensitivity: 0.03°C; each frame is recorded at 50 Hz.

Electrodes

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

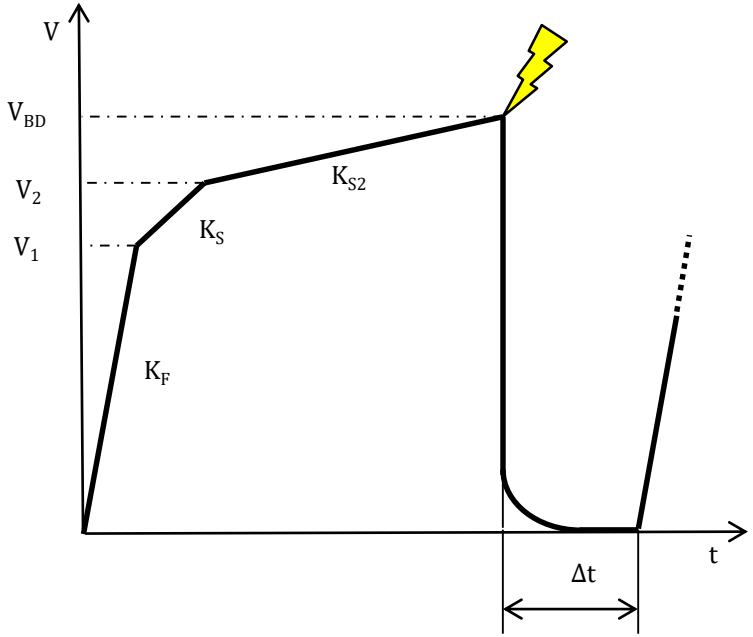


Electrodes treatment: dry polishing using abrasive sheets with decreasing grain size
acetone cleaning
ultrasound washing

Tension cycle

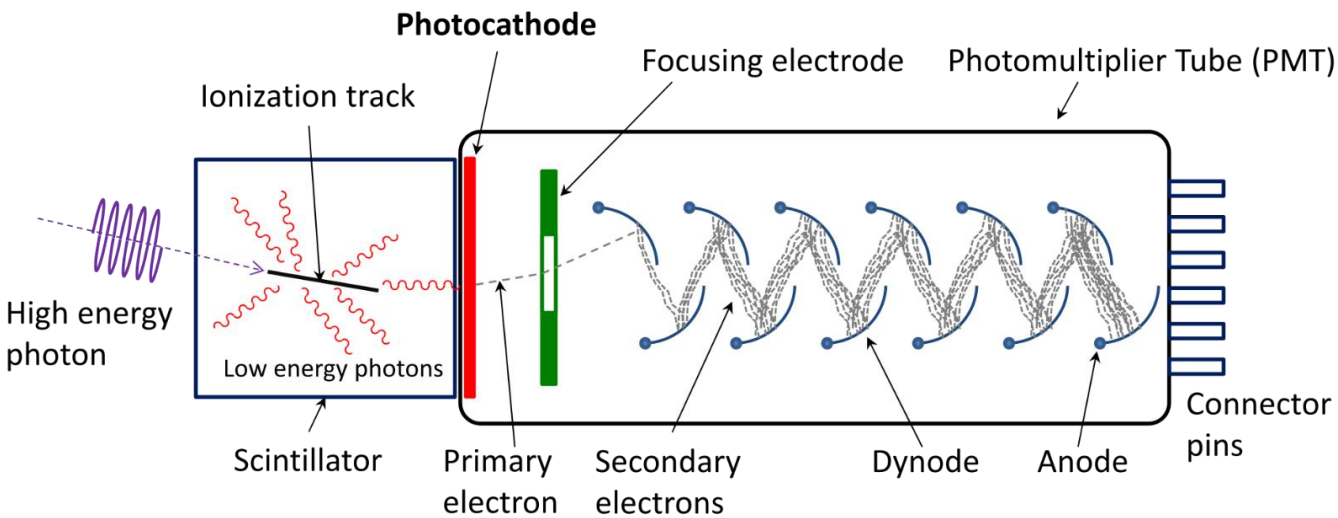
Tension is regulated by an automatic procedure, simmetrically operating on both power supplies:

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



X-ray diagnostics: the instrument

X-rays are emitted by accelerated electrons during high voltage conditioning: we study their energy spectrum in time, single events are distinguished.



EJ-228 plastic scintillator detector:
- intended for very fast timing applications;
- in air, 1 m from a glass window DN 100 (5 mm thick);
- connected to a CAEN DT5720B multichannel digitizer;
- Energy and time of each single photon detected is recorded up to 350 kHz.

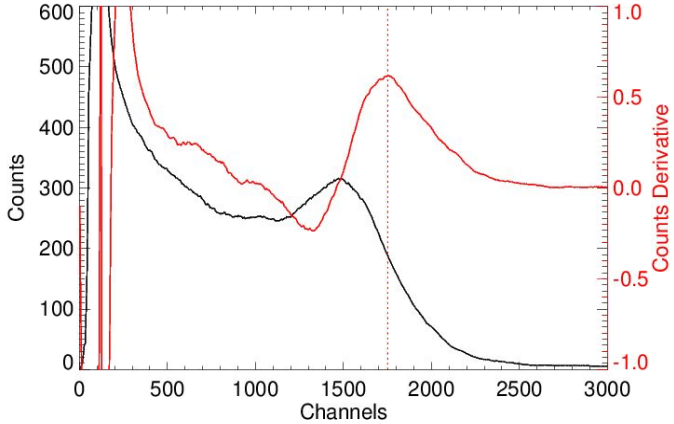
X-ray diagnostics: energy spectrum calibration

X-ray energy in this range in organic scintillators is mainly converted to scintillator light via single Compton scattering: the energy distribution is continuous, due to the different scattering angles, till a maximum value, named **Compton edge:**

$$E_C = \frac{2E^2}{m_e c^2 + E}$$ where E is the incident photon energy

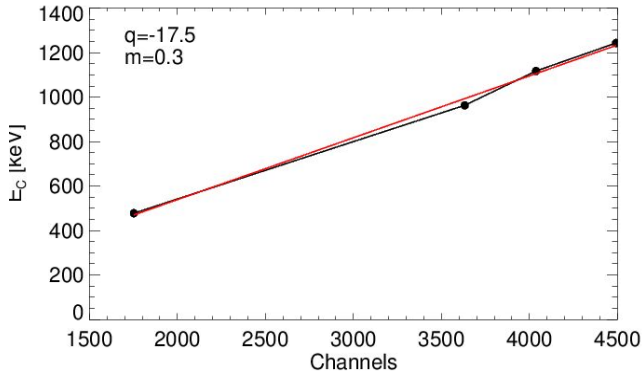
Radioactive sources used as known photons emitters:

- $^{40}K \rightarrow E = 1461$ keV
- $^{60}Co \rightarrow E = 1173$ keV, 1332 keV
- $^{137}Cs \rightarrow E = 662$ keV

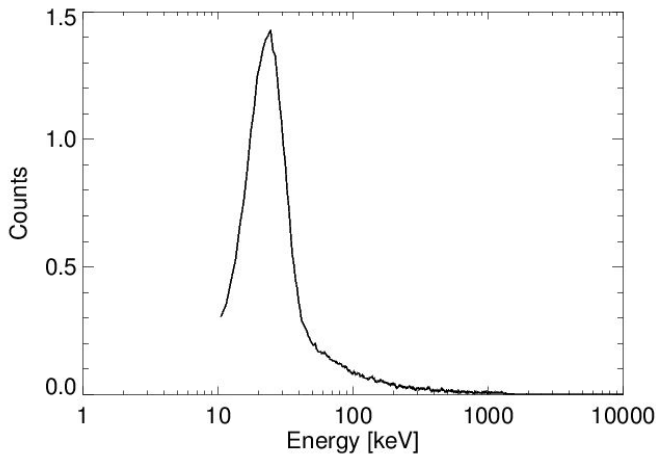


$$\boxed{E\ (\text{keV}) = E\ (\text{ch}) \cdot m}$$

convertion index

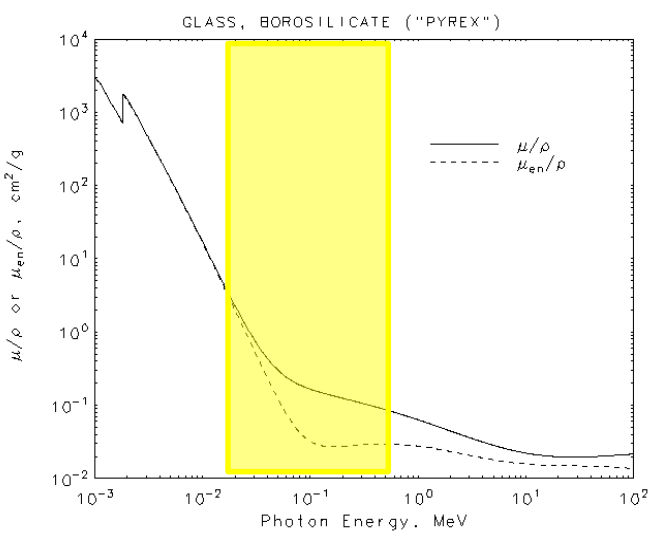


X-ray diagnostics: background and attenuation



Background radiation is subtracted by the measured energy spectrum

X-rays measurement is affected by the possibility to interact with the molecules of the vessel window and of the scintillator plastic:



