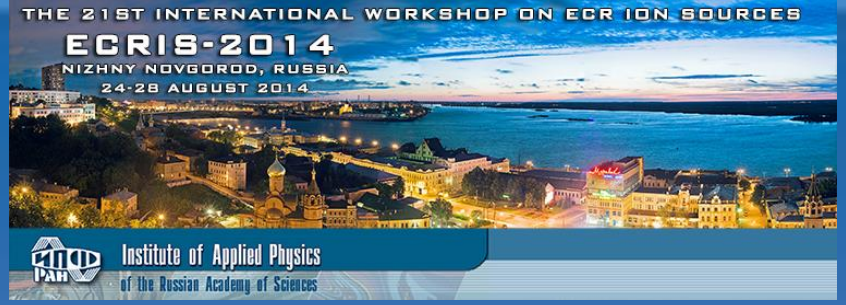

FIRST ION BEAMS EXTRACTED FROM A 60 GHZ ECR ION SOURCE USING POLYHELICES TECHNIQUE

T. Lamy for the collaboration

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F. Debray, C. Grandclement, P. Sala, C. Trophime – Grenoble, France
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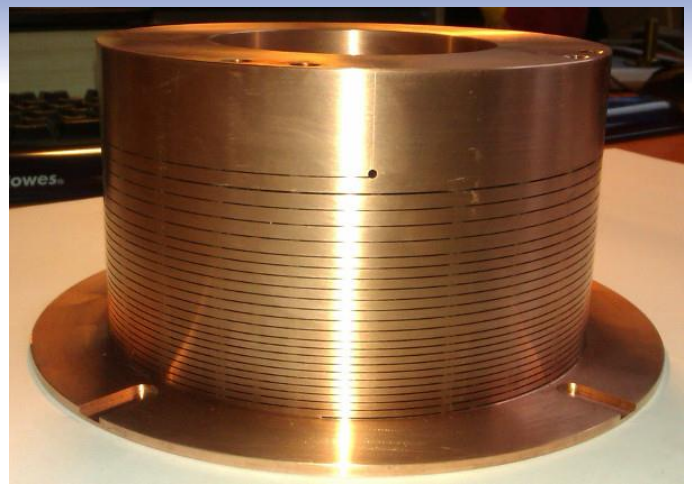
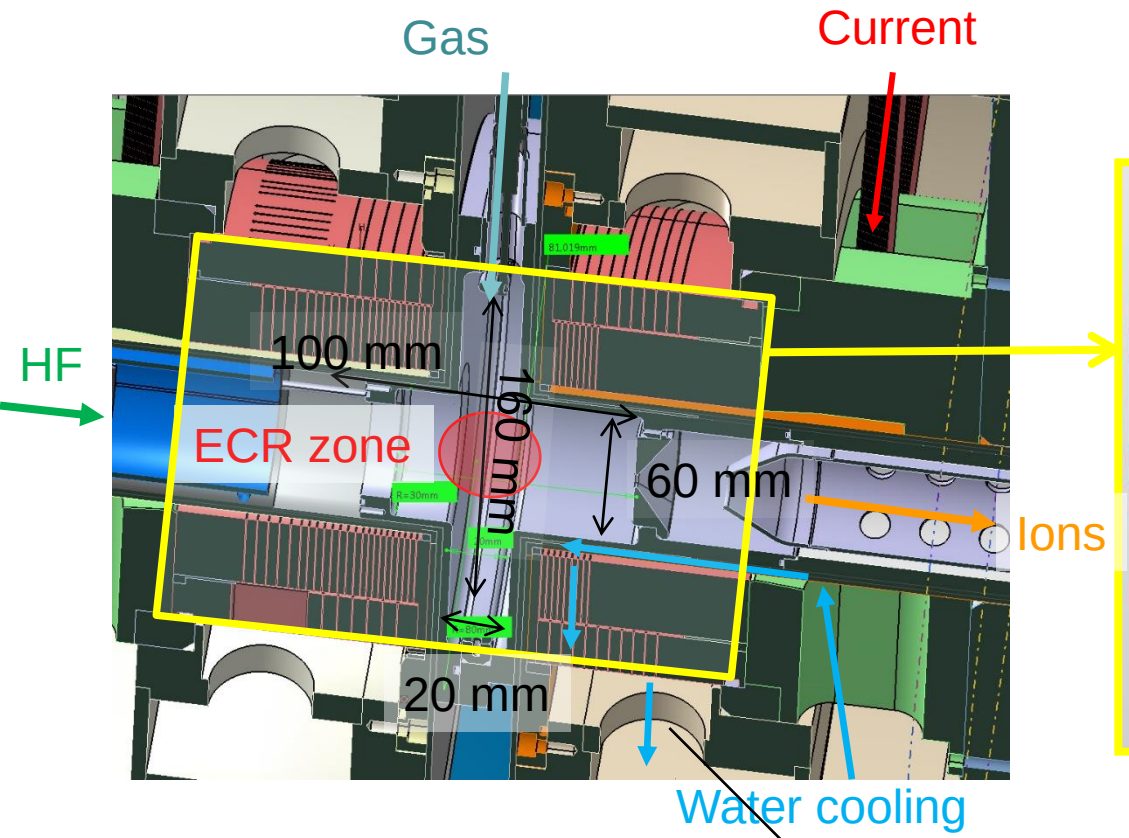
GYCOM Ltd, Nizhny Novgorod, Russia

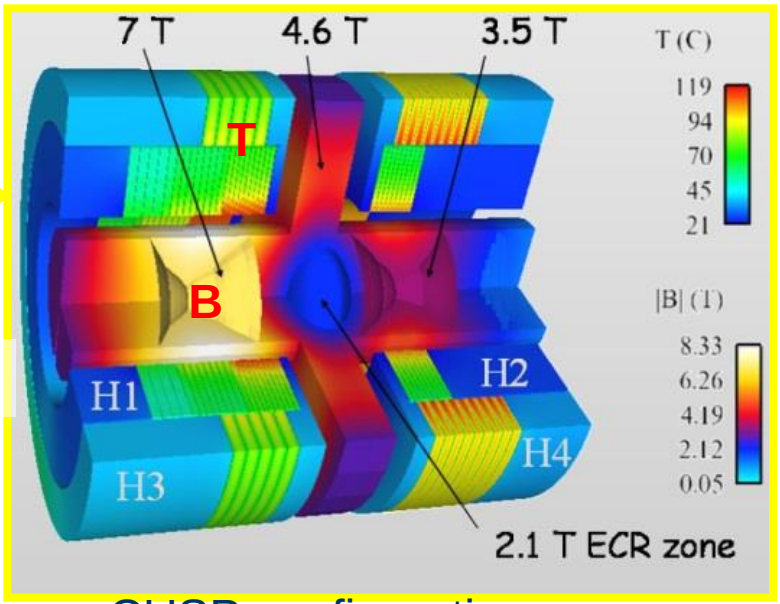
A few reminders (1)

The 60 GHz Prototype

4 copper helices : maximum current density 600 A/mm2
(the highest ever performed with such a technique)
Small volume plasma chamber : plasma < 100 cm3







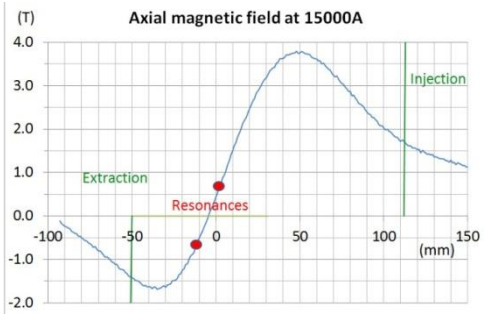
CUSP configuration
Getdp simulation at 30000 A

A few reminders (2)

After a few days of operation...

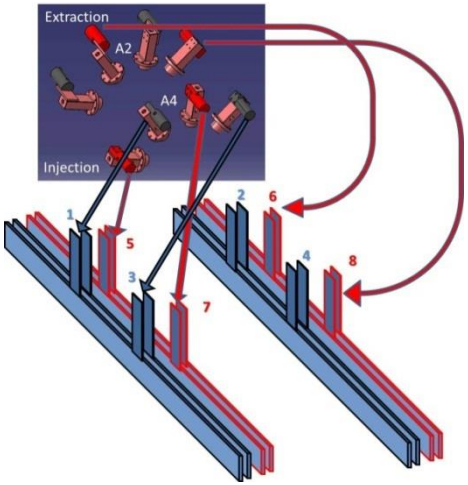
18 GHz operation at High Magnetic Field Laboratory (LNCMI)

- Operation up to 15000 A
- Plasma ignition at low power
- Presence of multicharged (a few charges) ions
- Intense 1+ ion beams (mA)

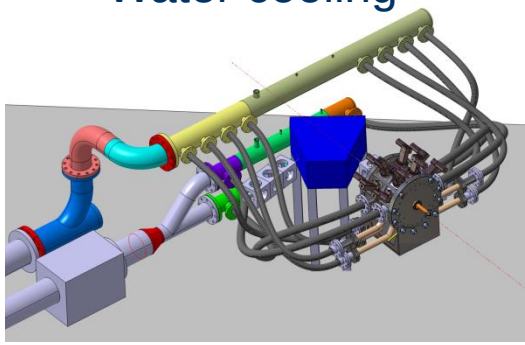


Then objective: 60 GHz and 26000A operation

- To have sufficient tuning to play with the resonance zone size
- Technical conditions at LNCMI



Water cooling



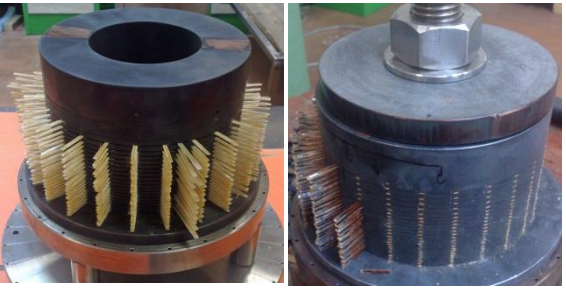
4 bus bars (15000 A – 400V)

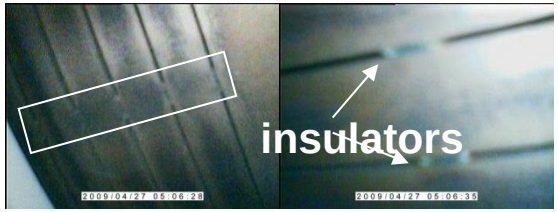
2 supplies in parallel, injection and extraction serial

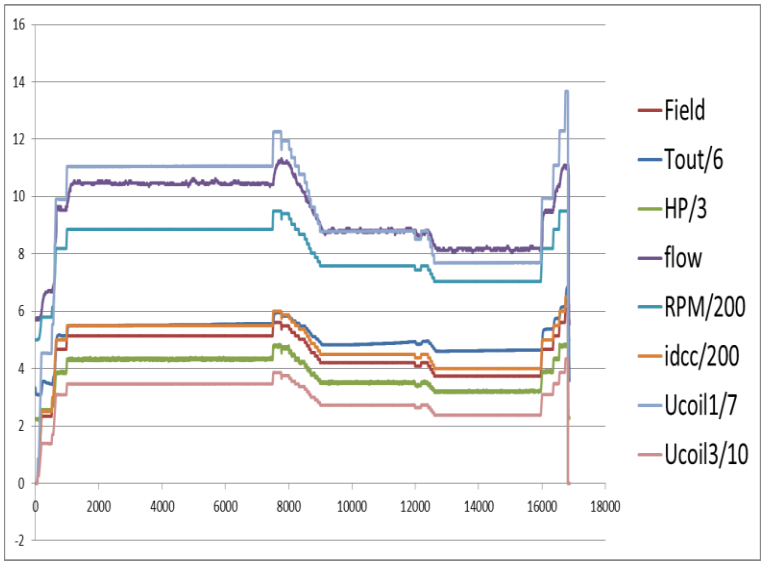
First test at 26000 A

Procedure

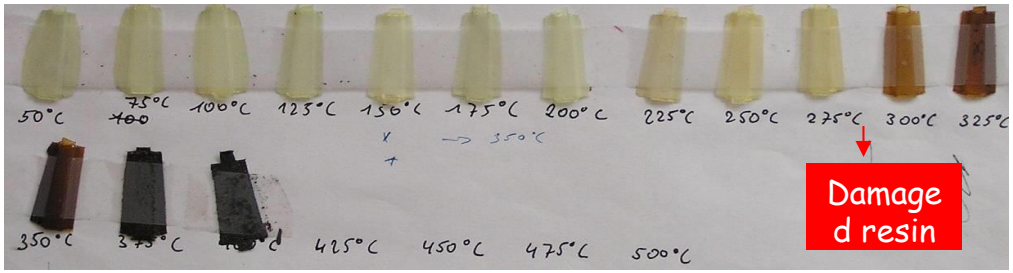
- Multi ramping from 0 to a given Ig, increase Ig at each ramp and record U(I) until Imax is reached.
- The system checks for a deviation from the previous curves and set an alarm for abnormal deviations





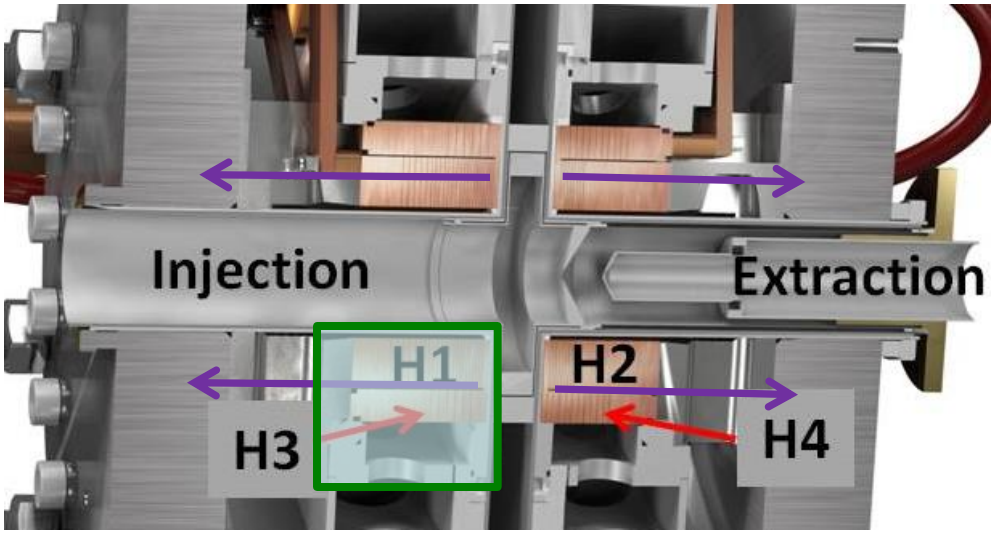


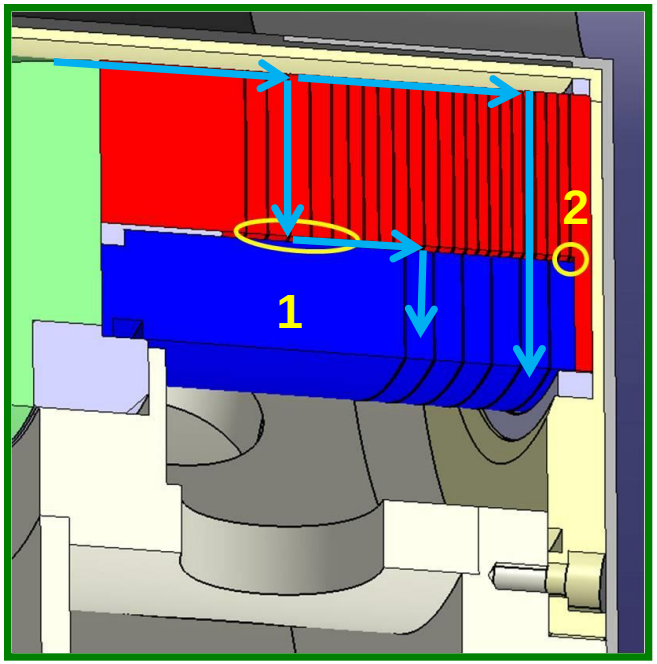
At 21000 A, we measured an irreversible 5 to 8% resistance decrease, letting us suspect insulators damages...