$$\Gamma = \Gamma_0 e^{-\mu x}$$

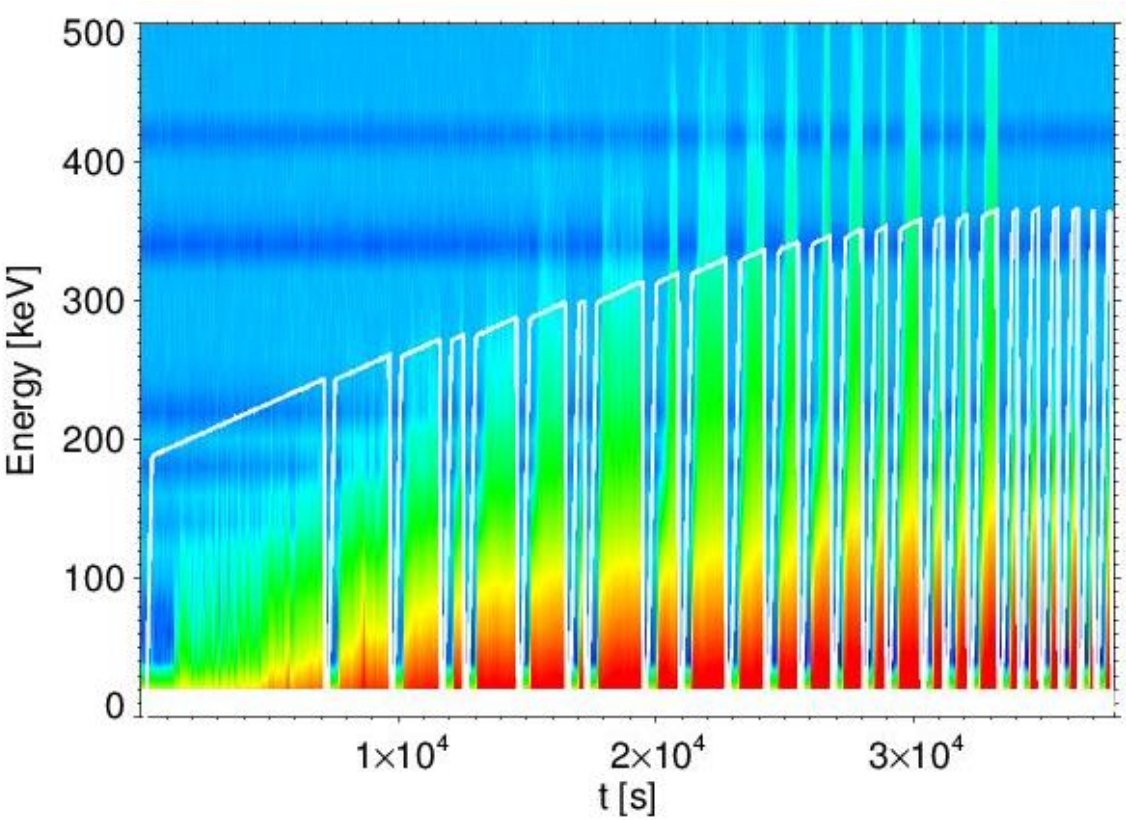
Attenuation coefficient

Glass: x_g=5 mm, PVT: x_p=60 mm

$$\Gamma_0 = \Gamma_m / \{e^{-\mu_g x_g}[1 - e^{-\mu_p x_p}]\}$$

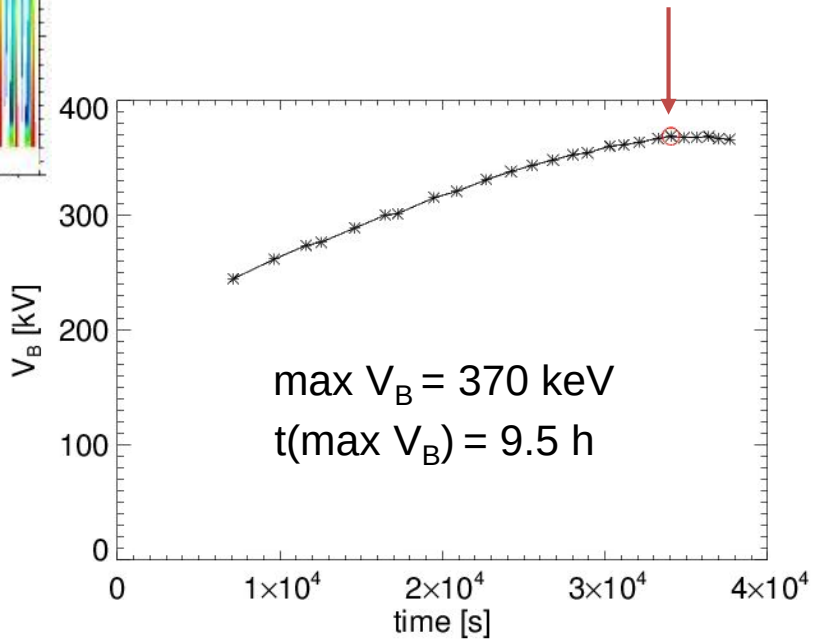
National Institute of Standards and Technology (NIST)

X-rays energy spectrum



X-rays energy spectrum during a conditioning session

It is a sum of Compton spectra

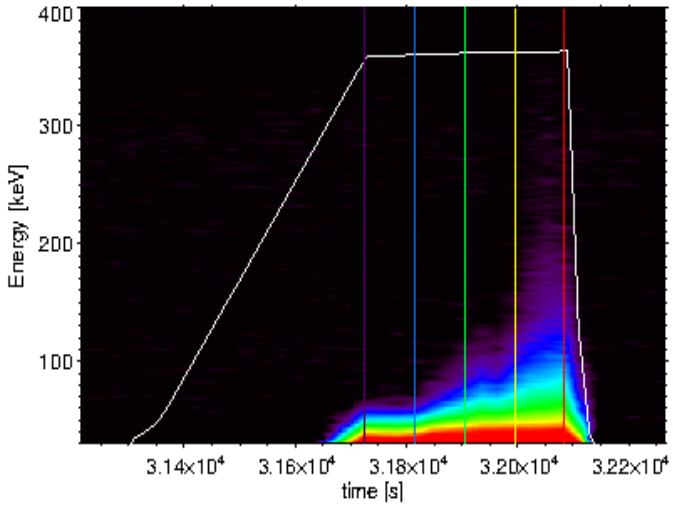


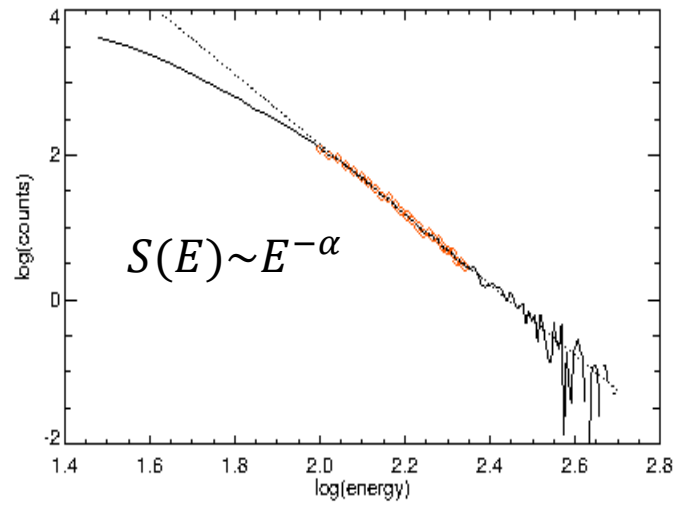
X-ray activity increases with the voltage, but not linearly.

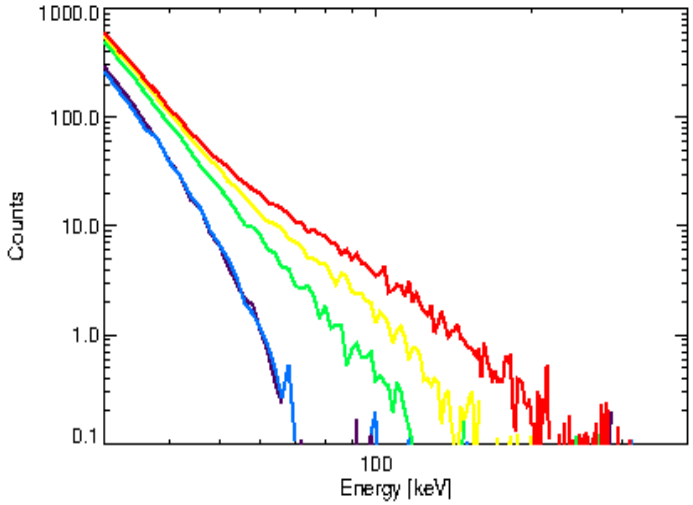
No high energy X-rays after the maximum tension value is achieved.