Insulators temperature resistance tests

First 26000 amperes failed test interpretation



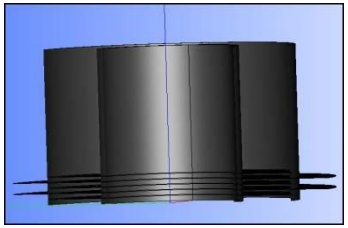


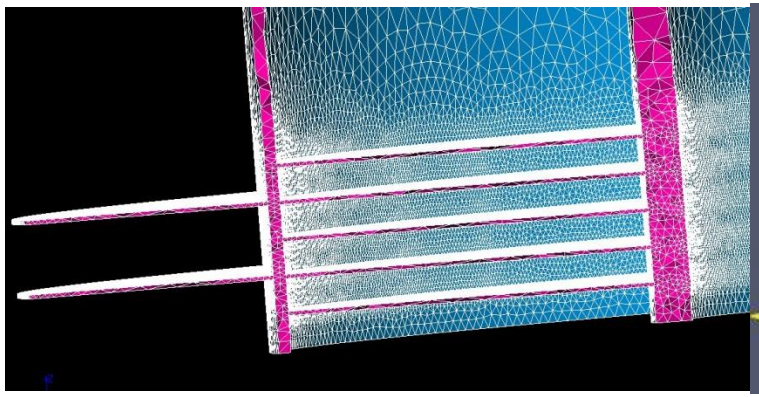
There is a repulsive force between each turn, ex: at 21000 A, total repulsive force of 300 kN

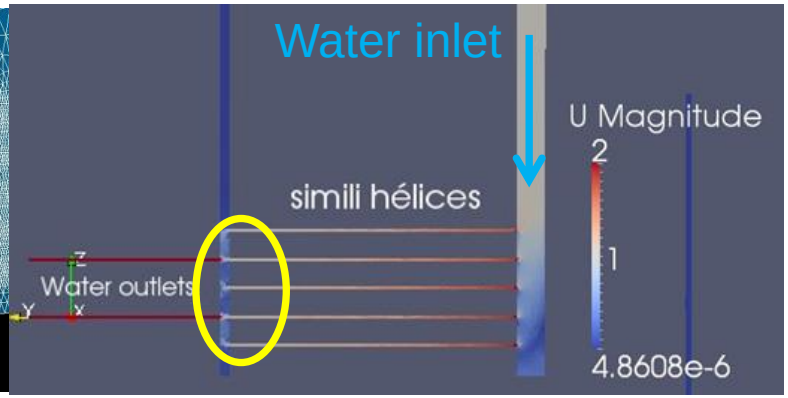
Cooling design problem

Simulation and correction

Simulation with CAELinux Freeware Salome-Meca for nuclear power plants (Matra, EDF, CEA), simplified model for the water volume



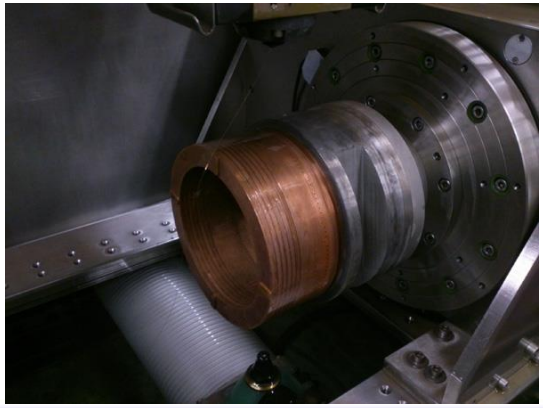




Lowest speed is at the outlet of the internal helix.

Construct a new H1 helix to replace the damaged one (2 months, ~7 k€)

Modify the external H3 to add slits



H3 Modification

Second test to reach 26000 A...

Successful, qualification for half an hour

I (A)	Coils Voltage (V)		Power (MW)
26000	**Inj.** Internal	77.1	2.0046
	Inj. External	17.65	0.4589
	Ext. Internal	42.42	1.10292
	Ext. External	41.47	1.07822
			Total power (MW)
			4.64464

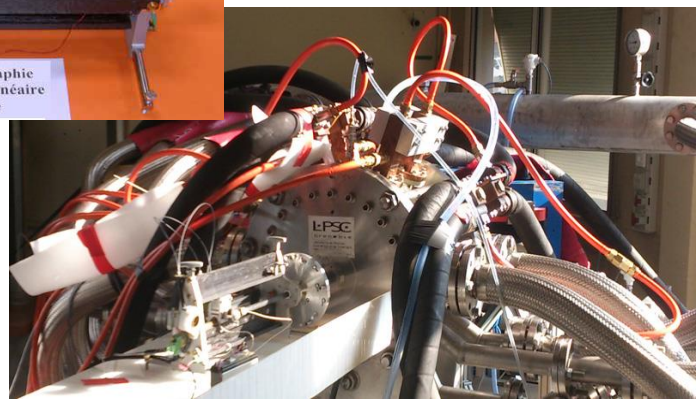
Cooling	Temperature (°C)	Pressure (bar)
Inlet	9	17.1
Outlet	35.3	4

40 l/s

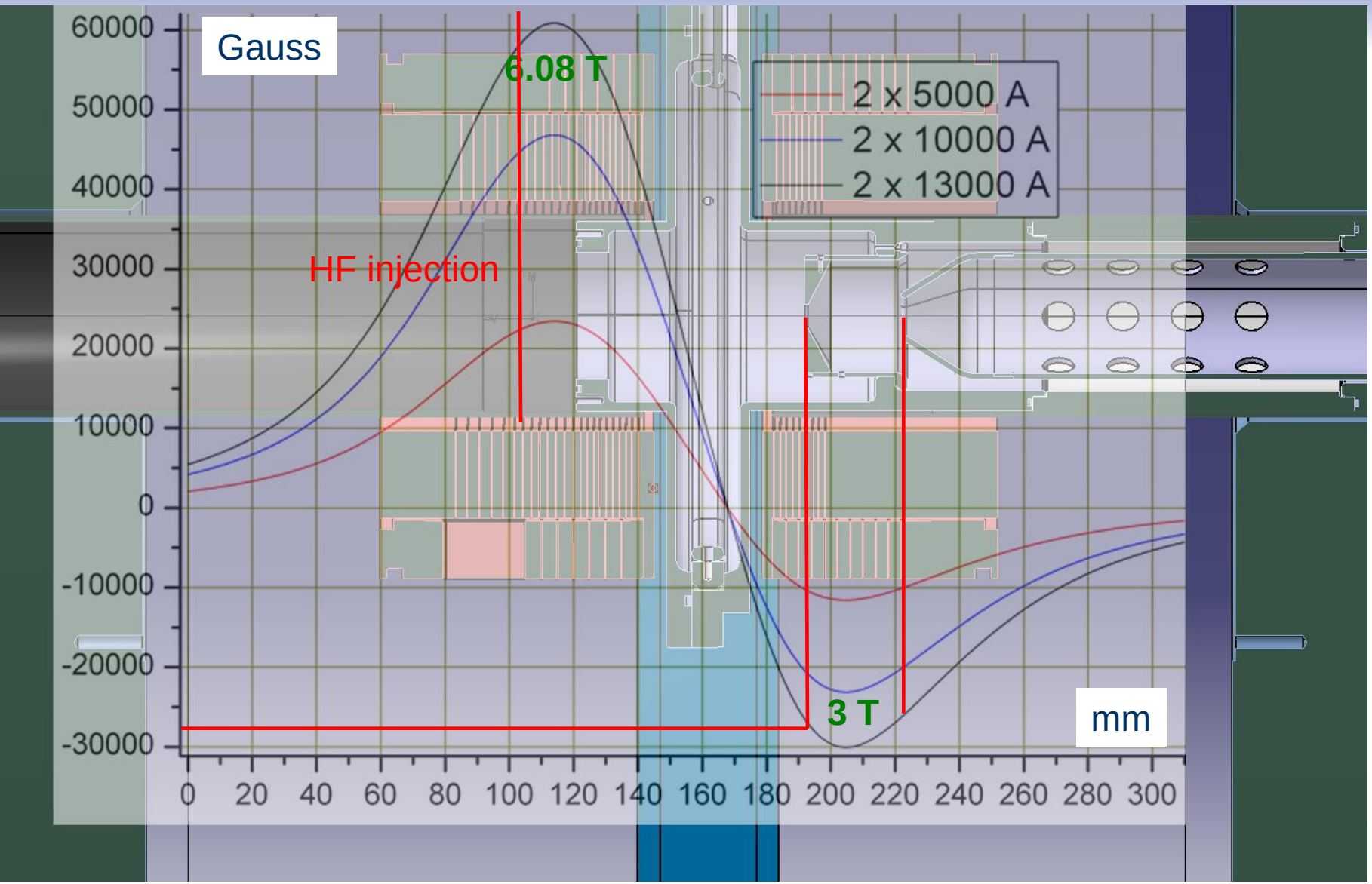
Then half a day to measure axial magnetic field

Flux integration measurement

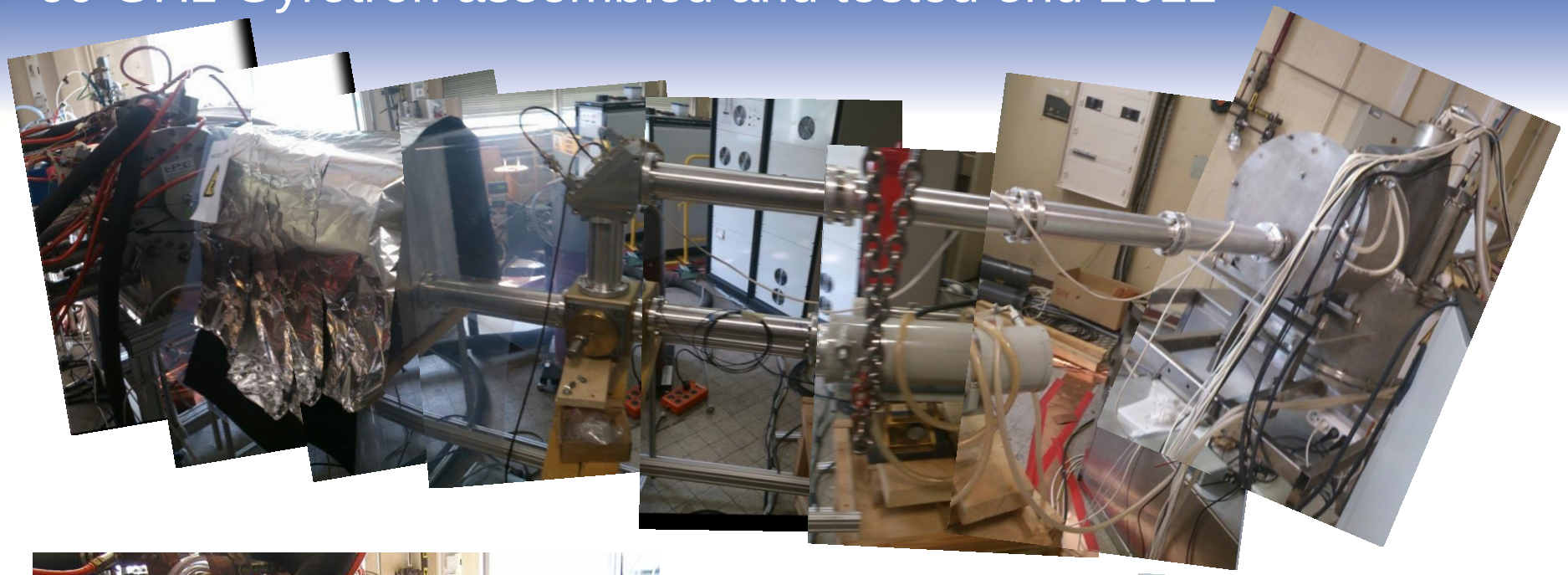
Integration interval: 0.1mm

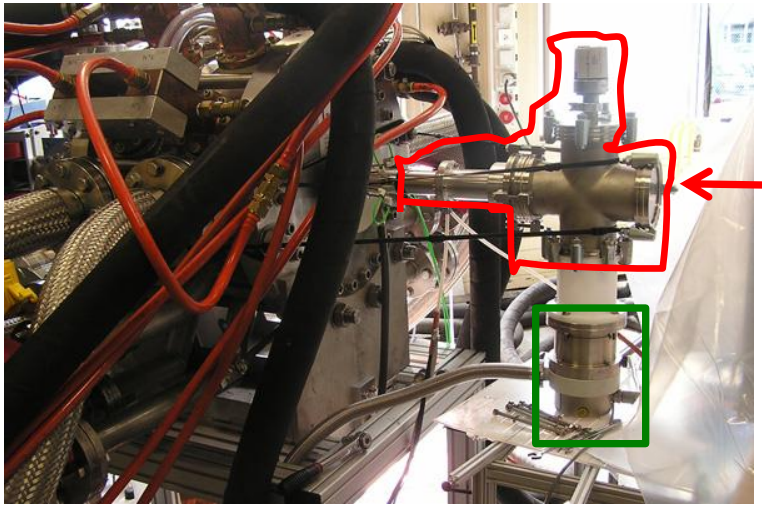


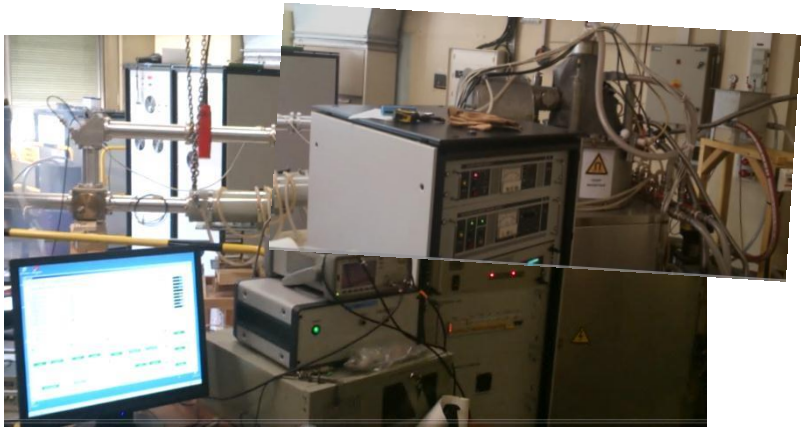
Magnetic field measurement on axis



60 GHz Gyrotron assembled and tested end 2012

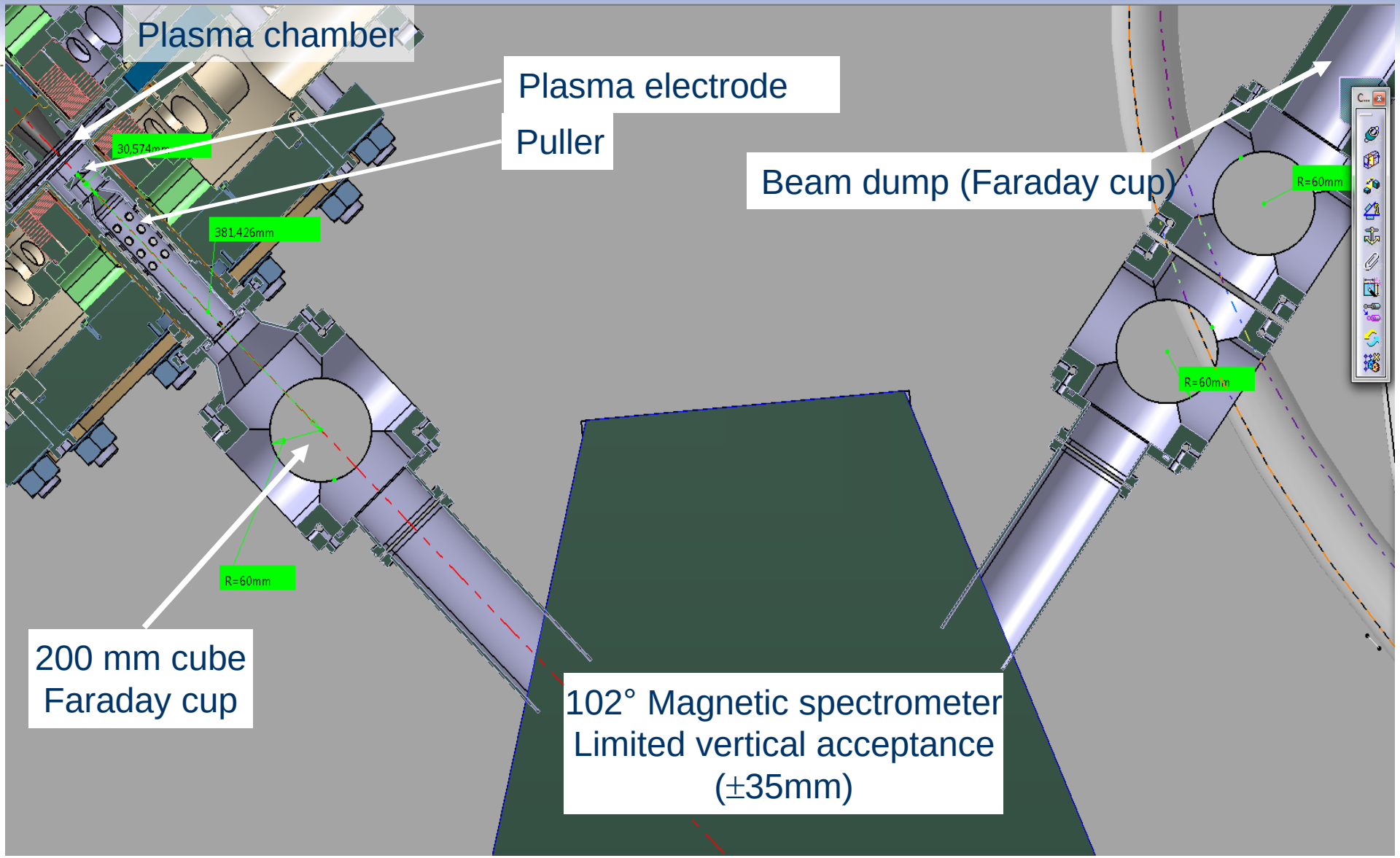






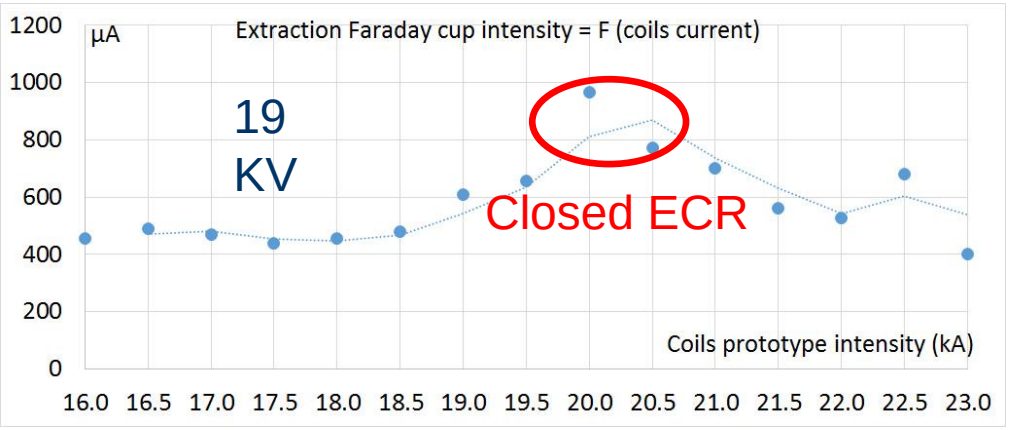
60 GHz – 300 kW – 2Hz - 50µs to 1 ms
Possible 100 kW - 5 Hz