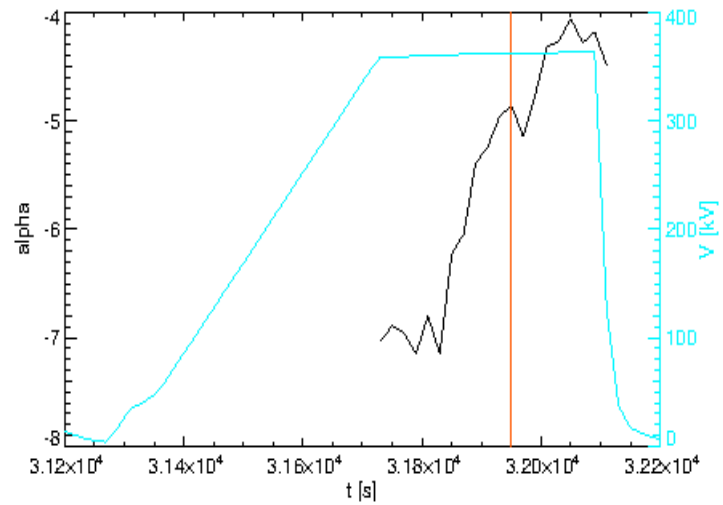
X-rays energy spectrum

The X-rays spectrum evolves within the tension cycle

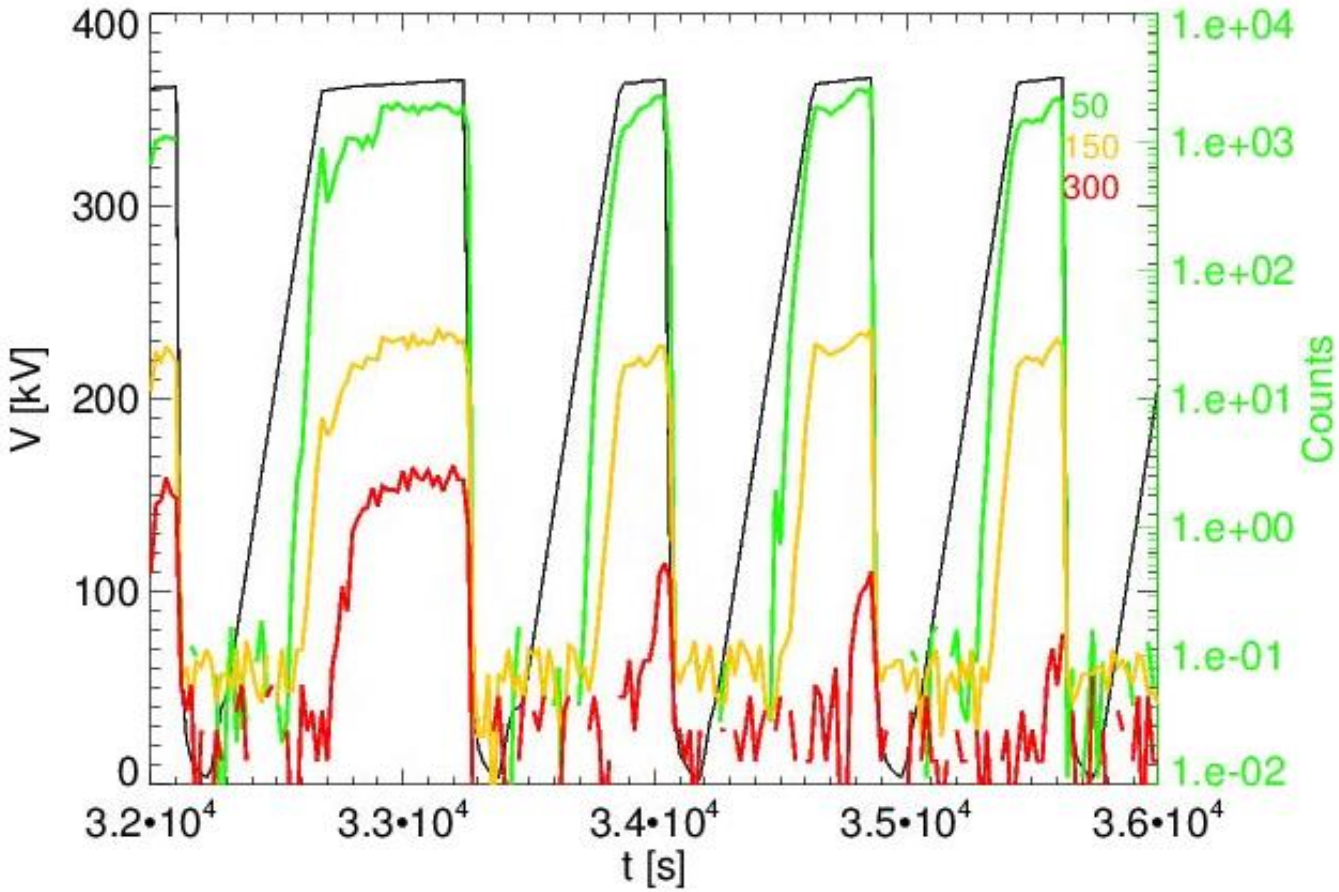








X-rays energy spectrum



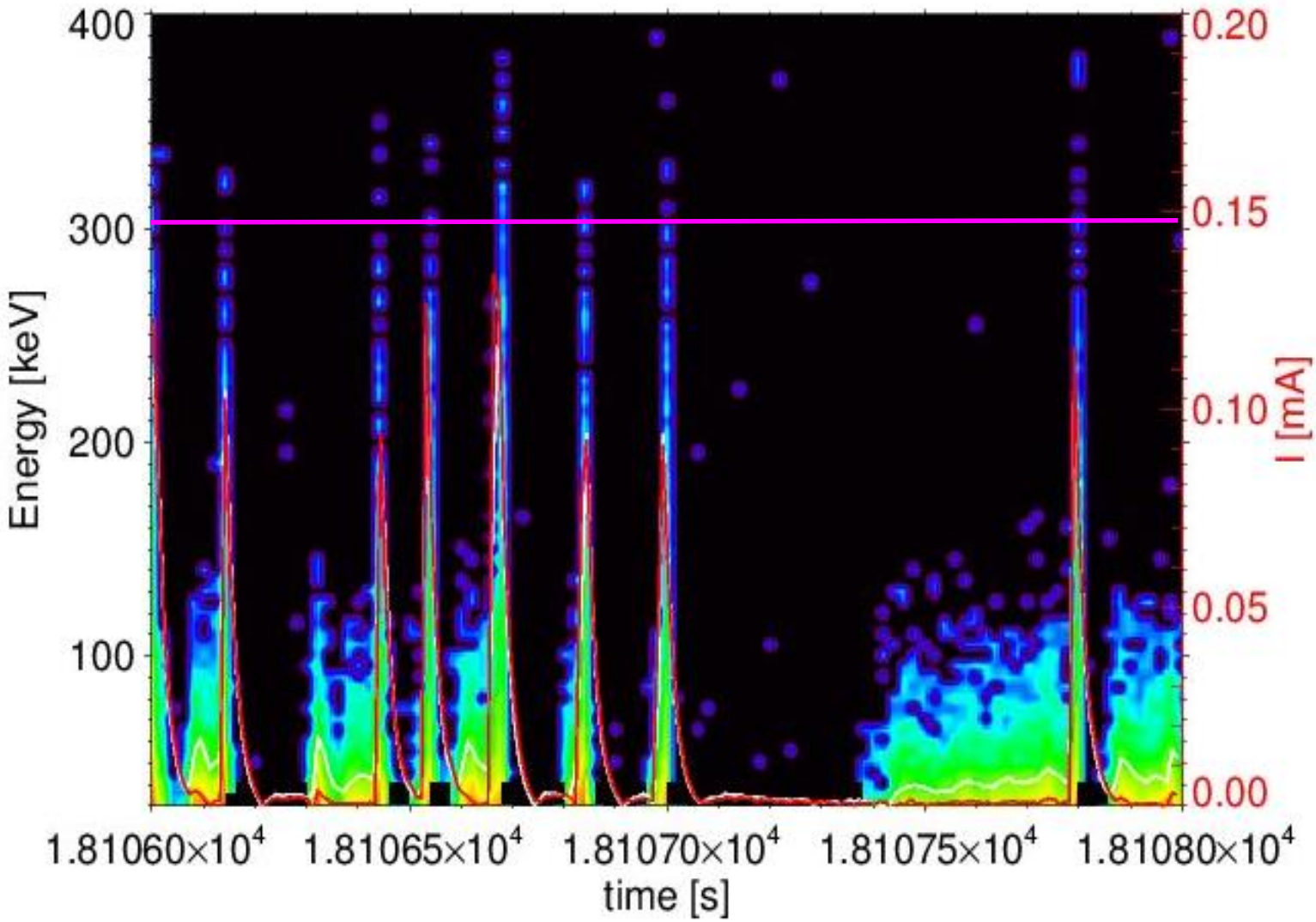
E_1=50 keV

E_2=150 keV

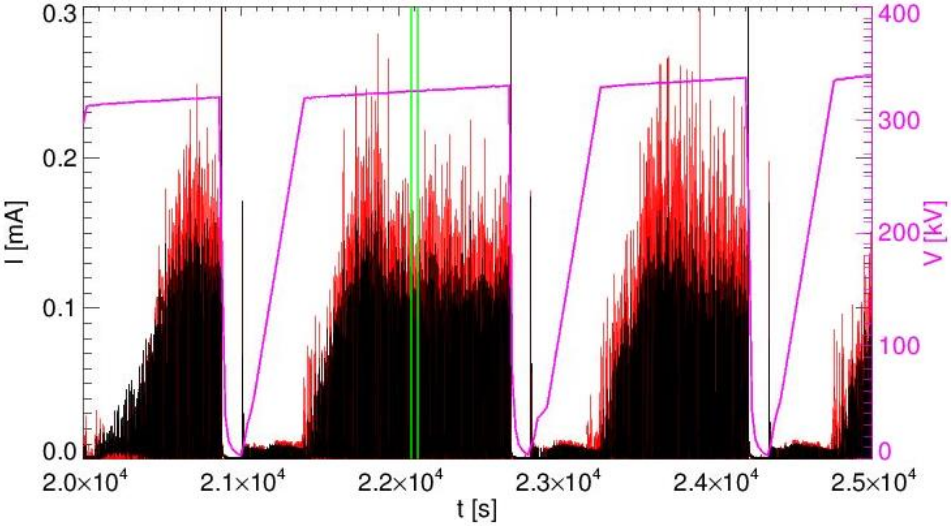
E_3=300 keV

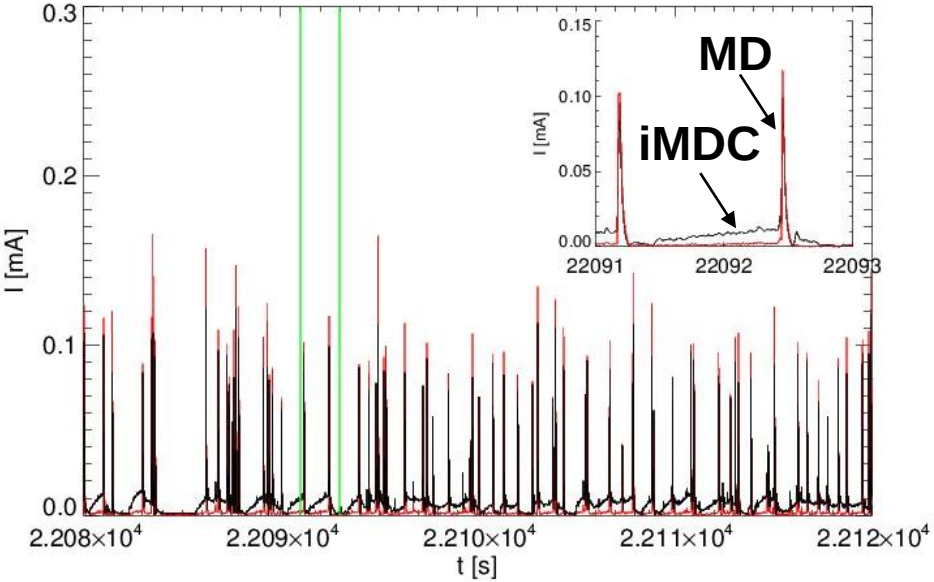
ΔE=10 keV

X-rays energy spectrum



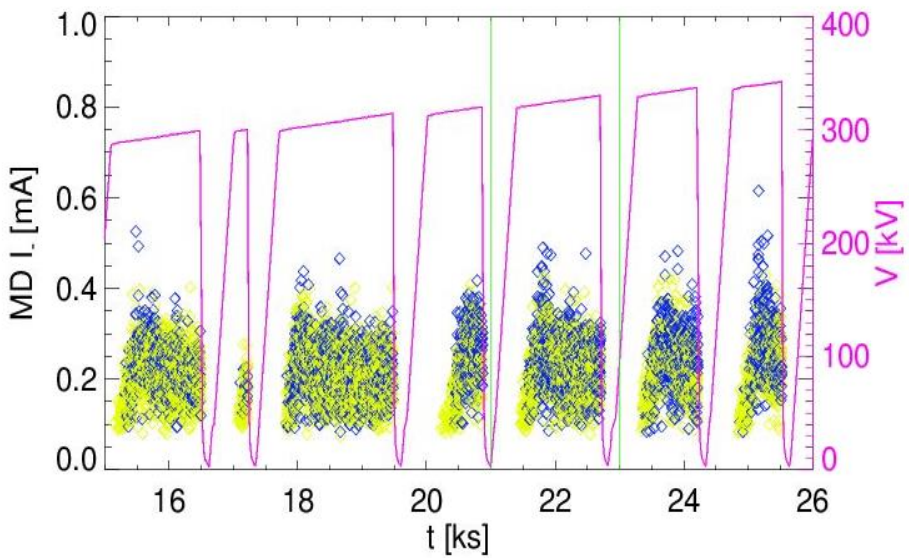