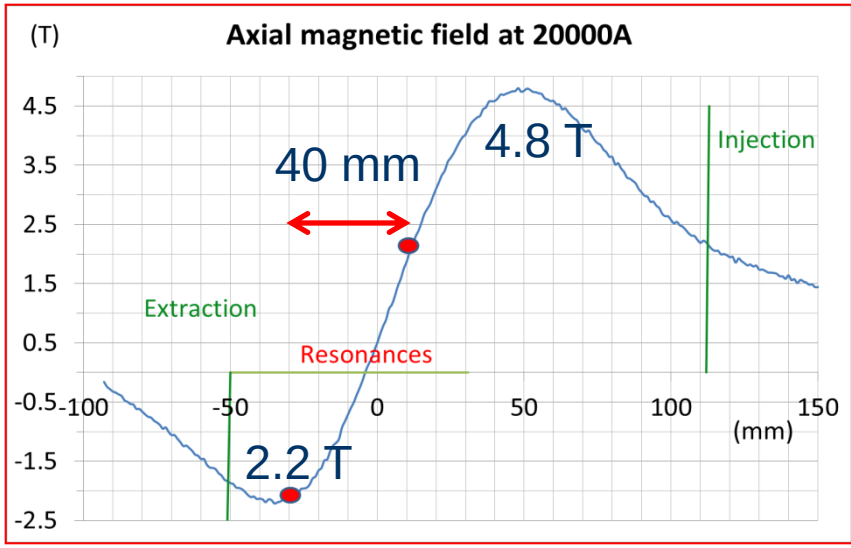
The beam line (too much simple)



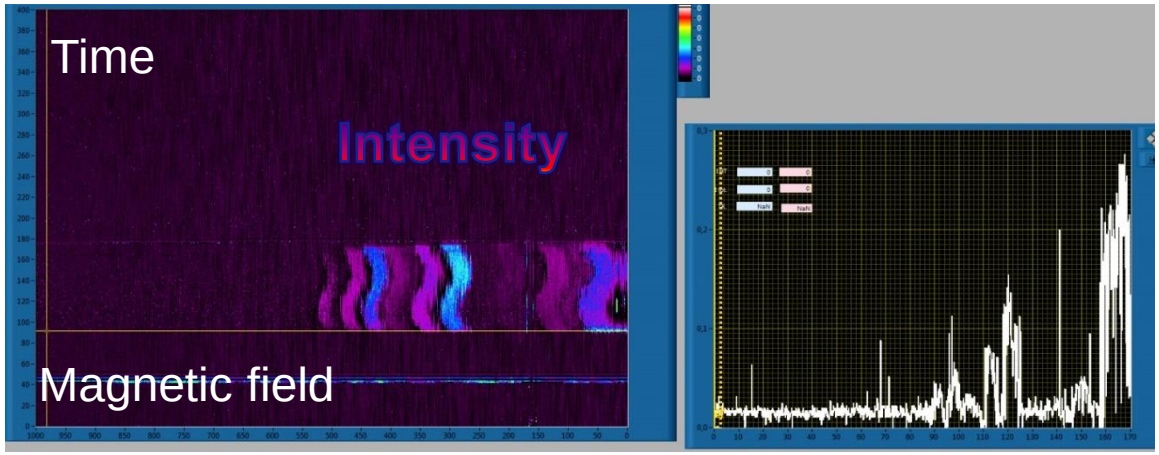
First beam in April 2014 : Argon

Plasma electrode hole D = 1mm
Distance from puller = 40 mm





First 3D spectrum

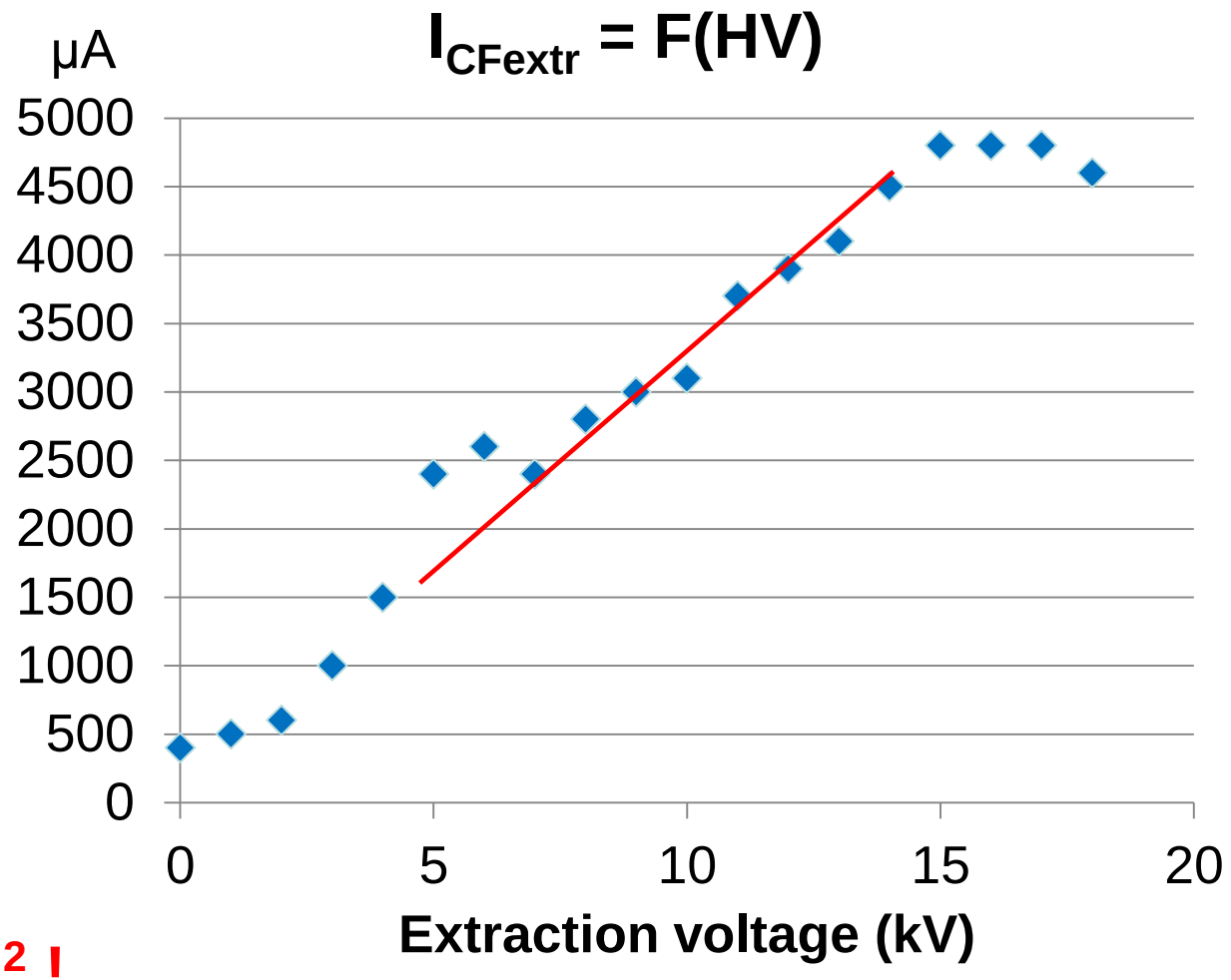


Second beam test in July 2014 : Oxygen

Plasma electrode hole
D = 1mm

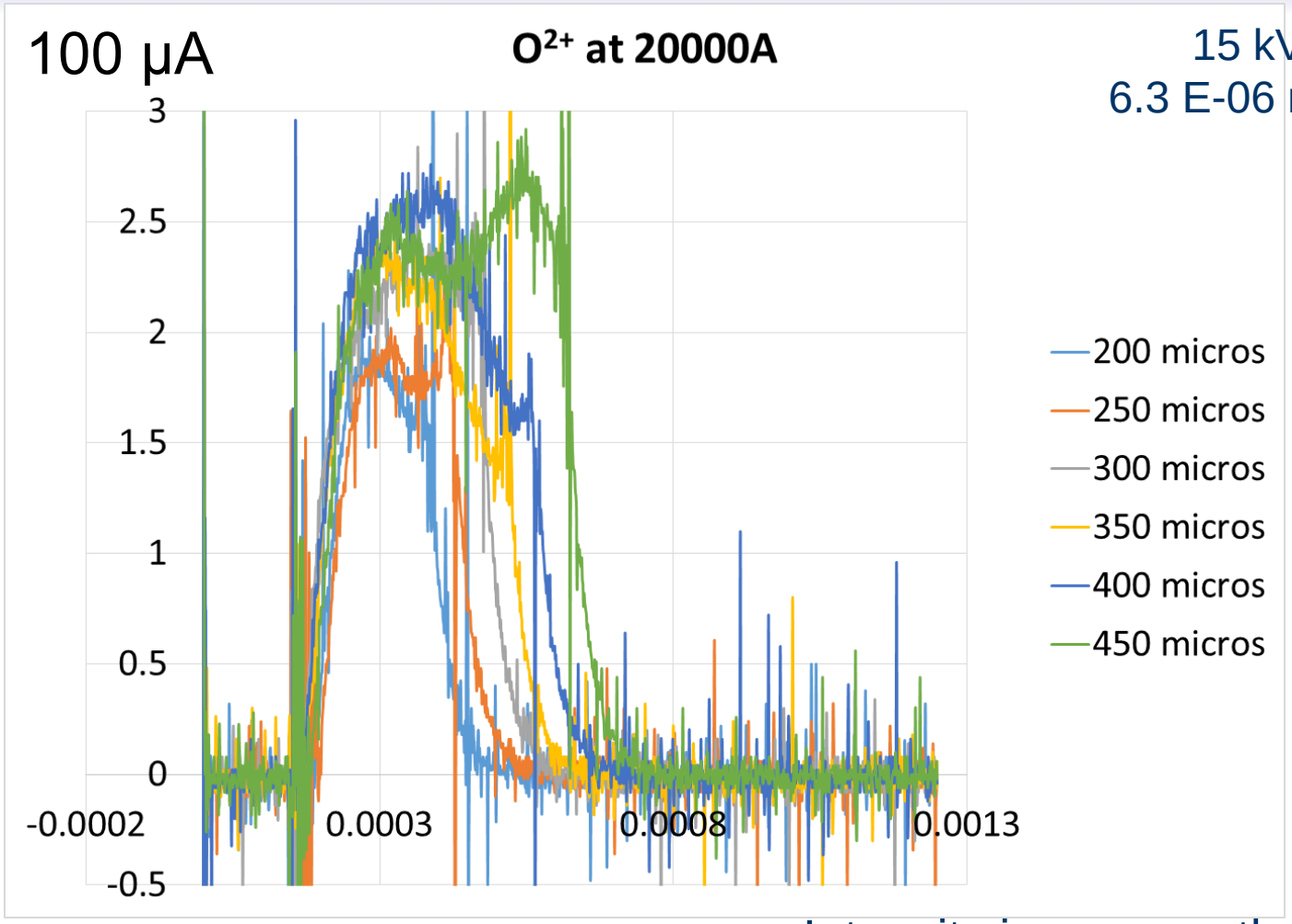
Distance from puller 30 mm

100 kW – 200 µs – 2 Hz
22 kA
1,1 E-05 mbar



Almost 600 mA/cm² !

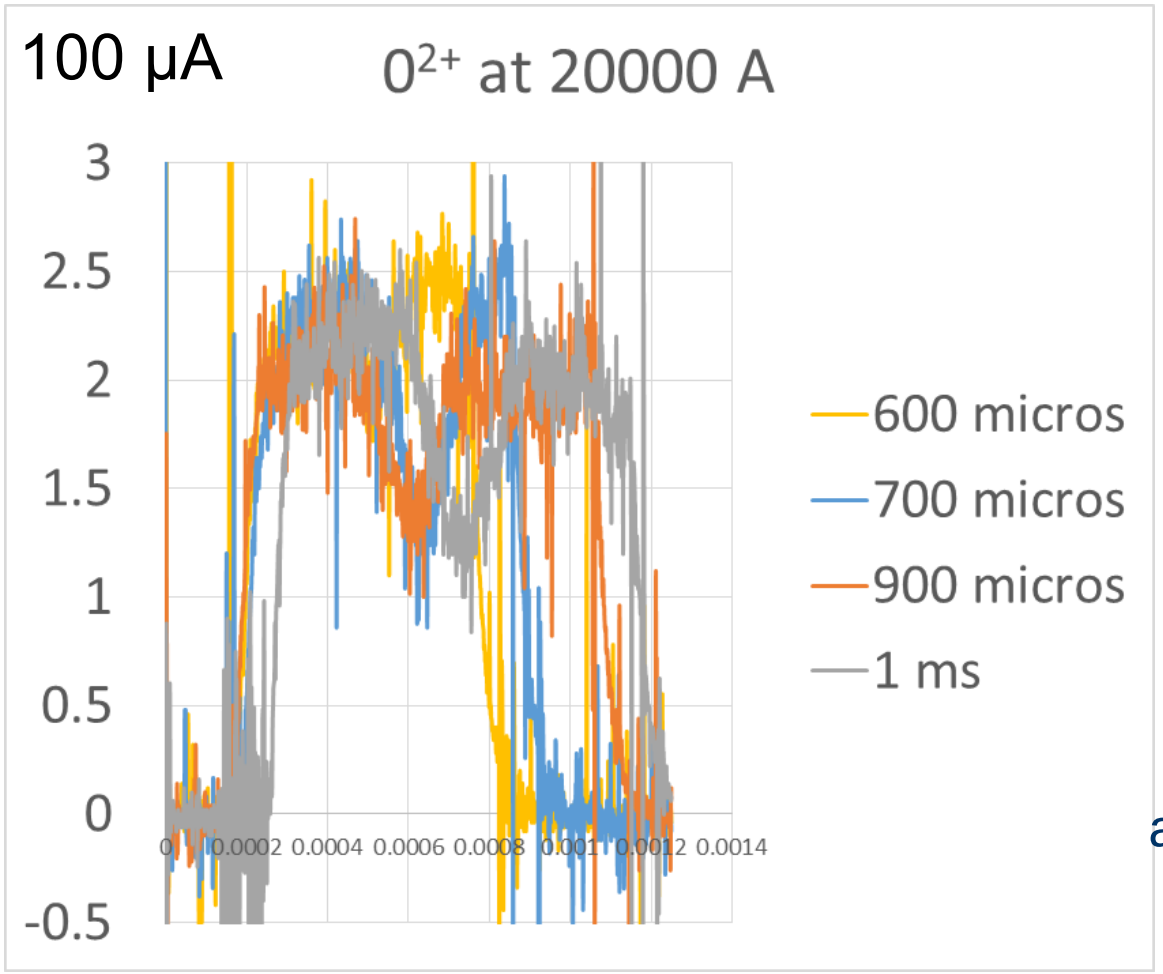
HF pulse length variation



15 kV
6.3 E-06 mbar

Intensity increases, then no gain with longer pulses

HF pulse length variation



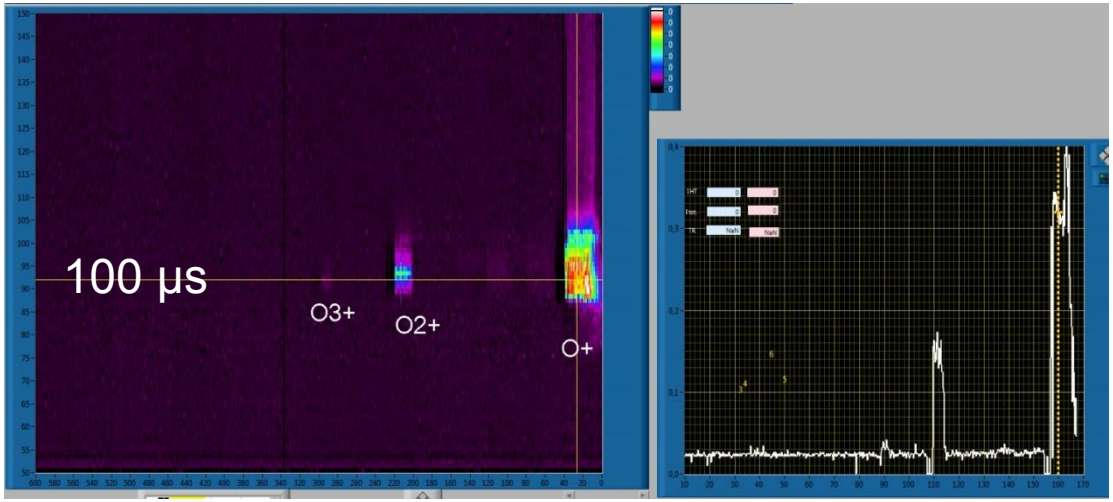
15 kV
6.3 E-06 mbar

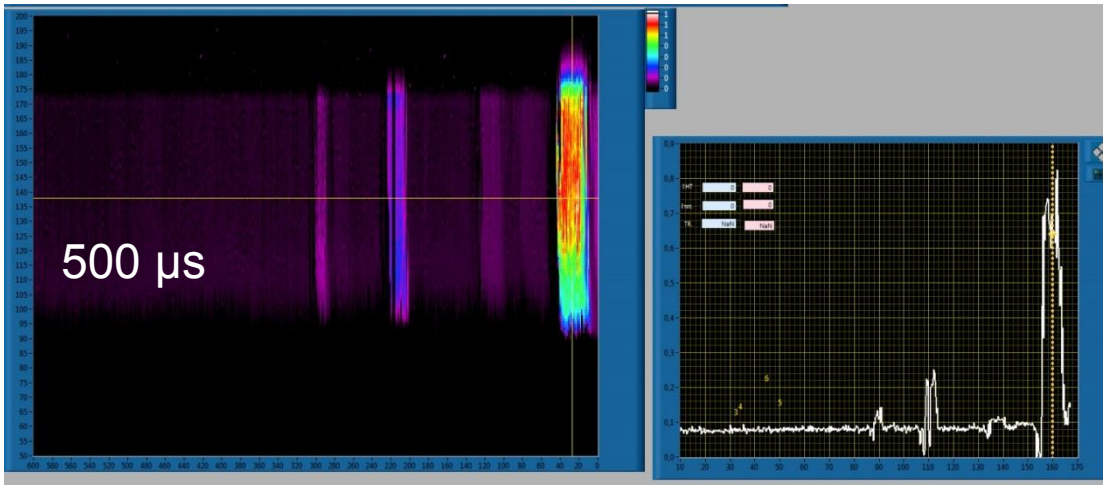
For longer pulses
some instabilities appear
and a decrease of the current