The current signals

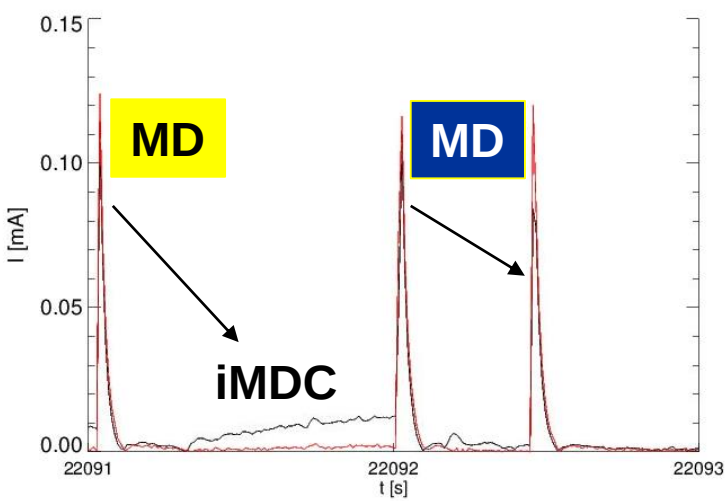


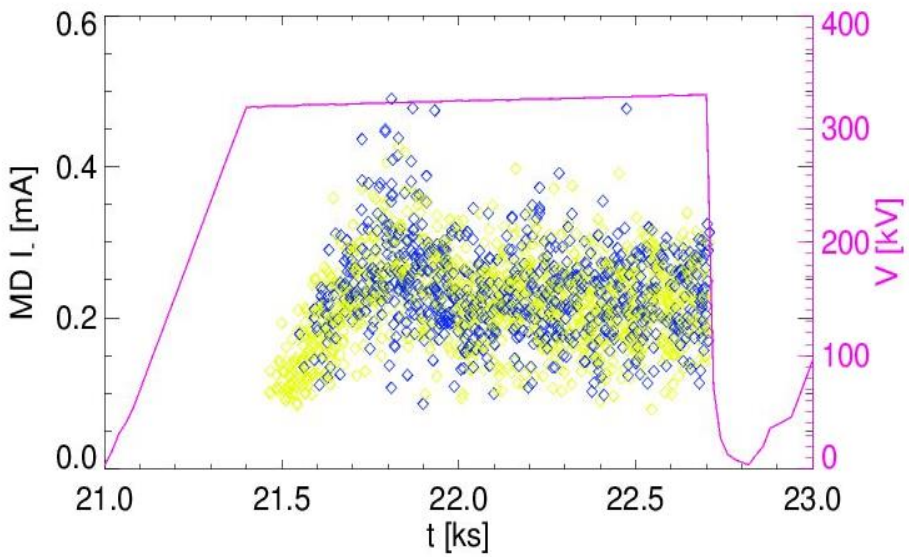


- I_+ and I_- both exhibit the occurrence of spikes or **microdischarges (MD):** it is an interation between electrodes.
- I_- signal measures an almost continuous current of about 0.01 mA, not simmetrically corresponded by the I_+, named in the following **inter-MD Current (iMDC).** The cathode interacts with the vessel.

The current signals

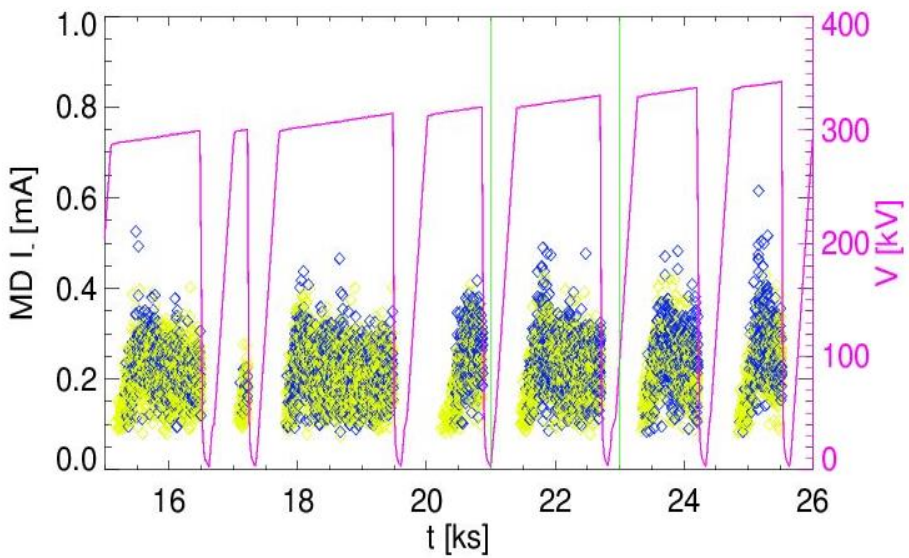


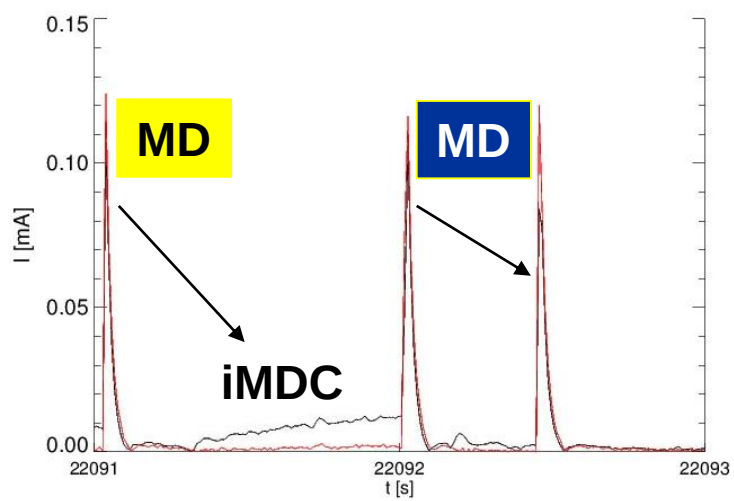


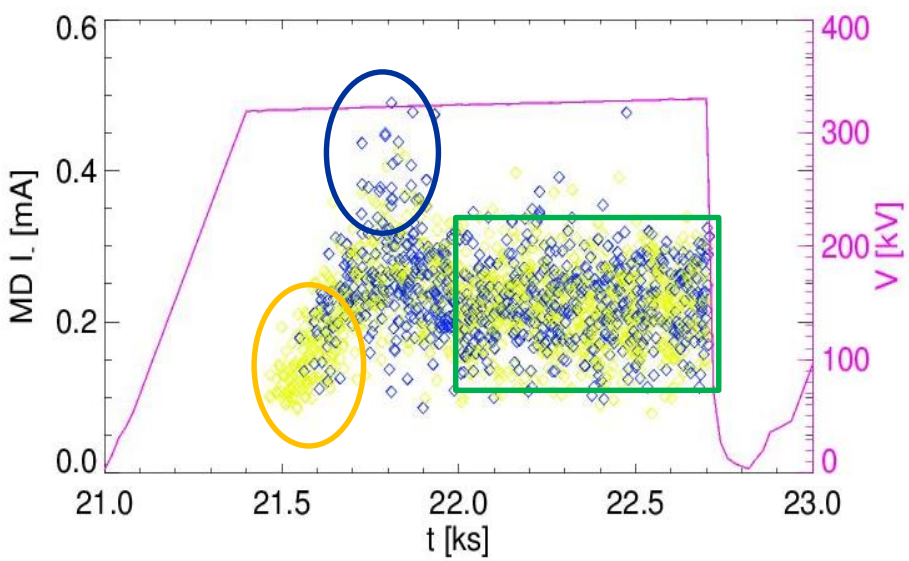


- MD followed by a non-zero iMDC
- MD followed by another MD

The current signals





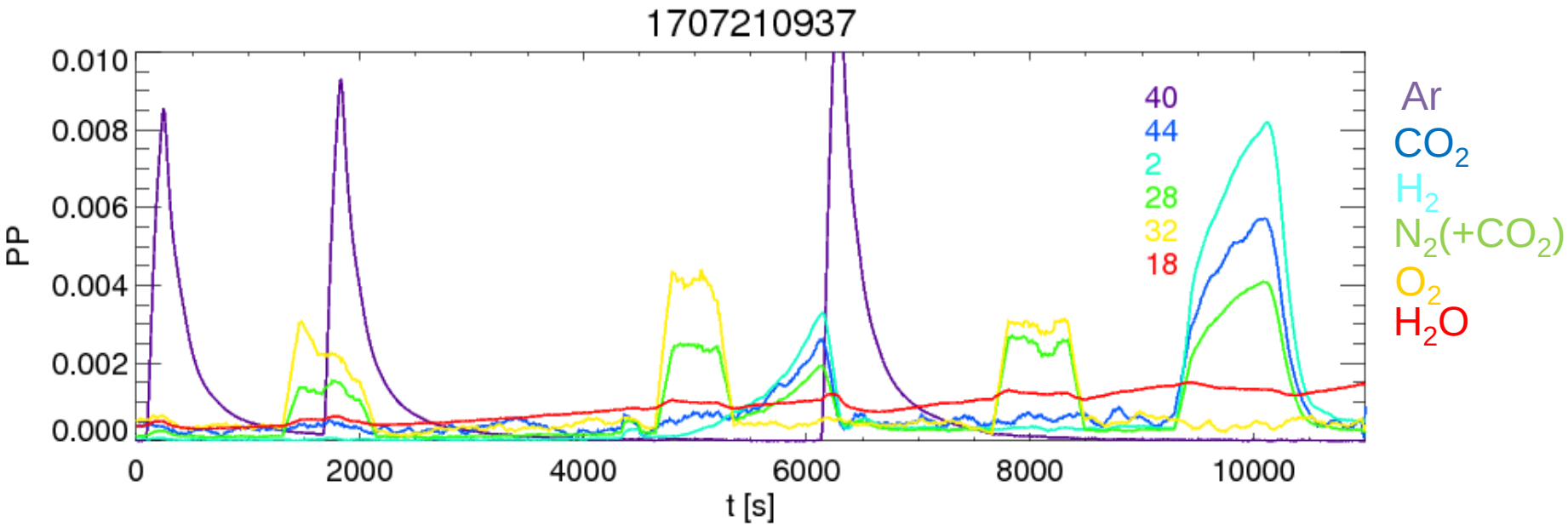


- ◇ MD followed by a non-zero iMDC
- ◇ MD followed by another MD

<u>For each tension cycle</u>:

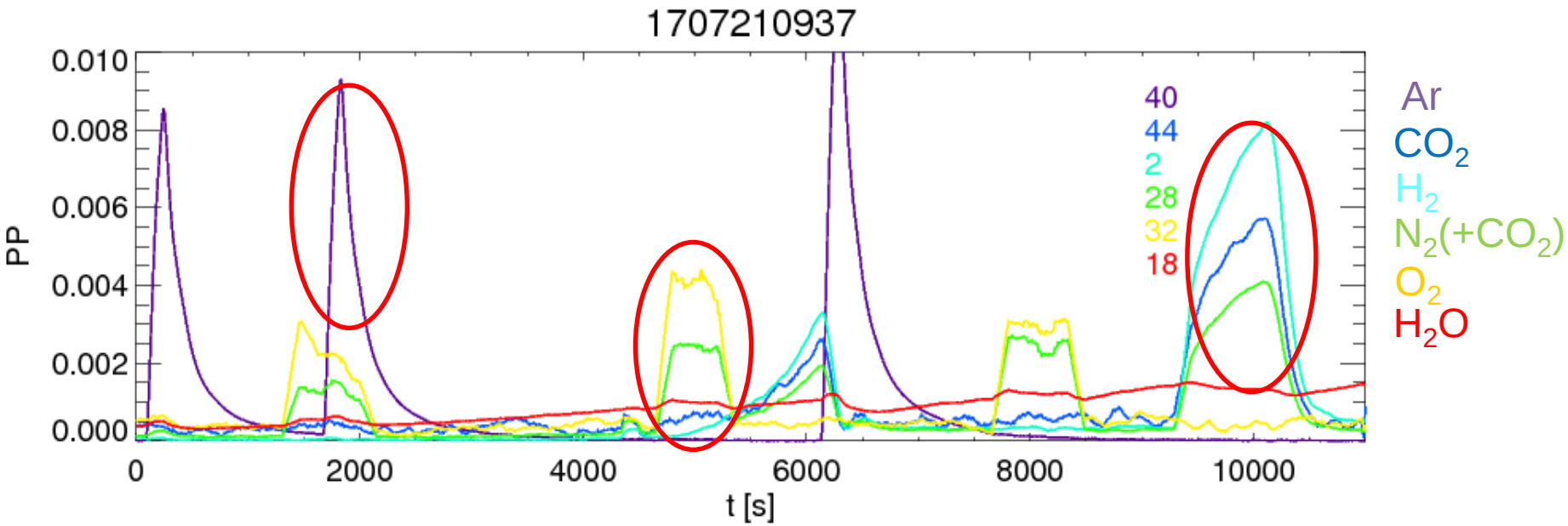
- ◇ small-current MD followed by iMDC accumulate in correspondence to the initial conditioning phase
- ◇ Intensive high current MD are seen at the end of this first initial phase;
- ◇ two types of events are almost evenly distributed.

RGA: different gas populations



Negative electrode connected to the vacuum vessel (0 V)