3D spectra for different HF pulse length

23000 A
15 kV
7.5 E-6 mbar
90 kW

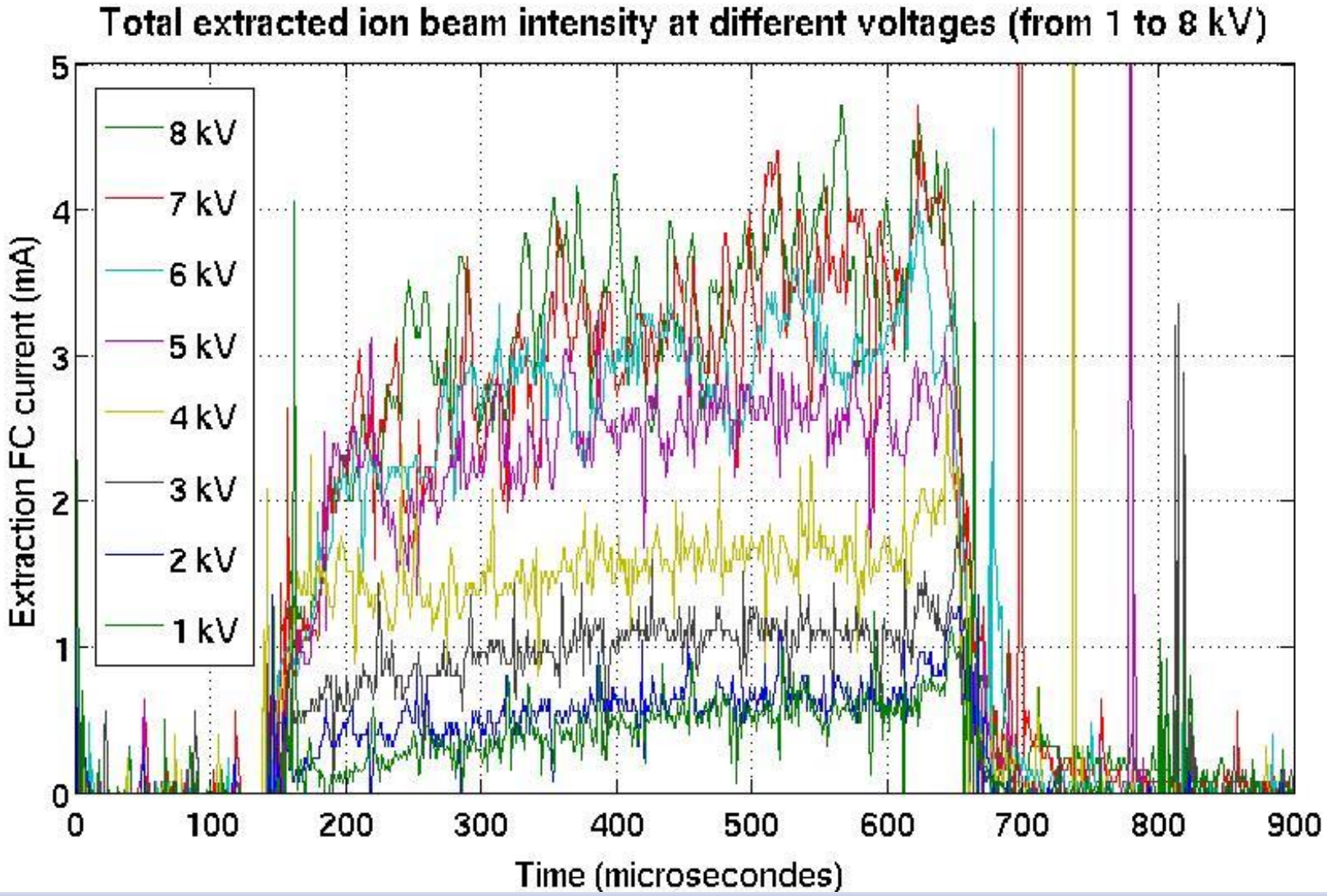
For pulses up to 500 µs
the intensity of all beams
Increases with the HF pulse length



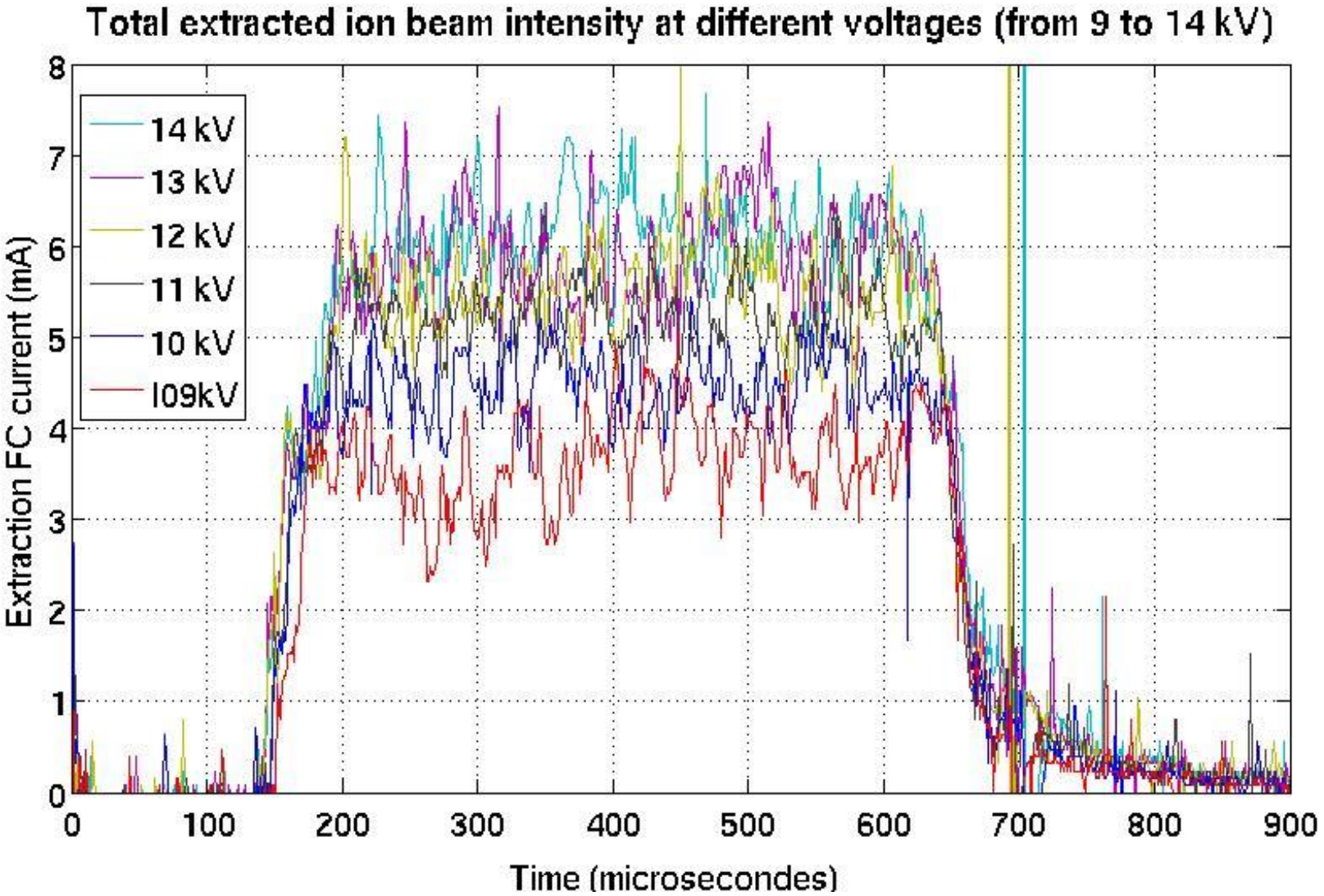


Time evolution of total current variation versus high voltage

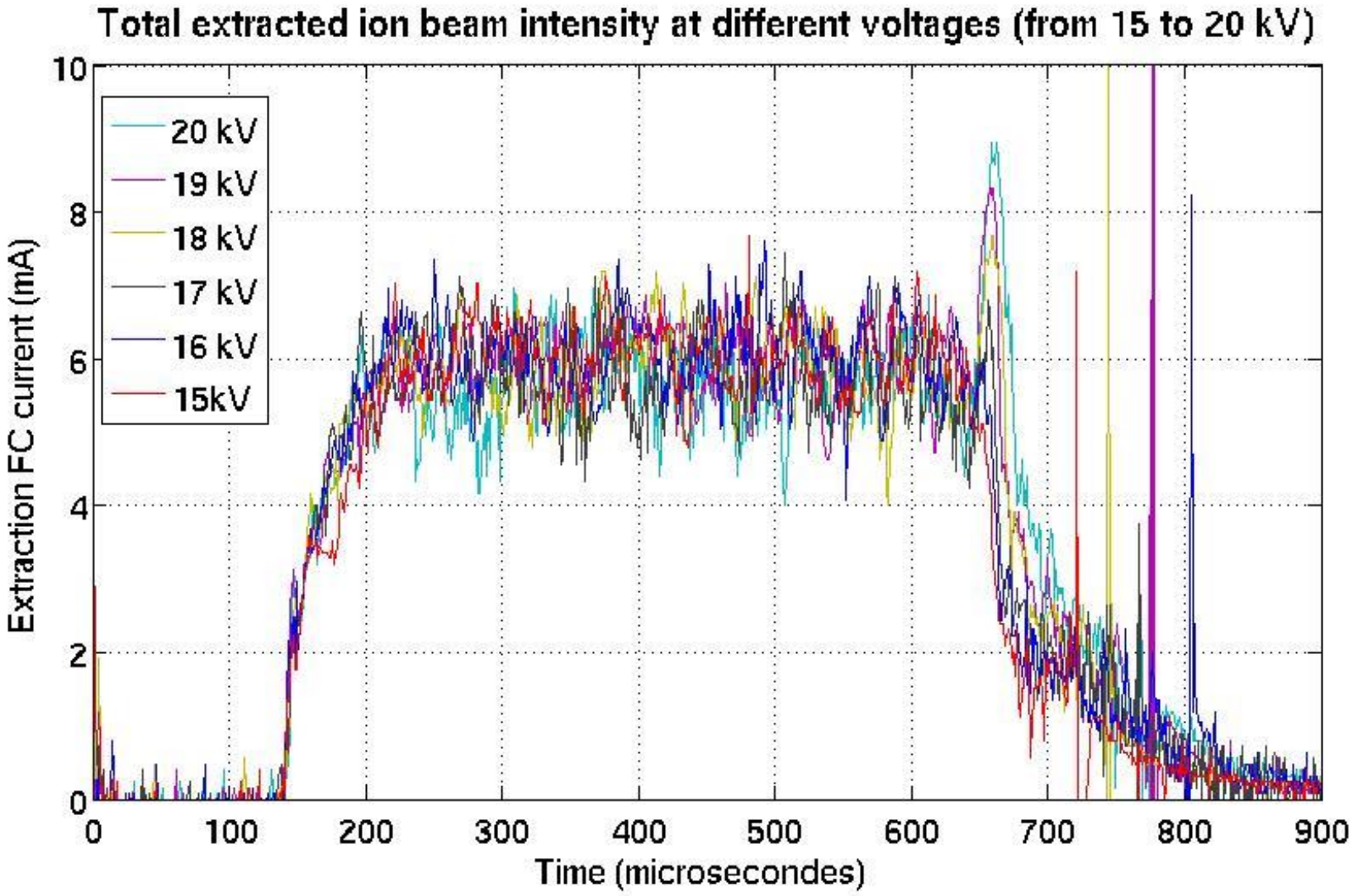
22000A Phf=80 kW - 500 µs, 1.1 E-05 mbar



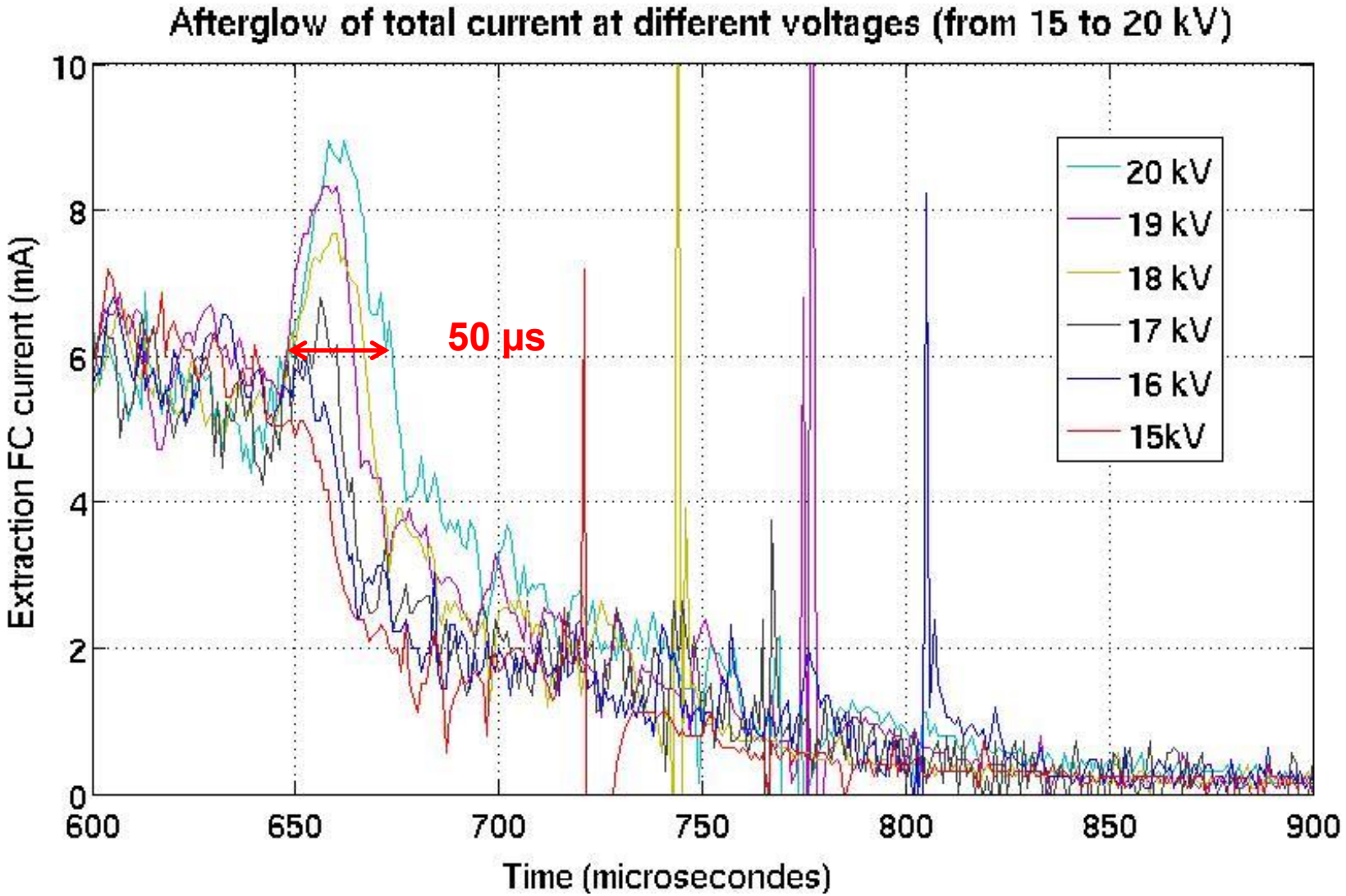
Time evolution of total current variation versus high voltage



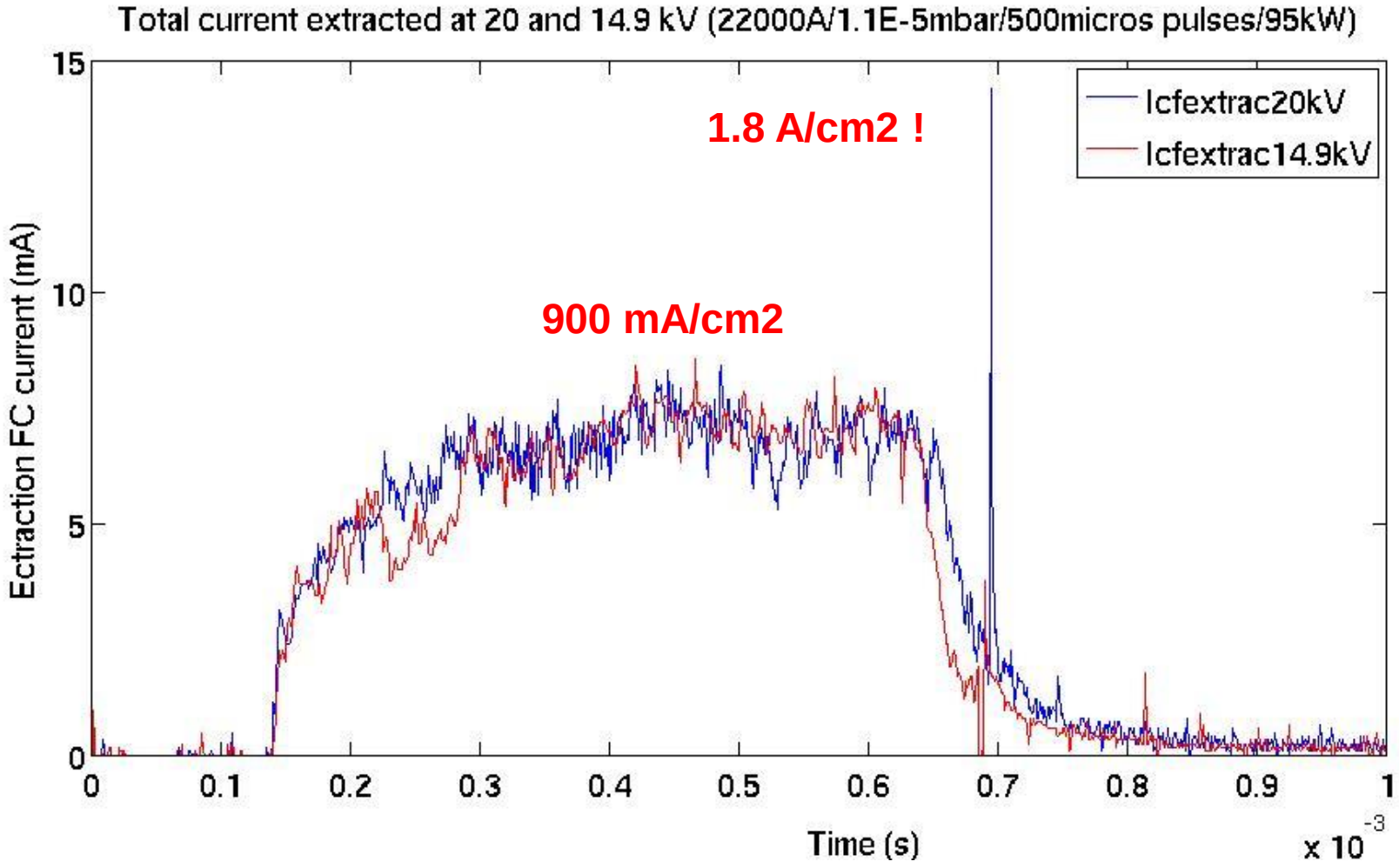
Time evolution of total current variation versus high voltage



Zoom on Afterglows

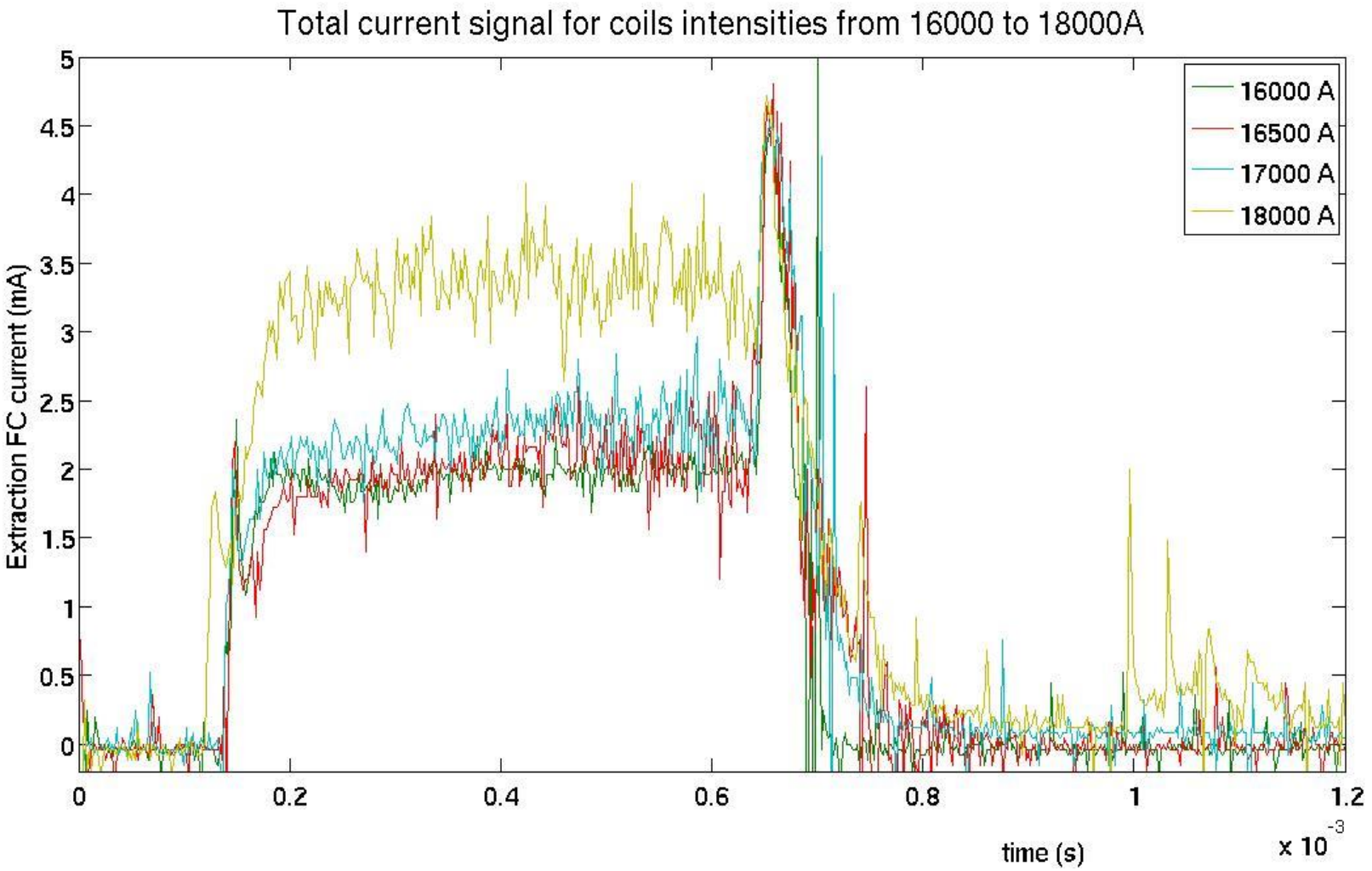


Total current versus high voltage

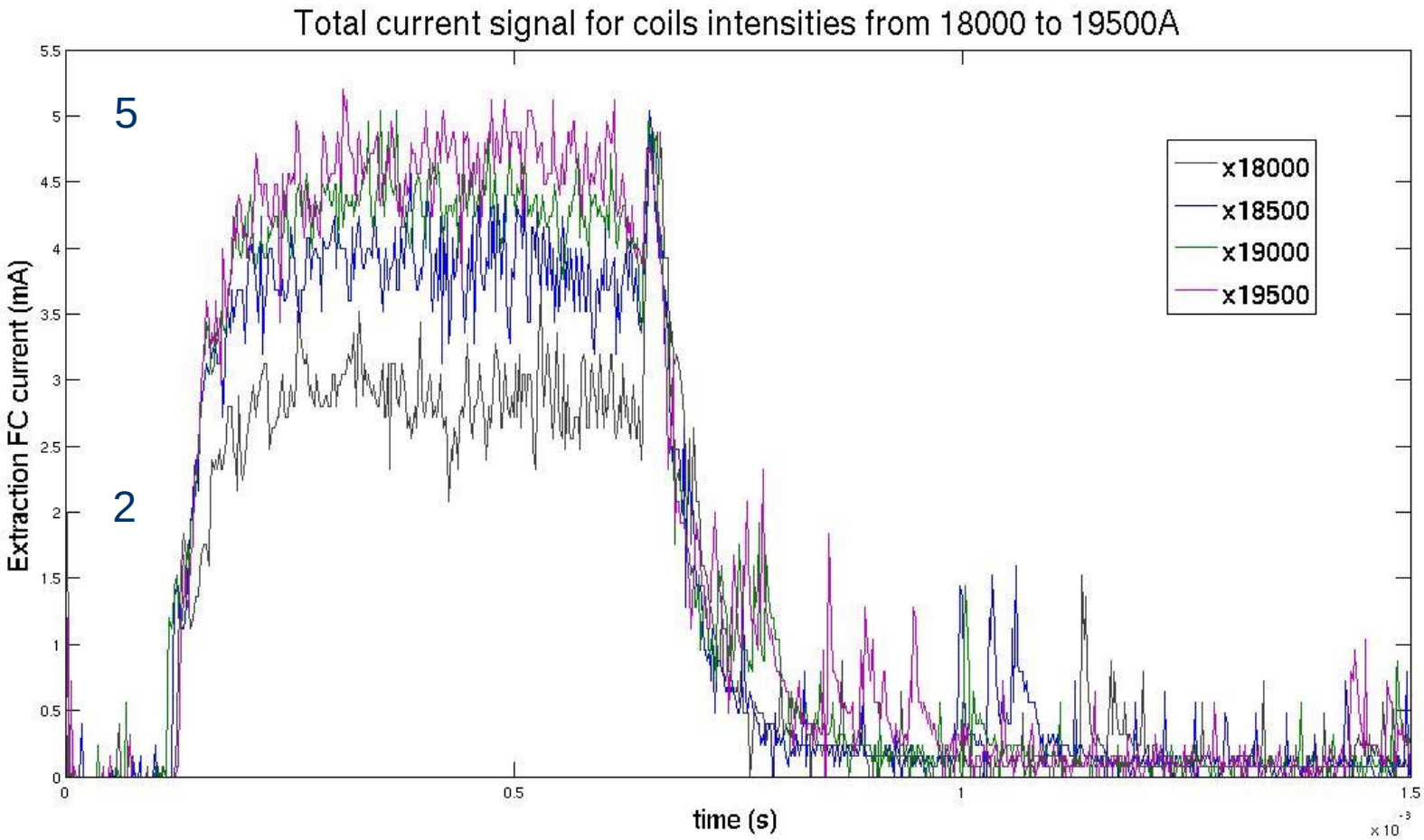


To be corrected by the hole size if the plasma electrode has melt...

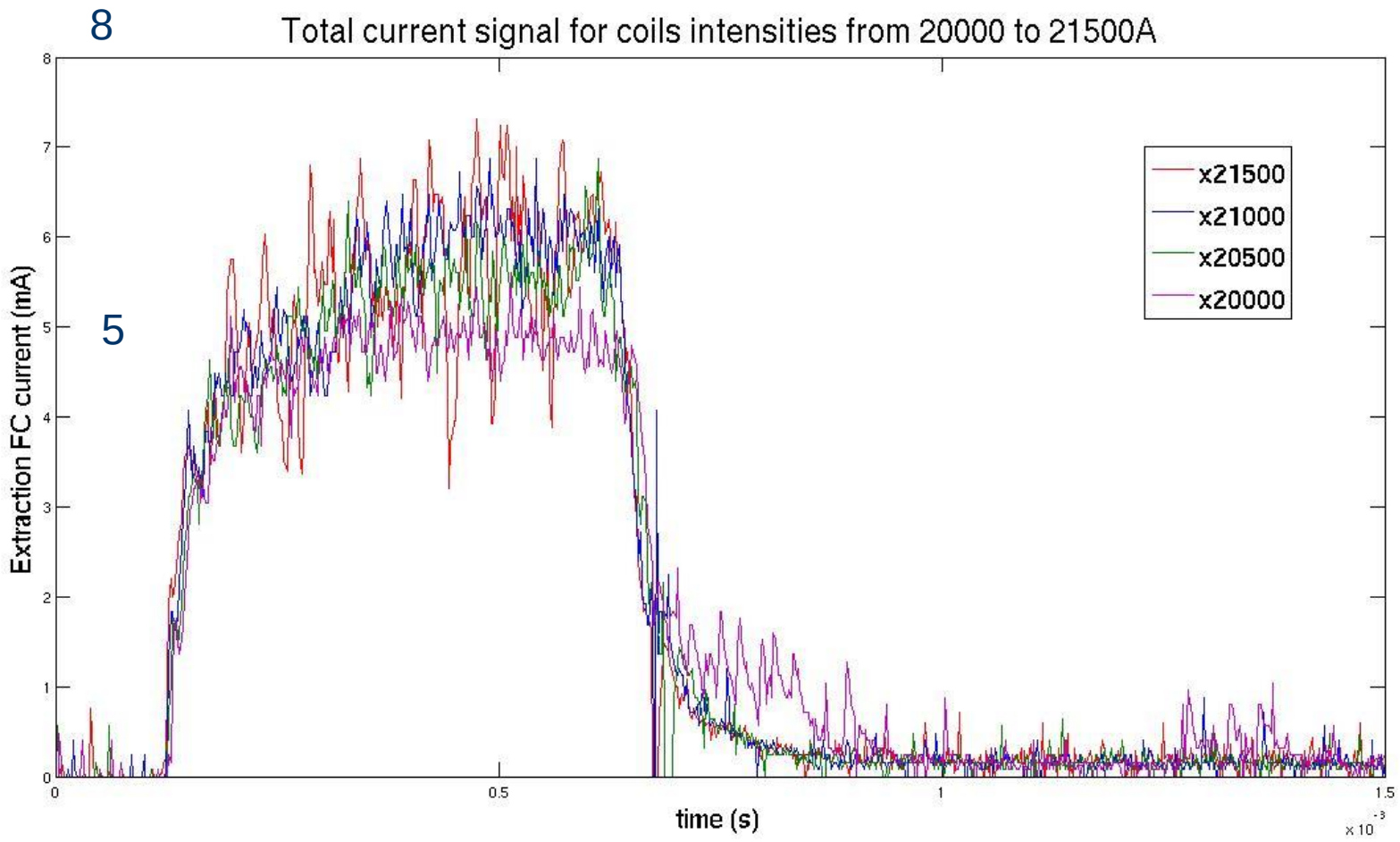
Total current versus coils intensity (16000 A to 18000 A)