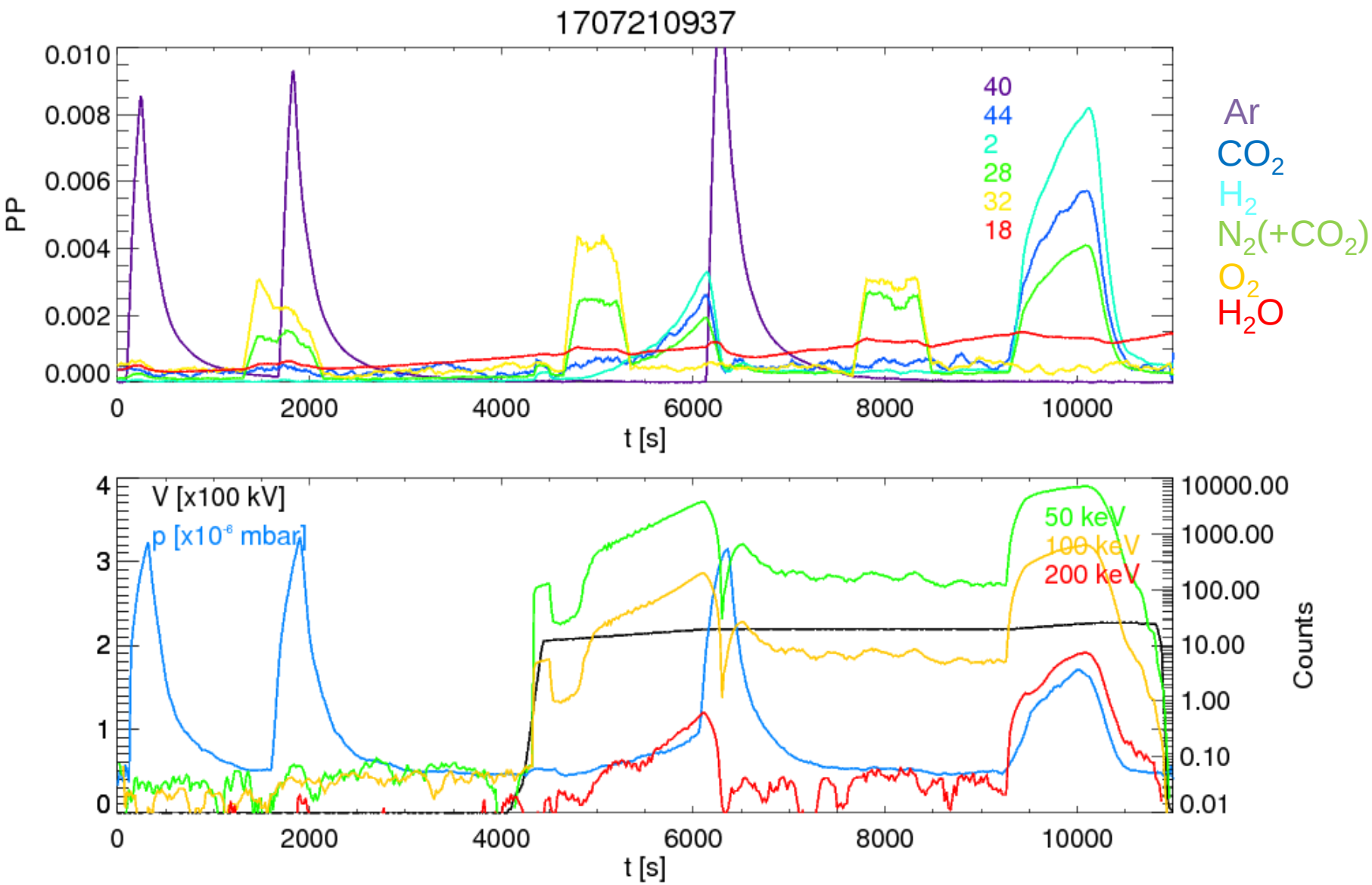
RGA: different gas populations



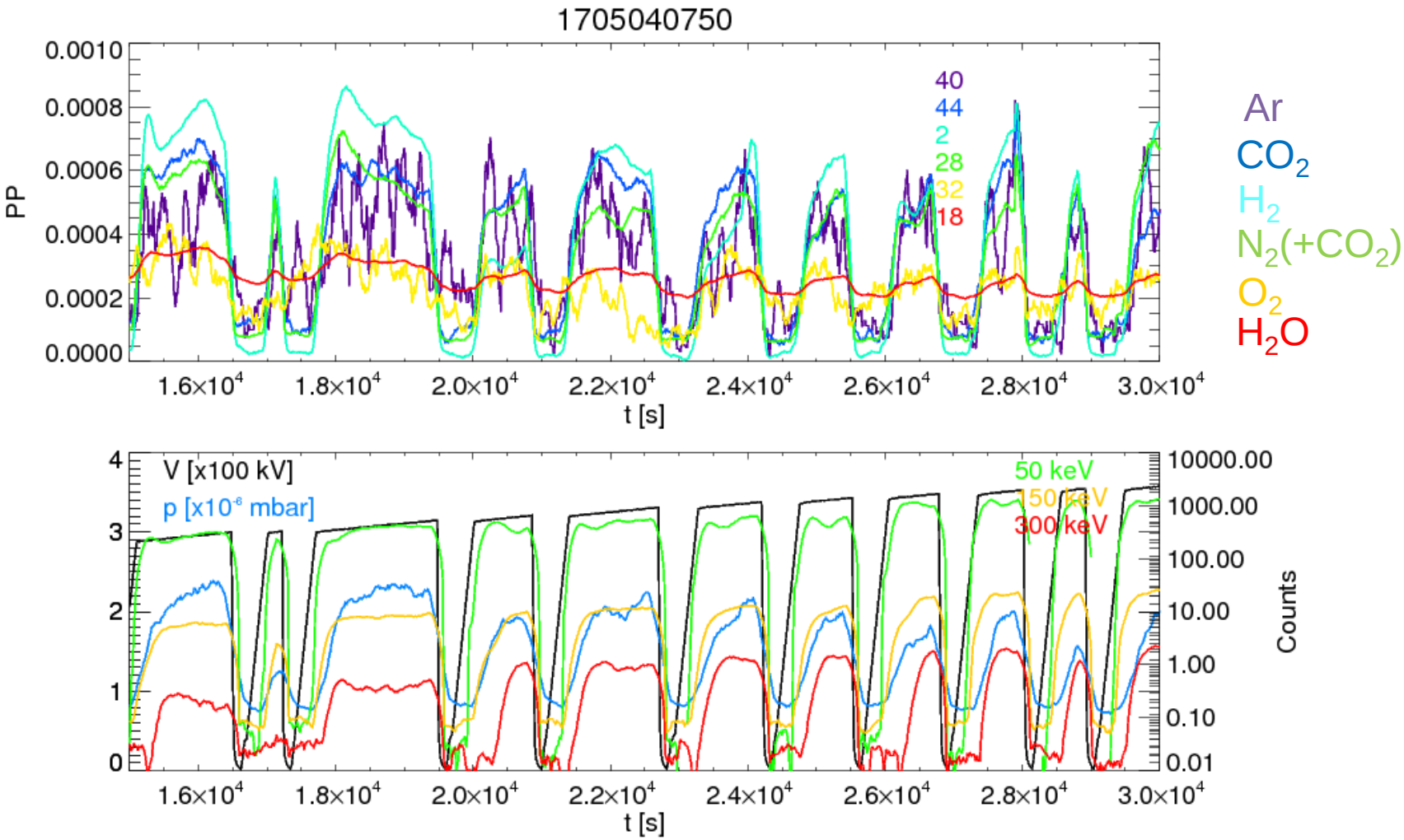
4 different gas populations:

- Argon (40) injection
- Air puff: O_2 (32), N_2 (28)
- Emission of H_2 (2), CO_2 (44), CO_2(+N2?) (28) in correspondence to high energy X-rays.
- H_2O (18) slightly increases in time

RGA: different gas populations



RGA: different gas populations



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- H_2O (18) slightly decreases in time

Summary and conclusions

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- HVPTF is an experimental device with the aim to investigate the voltage holding in vacuum in support of MITICA accelerator and as a physical phenomenon.
- Three new diagnostics have been implemented last year, in particular a X-rays detector.
- X-rays spectrum evolves during the tension cycle: high energy events increase during the conditioning.
- A clear relation between I_- current signal and X-rays measurement: MD are associated to high energy events, iMDC produces half energy X-rays.
- Different conditioning regimes are observed within the tension cycle, in particular during the initial phase.
- The emission of Hydrogen and Carbon dioxide is measured in correspondence of the high energy X-rays detection.

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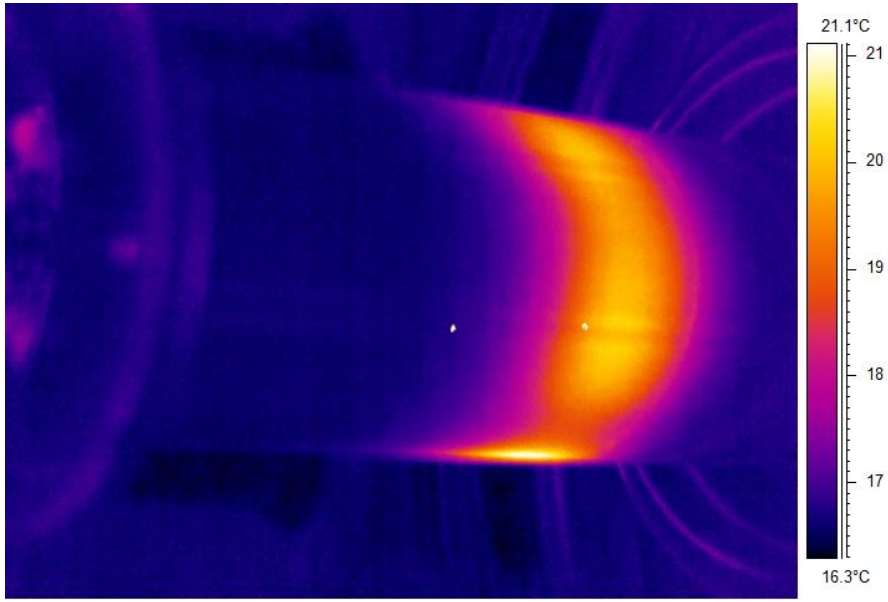
Thank you for the attention

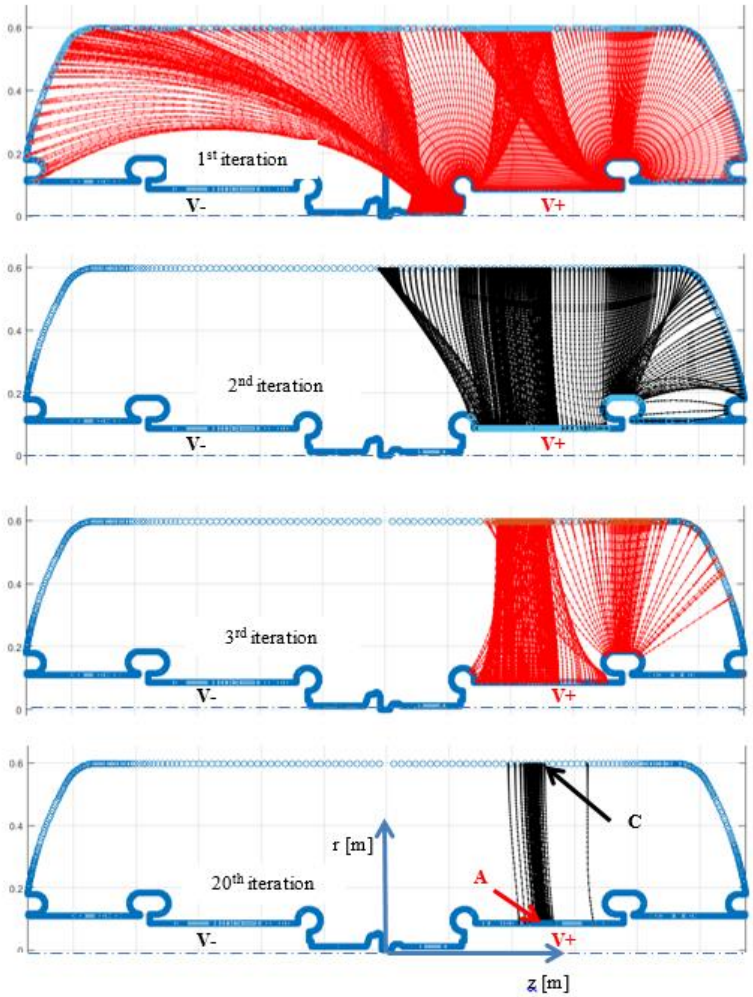
Iron and Chromium from the stainless steel anodic support



IR camera picture of the stainless steel (cantilever) arm connected to the positive power supply and supporting the planar electrode