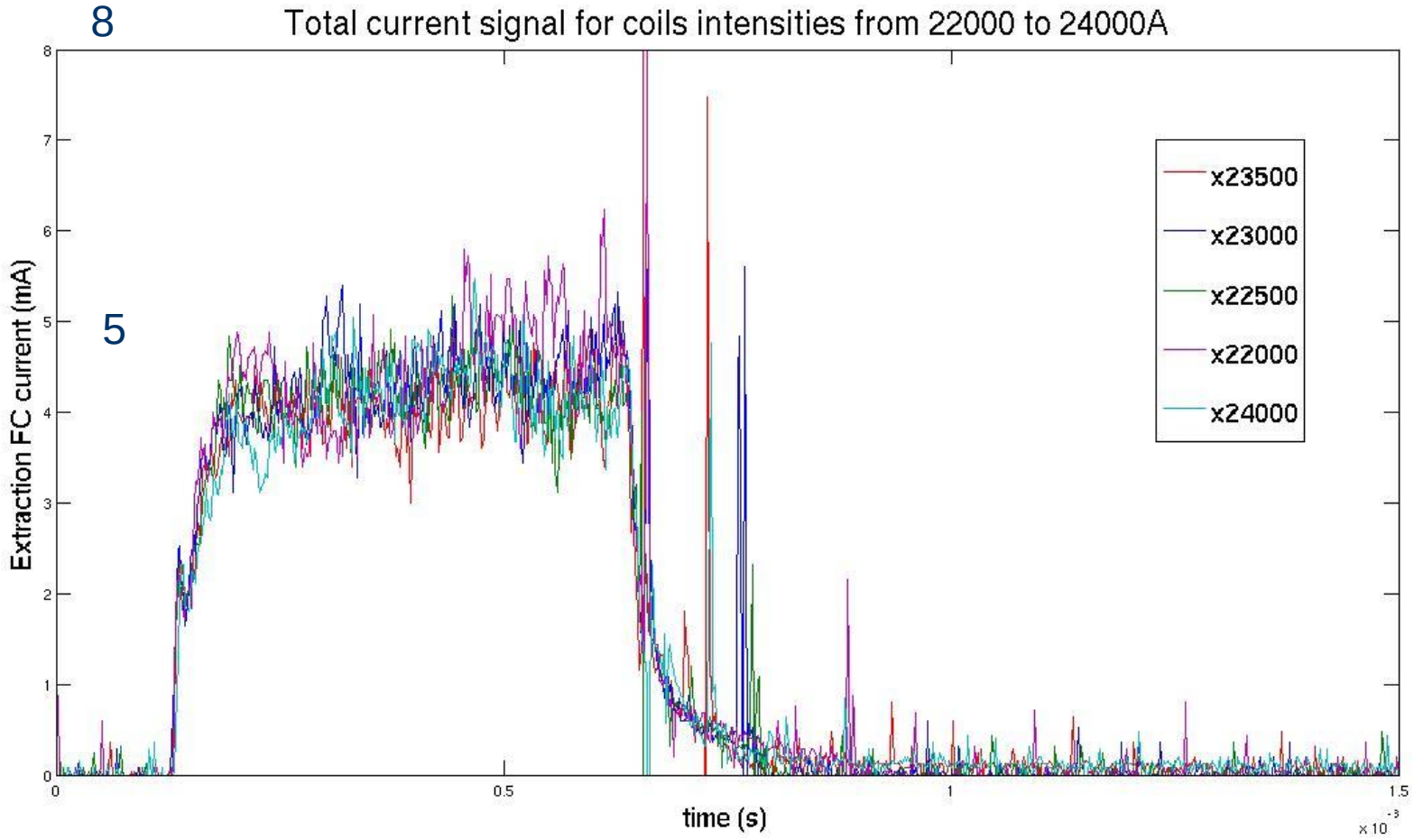
Total current versus coils intensity (18000 A to 19500 A)



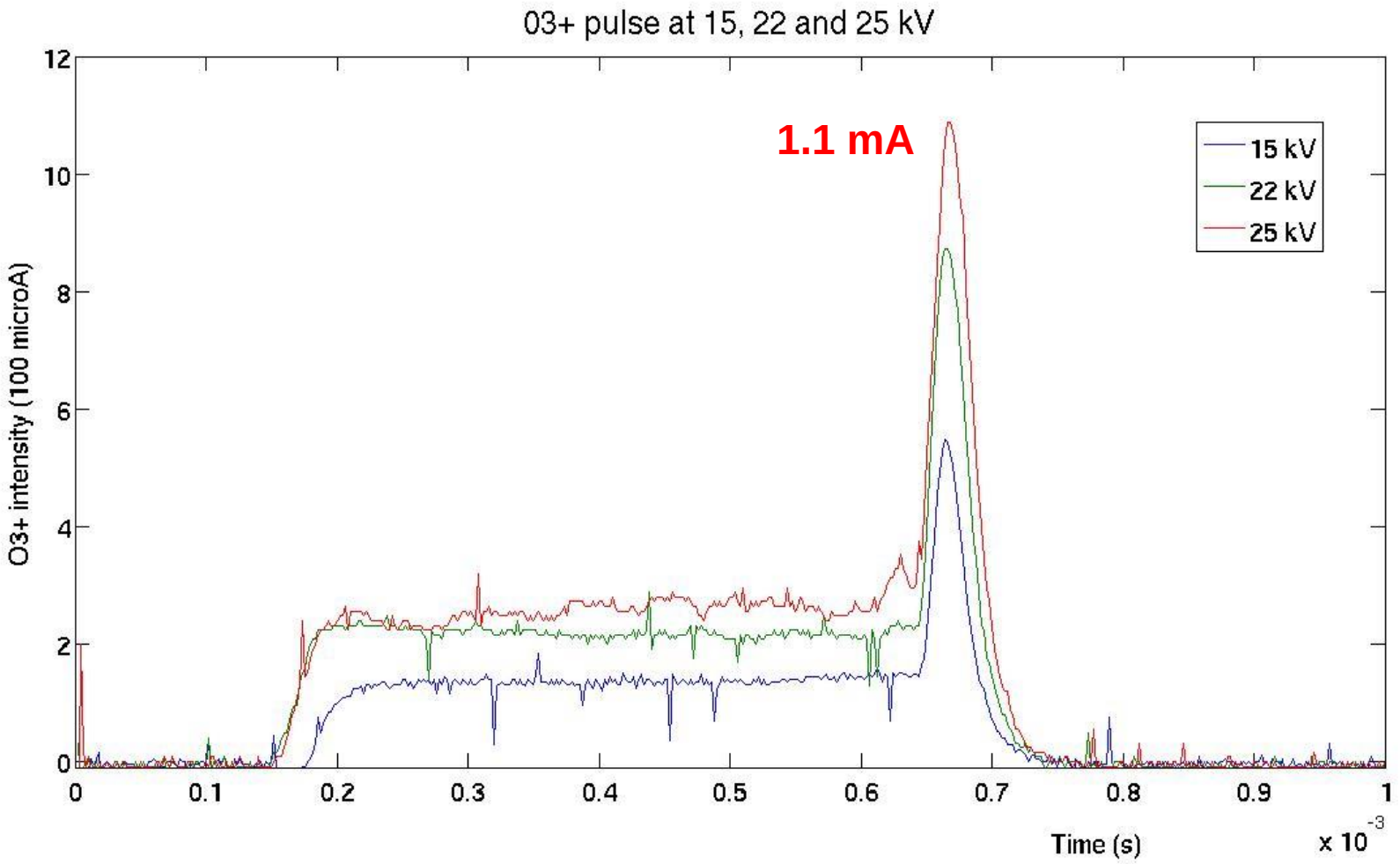
Total current versus coils intensity (20000 A to 21500 A)



Total current versus coils intensity (22000 A to 24000 A)

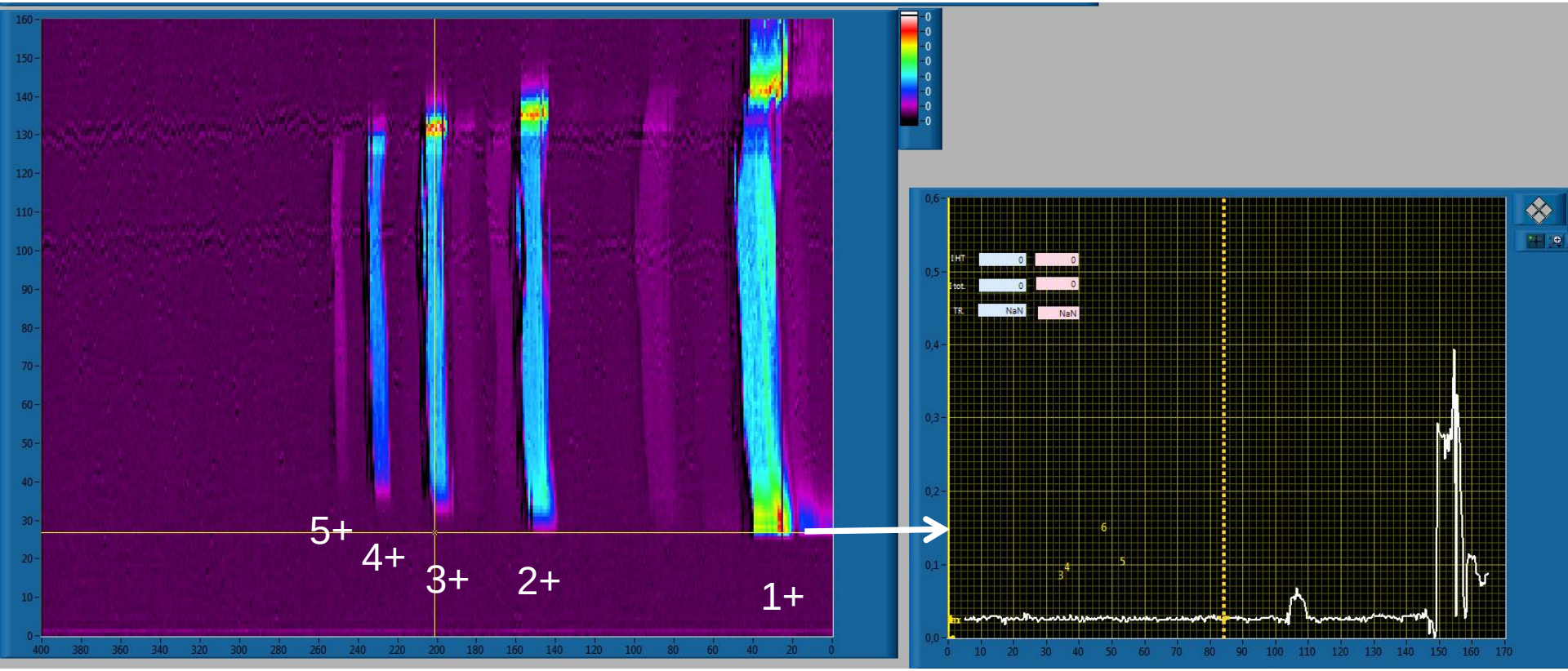


O^{3+} signal at different extraction voltages



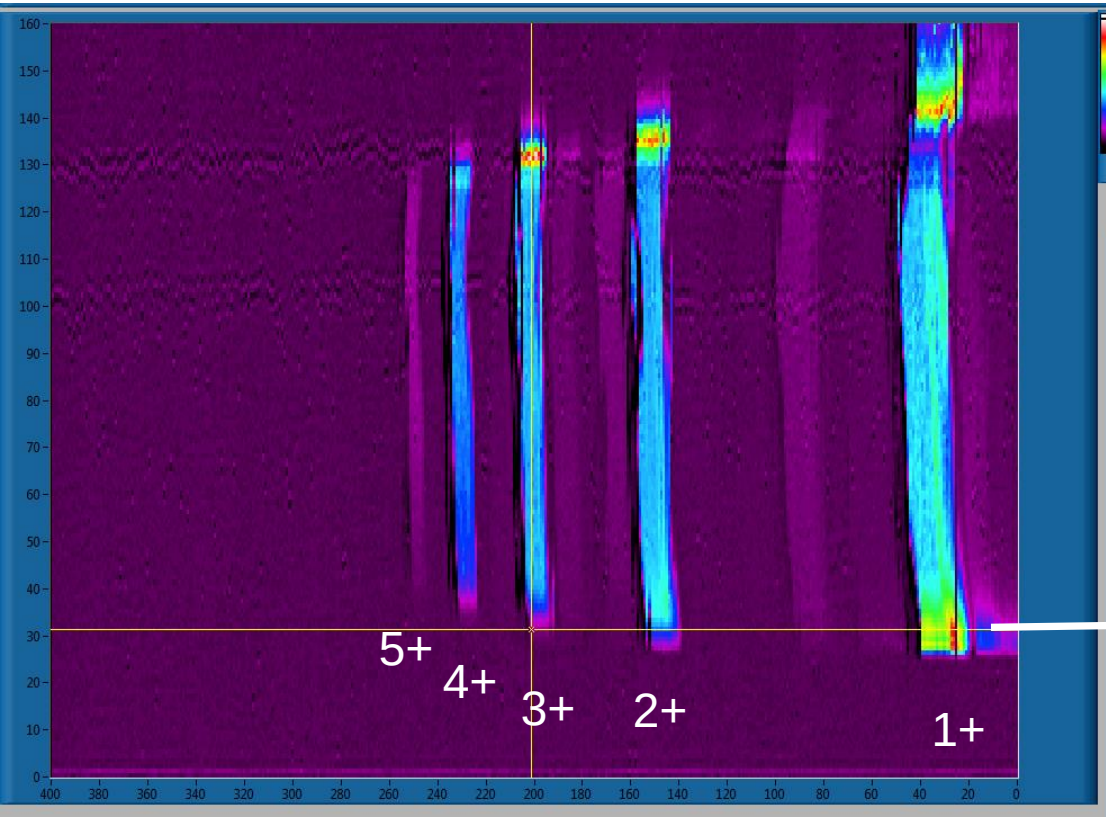
3D spectra of multicharged oxygen ions (1)