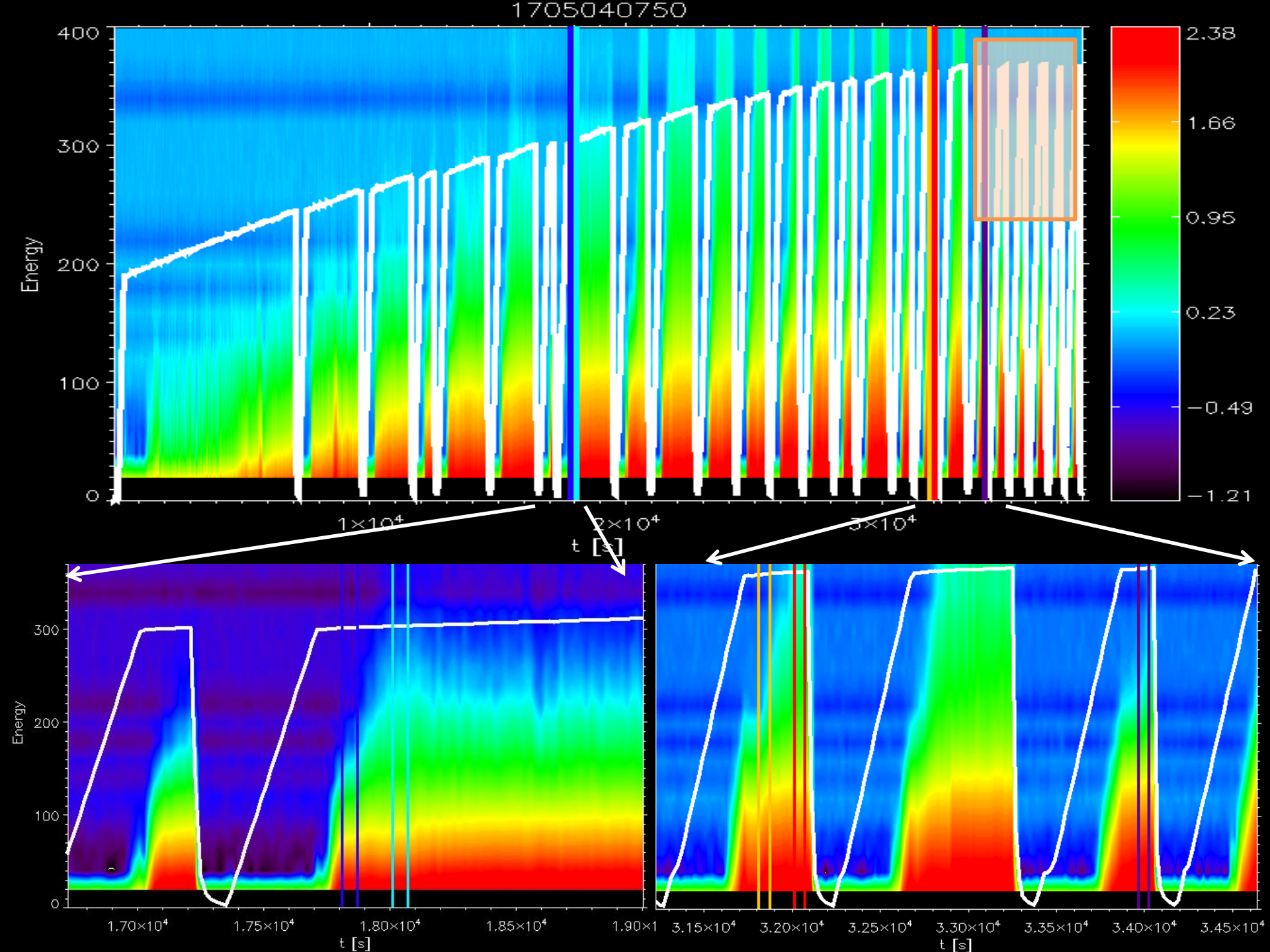
Vessel inner wall : two circumferential stains are progressively appeared during the execution of the high voltage tests

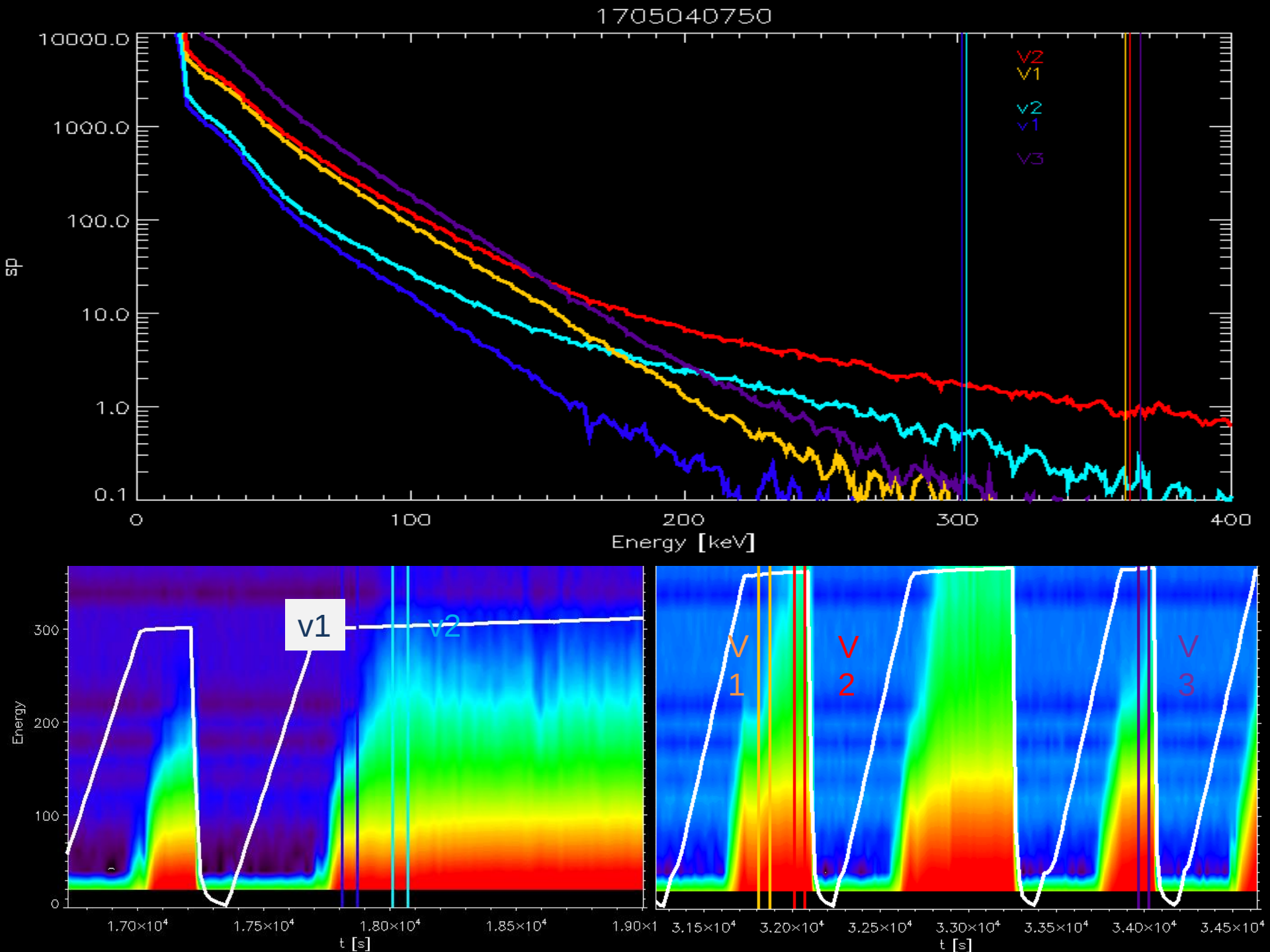
N. Pilan et al. “Evidences of accumulation points in cascade regenerative phenomena observed in high voltage dc devices insulated by vacuum“ submitted to *New Journal of Physics*.