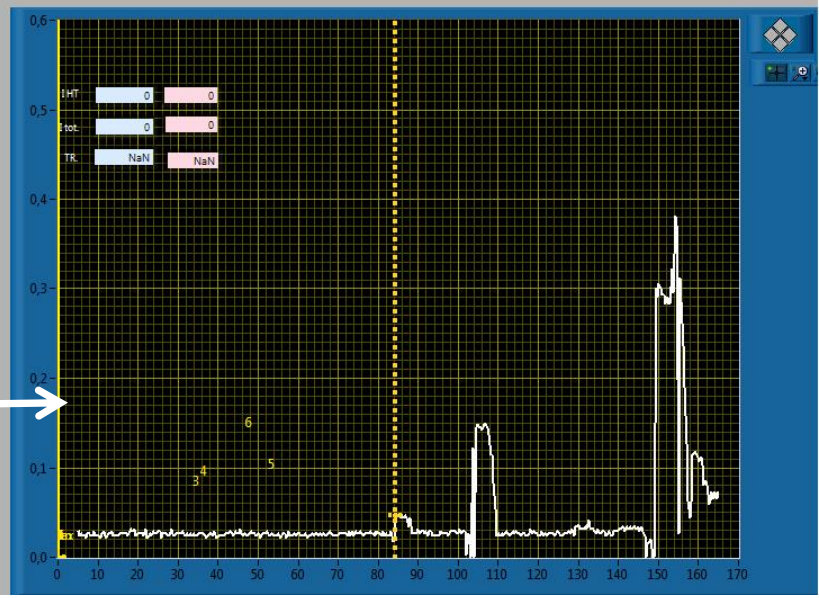
18000 A – 15 kV – 56 kW



Ion creation

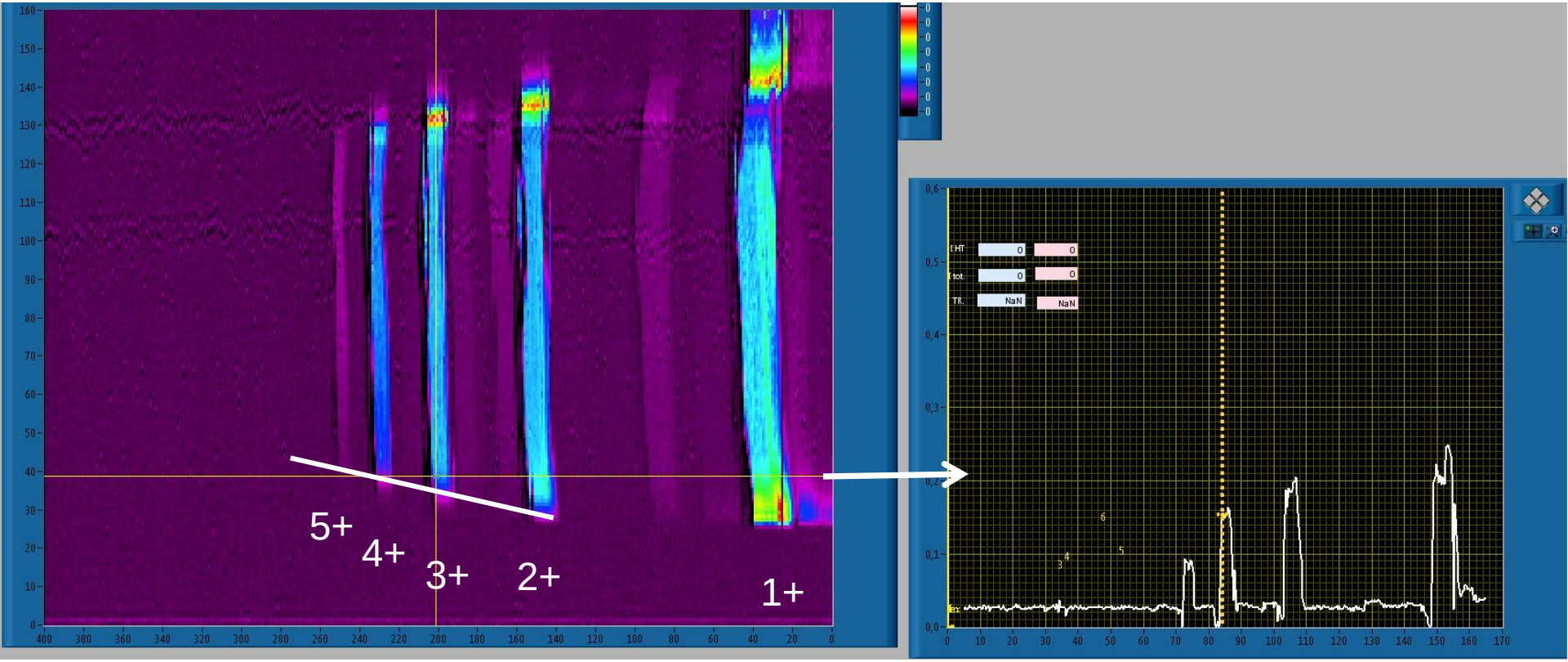
18000 A – 15 kV – 56 kW





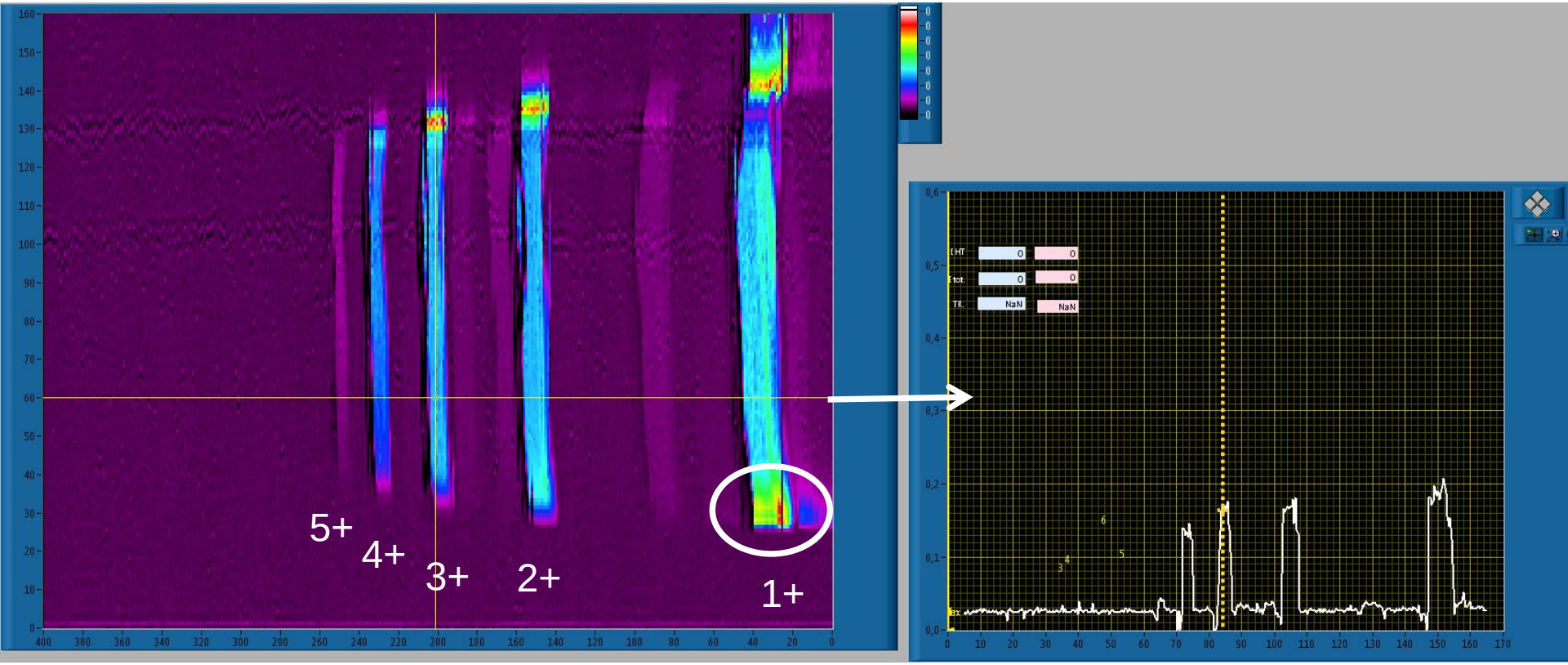
Ion creation

18000 A – 15 kV – 56 kW



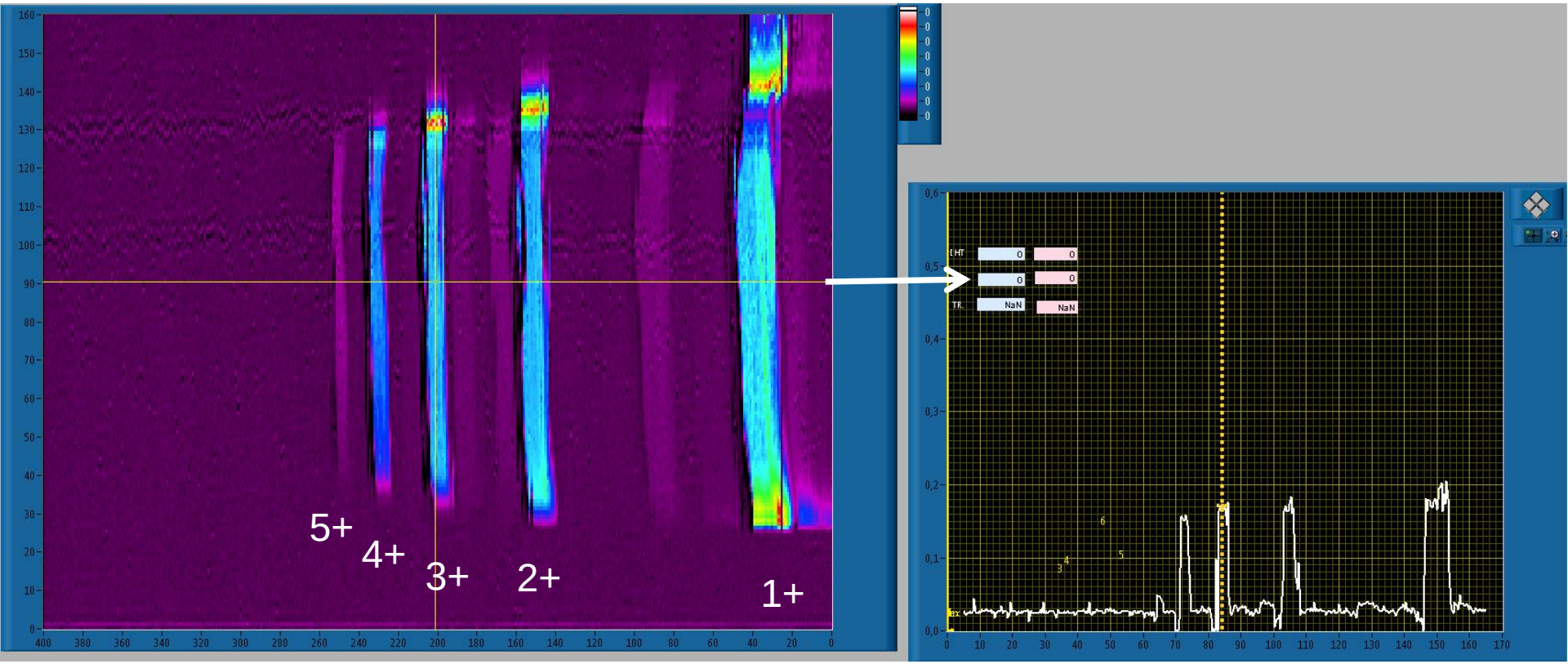
Ion creation

18000 A – 15 kV – 56 kW



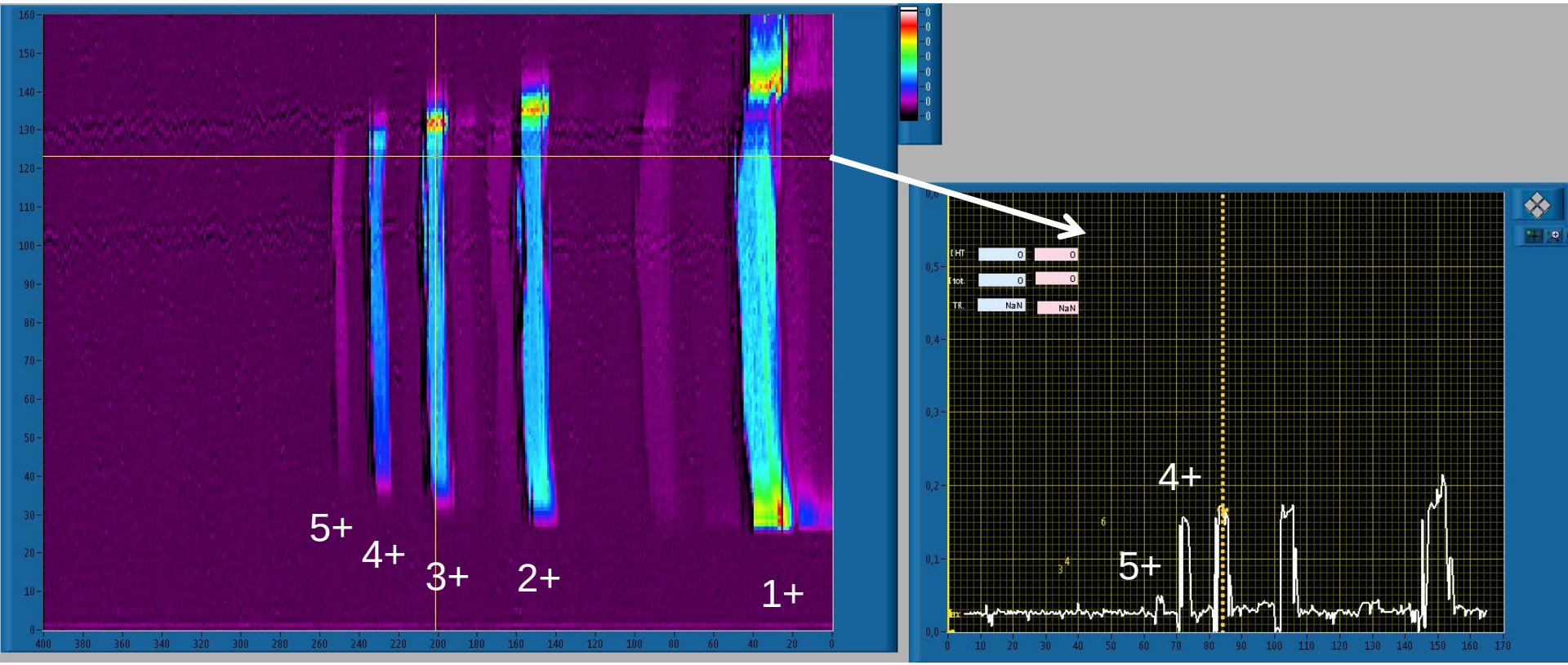
Ionization equilibrium

18000 A – 15 kV – 56 kW



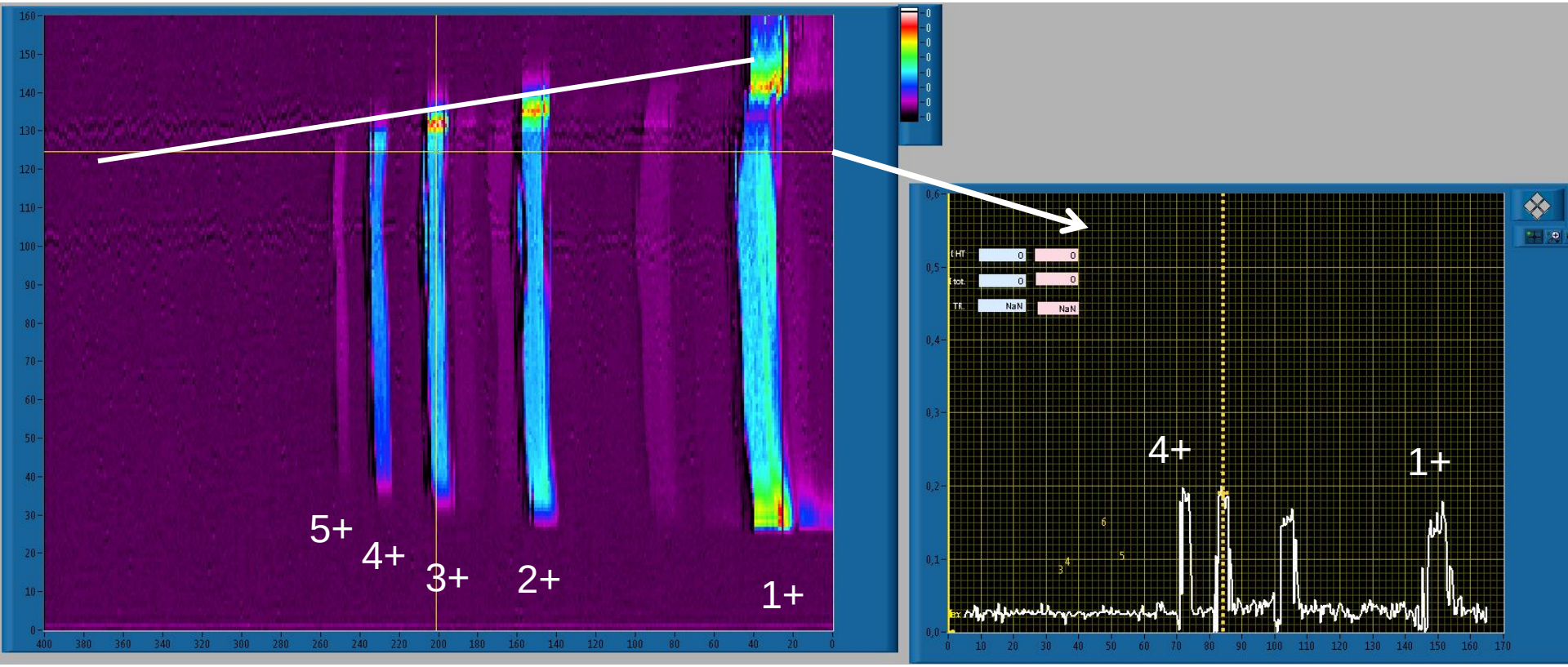
Ionization equilibrium

18000 A – 15 kV – 56 kW



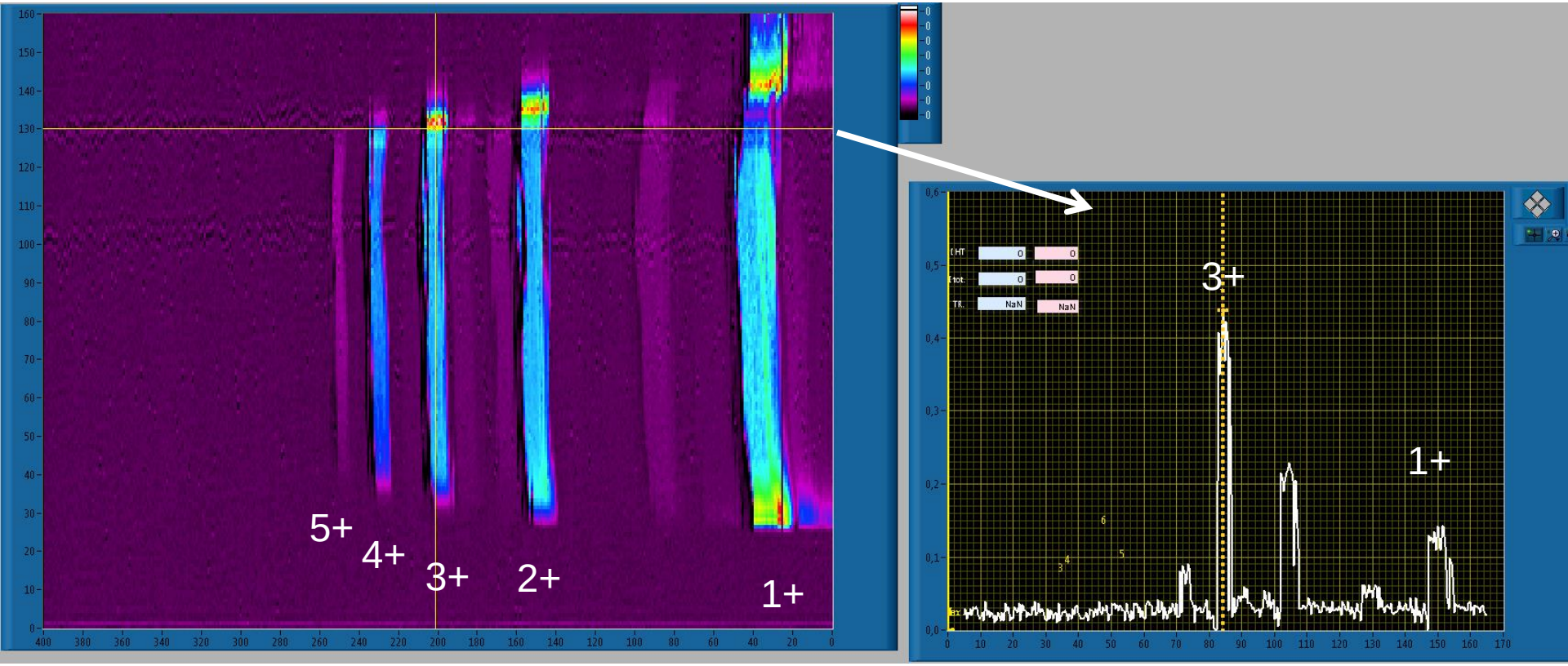
Ionization equilibrium (and HF stop)