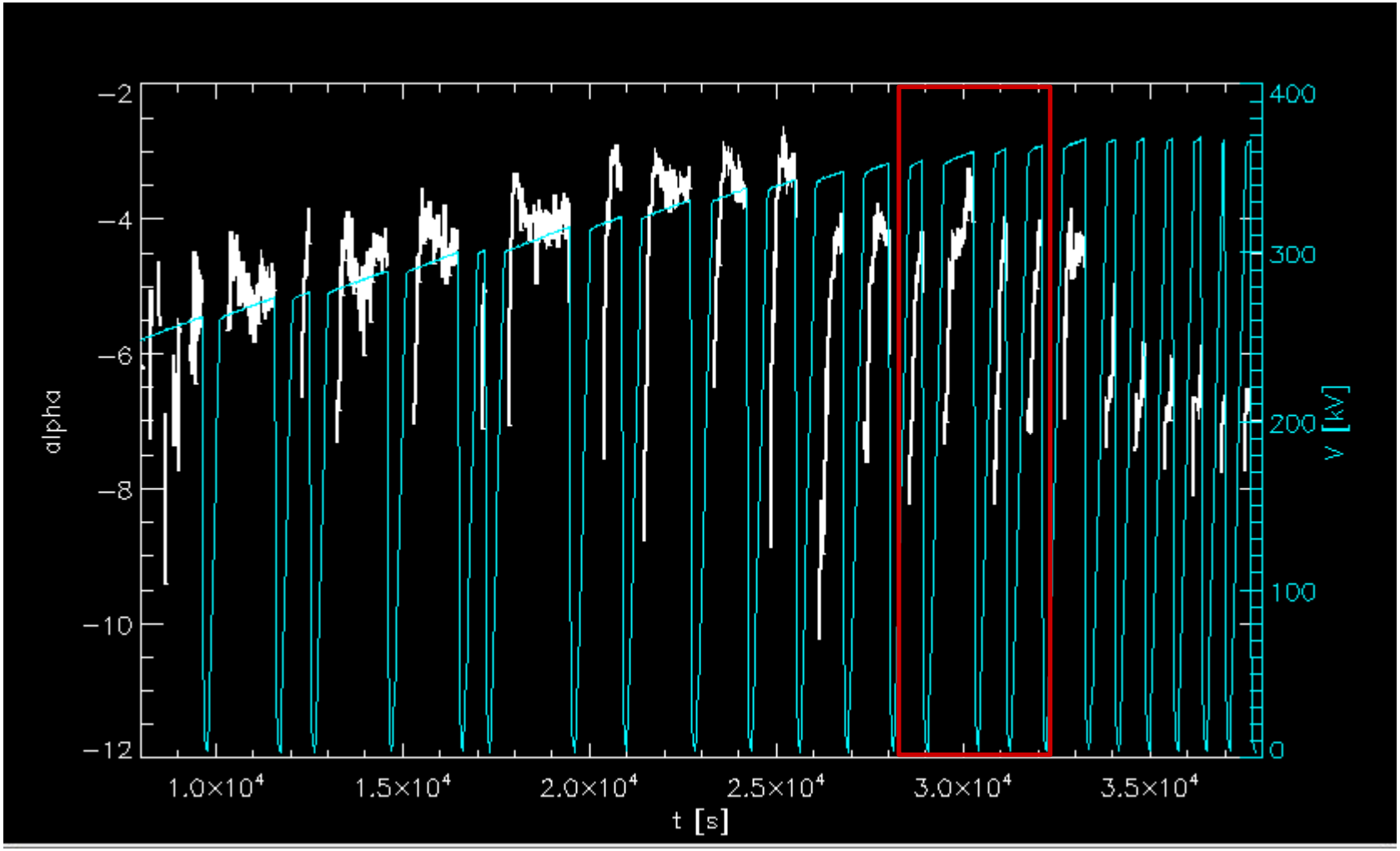


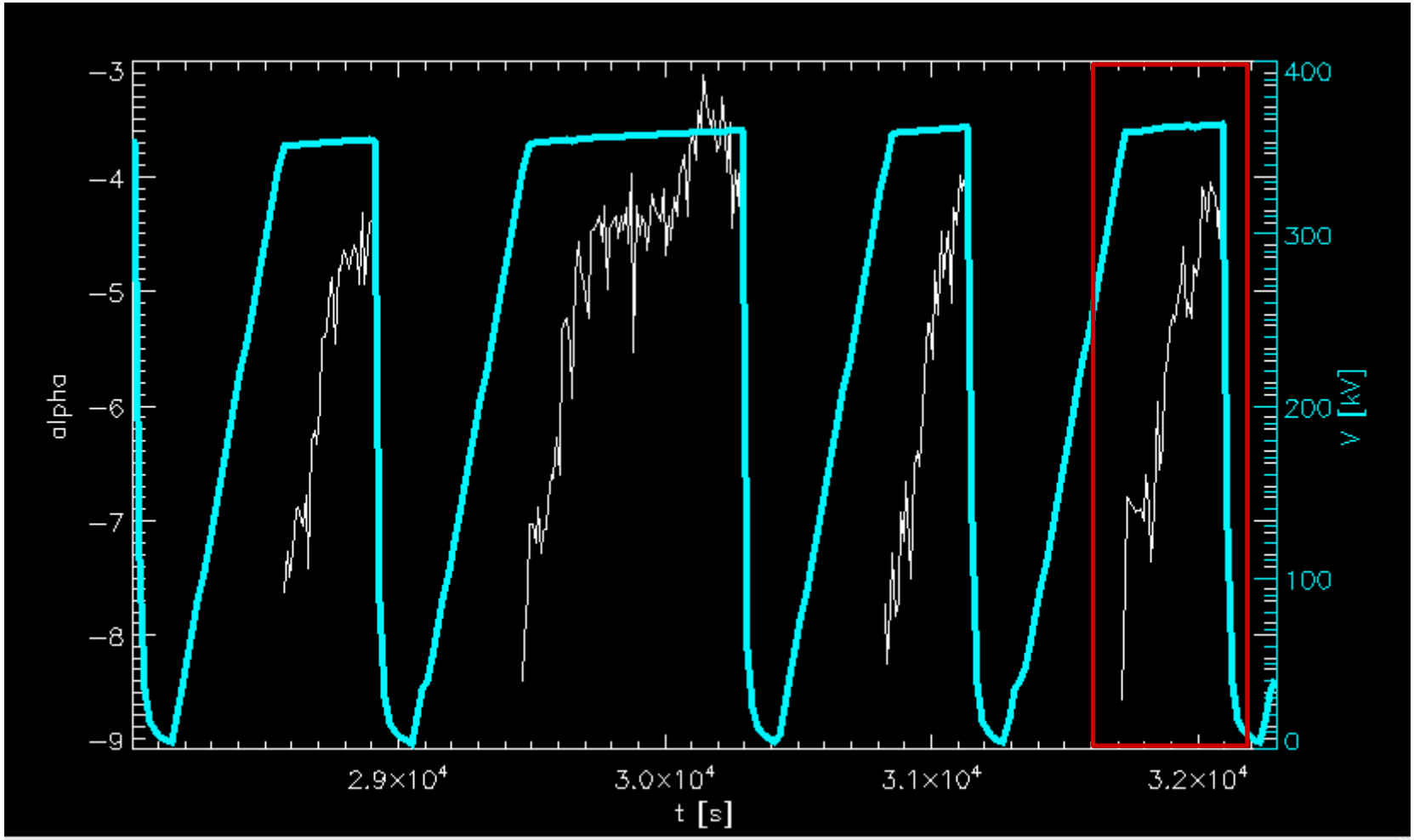
The trajectories of positive charged particles, uniformly distributed on the anodic surfaces, have been integrated considering the an axialsimmetric electrostatic field map.
The trajectory stops when a charged particle hit an electrode, than the sign of the charge is changed and a new trajectory is integrated. The process has been repeated up to a condition characterized by a stationary mutual-exchange of trajectories. In this geometry, twenty iterations are necessary to converge toward the final configuration.

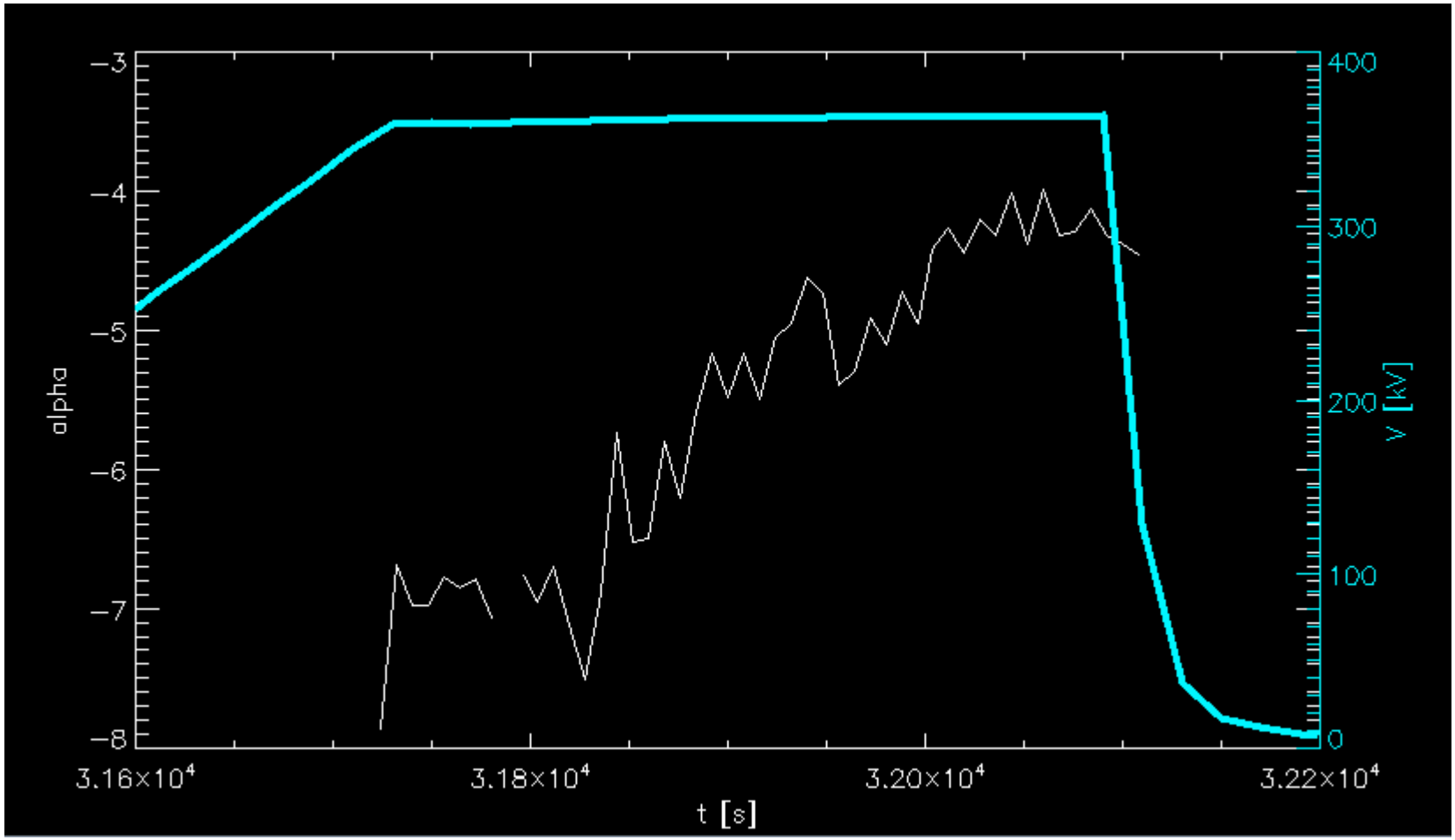
M. Cavenago et al, "Cascades of Secondary Particles in High Voltage Accelerators", Comsol, Stockholm (2010).


1705040750
Energy
400
300
200
100
0
1×10⁴
2×10⁴
3×10⁴
t [s]
2.38
1.66
0.95
0.23
−0.49
−1.21
Energy
300
200
100
0
1.70×10⁴
1.75×10⁴
1.80×10⁴
1.85×10⁴
t [s]
3.15×10⁴
3.20×10⁴
3.25×10⁴
3.30×10⁴
3.35×10⁴
3.40×10⁴
3.45×10⁴
t [s]


1705040750
V2
V1
v2
v1
V3
sp
10000.0
1000.0
100.0
10.0
1.0
0.1
0
100
200
300
400
Energy [keV]
v1
v2
Energy
300
200
100
0
1.70×10⁴
1.75×10⁴
1.80×10⁴
1.85×10⁴
t [s]
V 1
V 2
V 3
3.15×10⁴
3.20×10⁴
3.25×10⁴
3.30×10⁴
3.35×10⁴
3.40×10⁴
3.45×10⁴
t [s]


alpha
−2
−4
−6
−8
−10
−12
V [kV]
400
300
200
100
0
1.0×10^4
1.5×10^4
2.0×10^4
2.5×10^4
3.0×10^4
3.5×10^4
t [s]


alpha
−3
−4
−5
−6
−7
−8
−9
V [kV]
400
300
200
100
0
2.9×10⁴
3.0×10⁴
3.1×10⁴
3.2×10⁴
t [s]



Δt=8 s;
Interpolation: E=[100,220] keV