18000 A – 15 kV – 56 kW



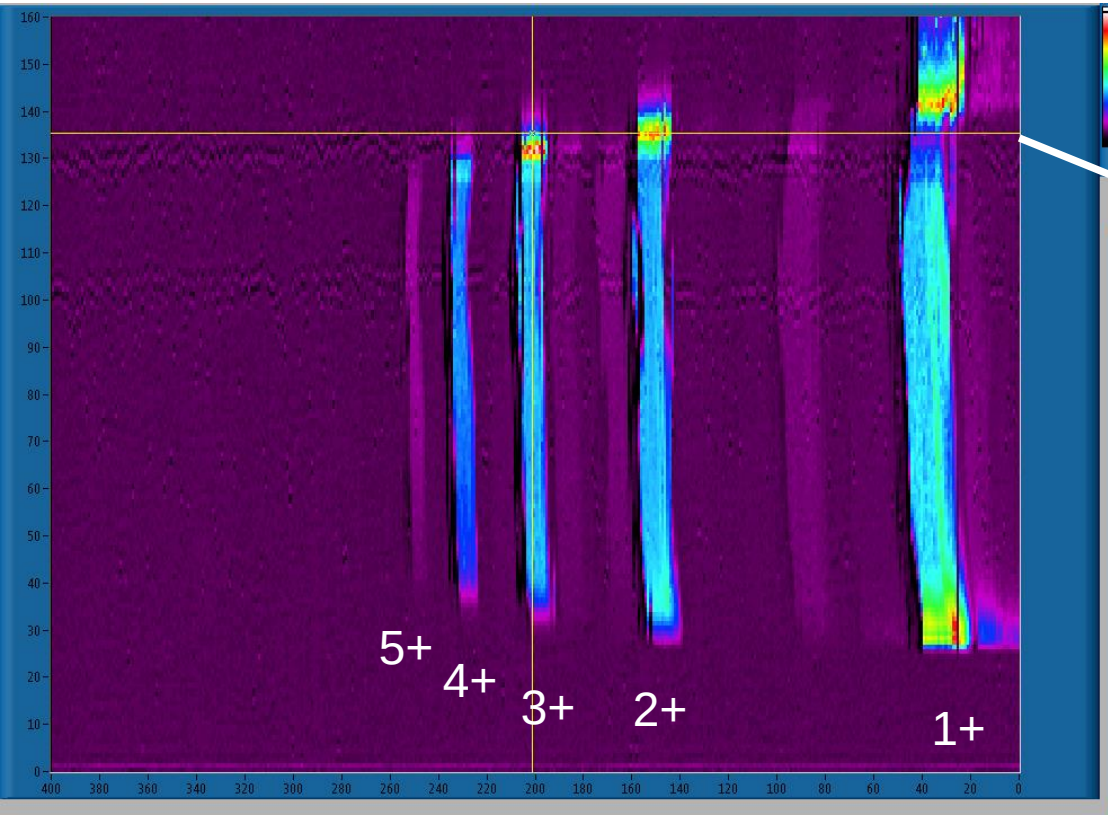
4+ Afterglow

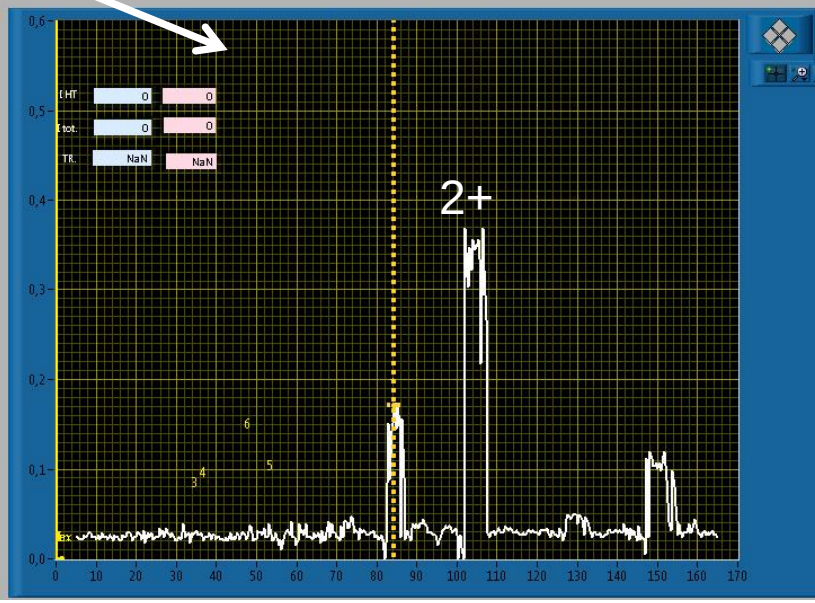
18000 A – 15 kV – 56 kW



3+ Afterglow

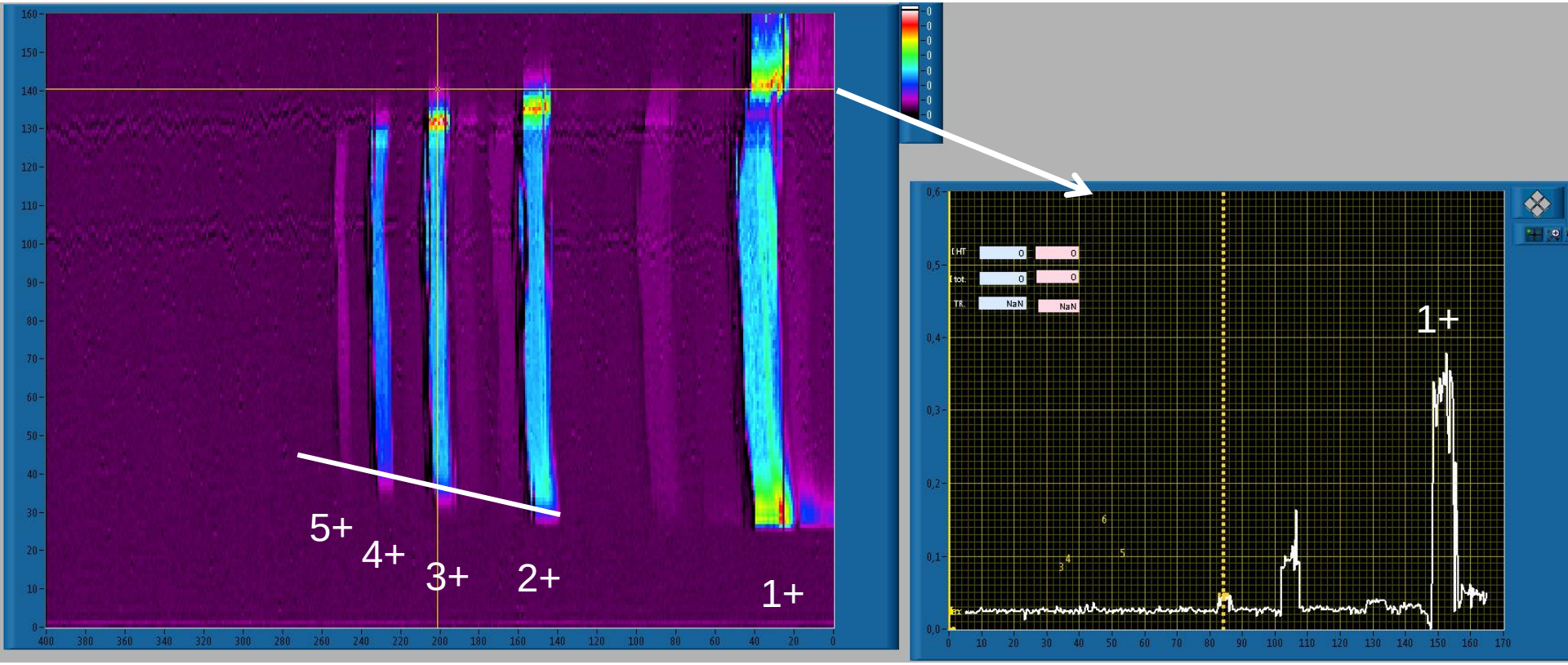
18000 A – 15 kV – 56 kW





2+ Afterglow

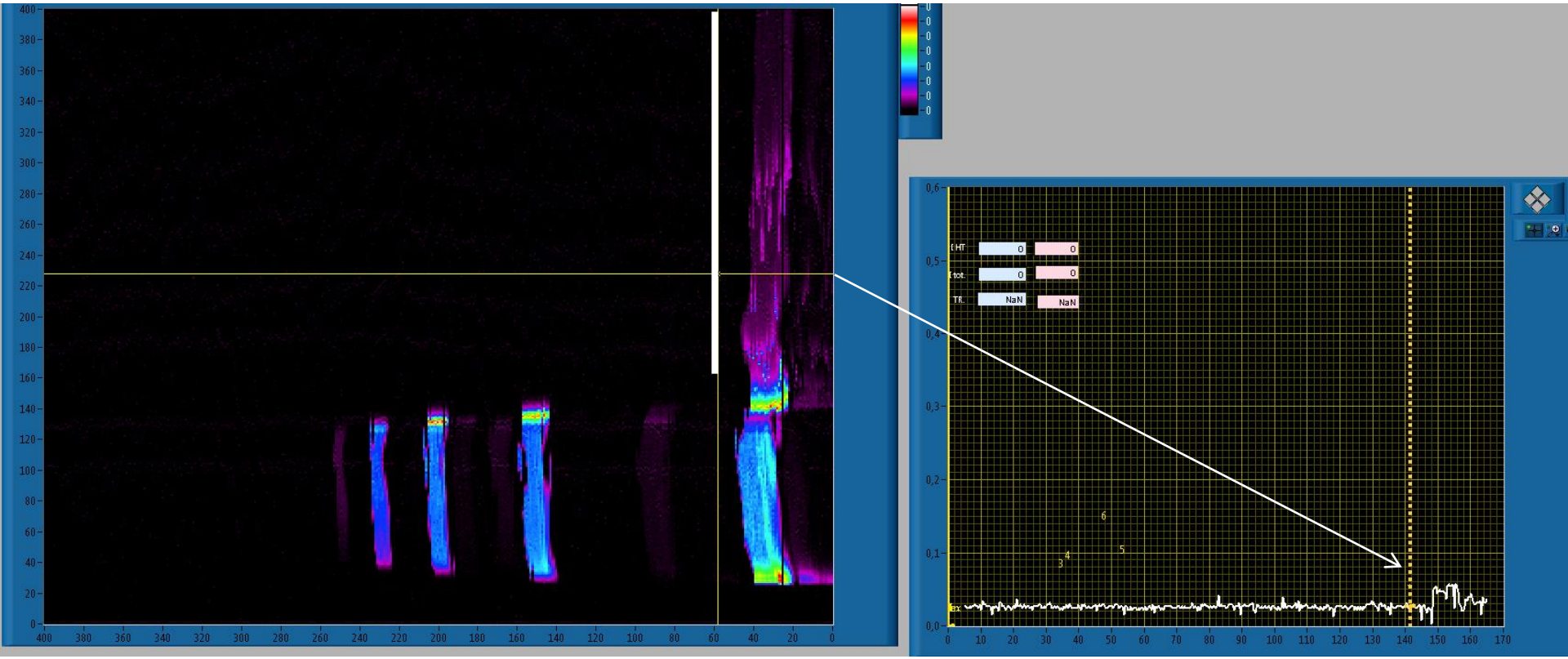
18000 A – 15 kV – 56 kW



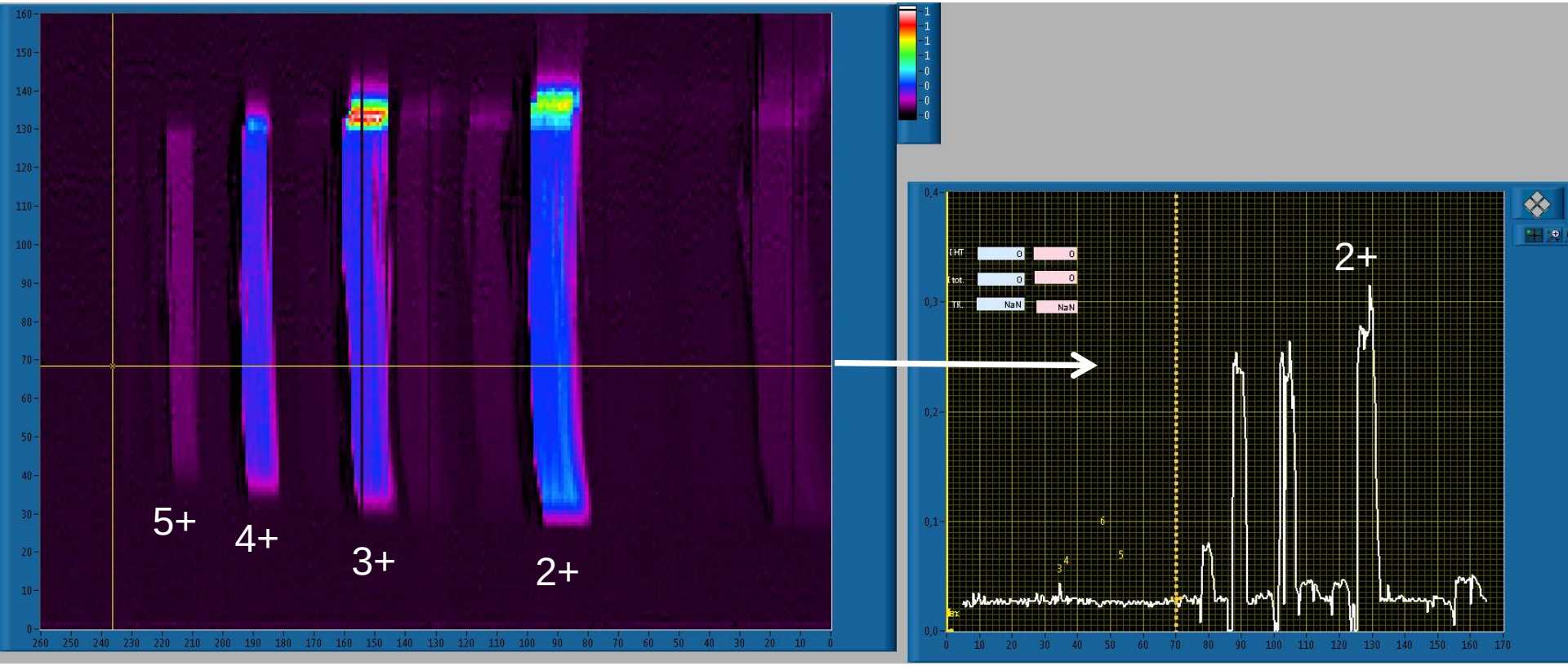
1+ Afterglow

18000 A – 15 kV – 56 kW

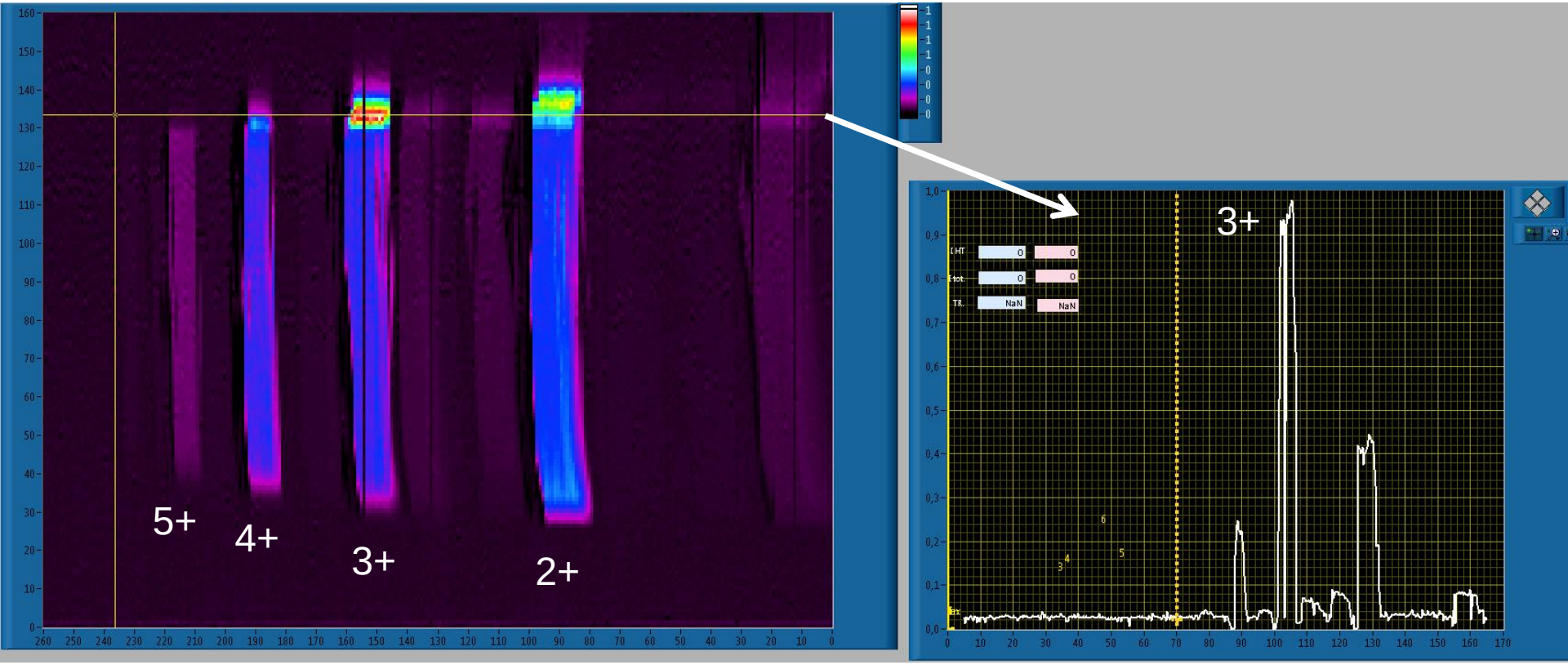
1+ tail



18000 A – 22 kV – 56 kW



18000 A – 22 kV – 56 kW



Conclusions

- **Unfortunately the present results are obtained with an extremely poor transmission**
- **A high frequency ECR source based on a cusp with high magnetic field and a closed ECR zone has obvious confinement properties**
- **It is able to produce amperes of ion beams**
- **A lot of plasma physics studies can be considered...**

Thank you !

I dedicate my talk to Vladimir Zorin
My colleague and friend