A closer look at a stationary plasma thruster (SPT-100D EM1)

C. Bundesmann[1], M. Tartz[1], F. Scholze[1],
F. Scortecci[2], R.Y. Gnizdor[3], H. Neumann[1]

[1] Leibniz-Institute of Surface Modification, 04318 Leipzig, Germany
[2] Aerospazio Tecnologie s.r.l., 53040 Rapolano Terme, Italy
[3] EDB Fakel, 236001 Kaliningrad, Russia

Stationary Plasma Thruster (Hall effect thruster)

Image source: www.wikipedia.com

- Stationary plasma thruster belong to the class of electric propulsion thrusters

⇒ Hall effect thruster

- Developed mainly in the Soviet Union/Russia
- Over 200 SPTs have been flown on Soviet/Russian satellites in the past thirty years (mainly used for station keeping or small orbital corrections).

Stationary Plasma Thruster (Hall effect thruster)

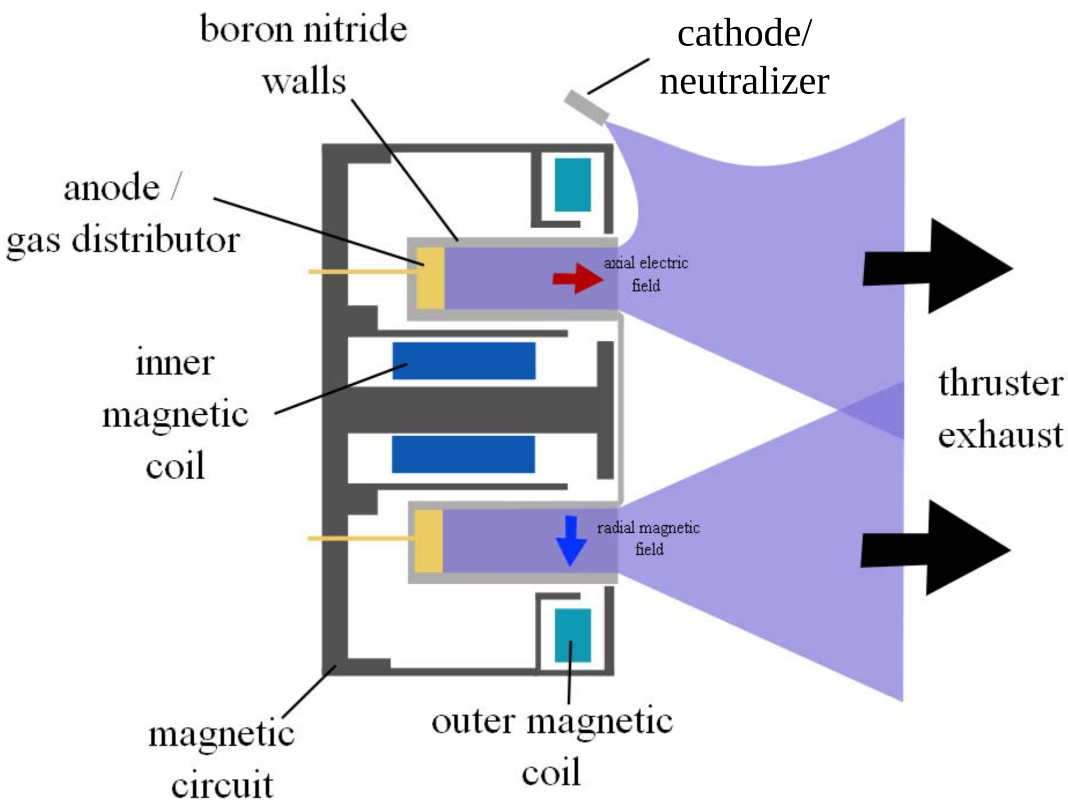
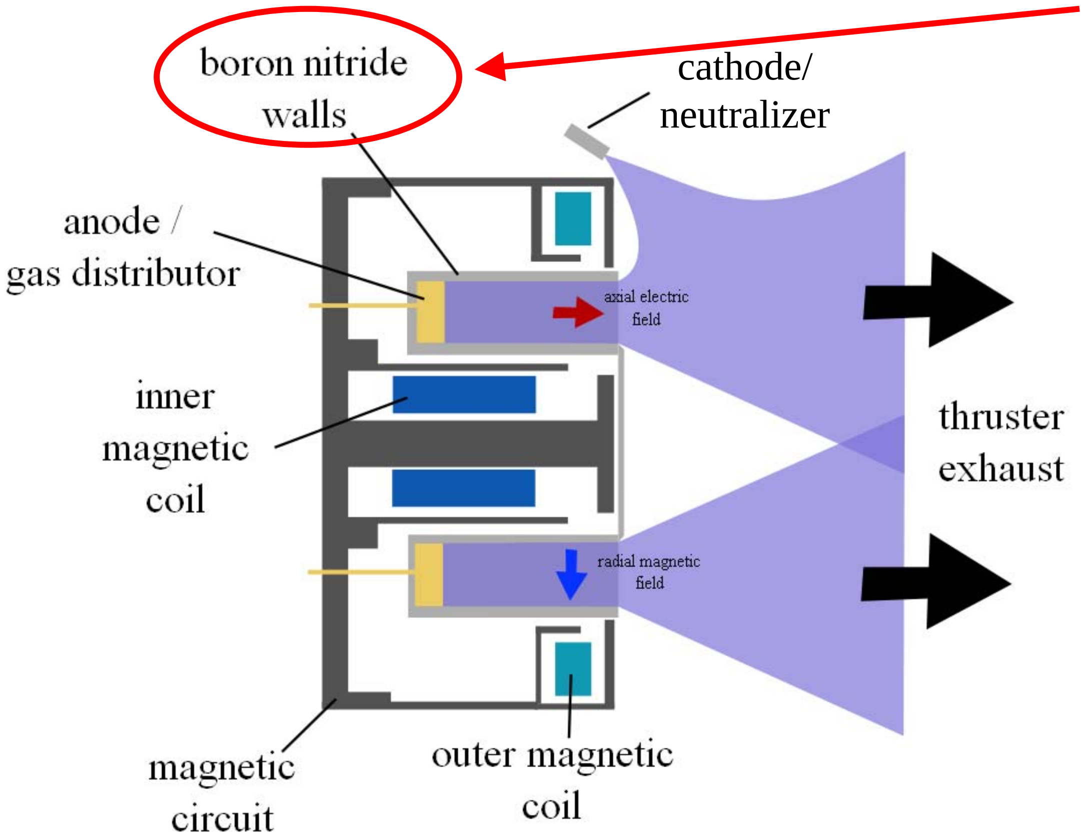


Image source: www.wikipedia.com

Working principle

- Electrons emitted by cathode circulate around the axis of the thruster (due to an radial magnetic field ↓ of a few milliteslas) with a slow axial drift towards the anode (due to an axial electric field → between cathode and anode)
- Xe particles become ionized by collision with high energy circulating electrons and accelerated by axial electric field
- Cathode acts also as neutralizer

Stationary Plasma Thruster (Hall effect thruster)



Life-limiting factor

- Erosion of ceramics (usually boron nitride) walls

Plasma generation complex, knowledge is limited

Need for advanced in-situ diagnostics

Image source: www.wikipedia.com

Motivation – In-situ characterization

1. Saves time and costs

In-situ characterization does not require
- breaking the vacuum,
- or dismounting/dismantling the thruster

2. Thruster performance evaluation

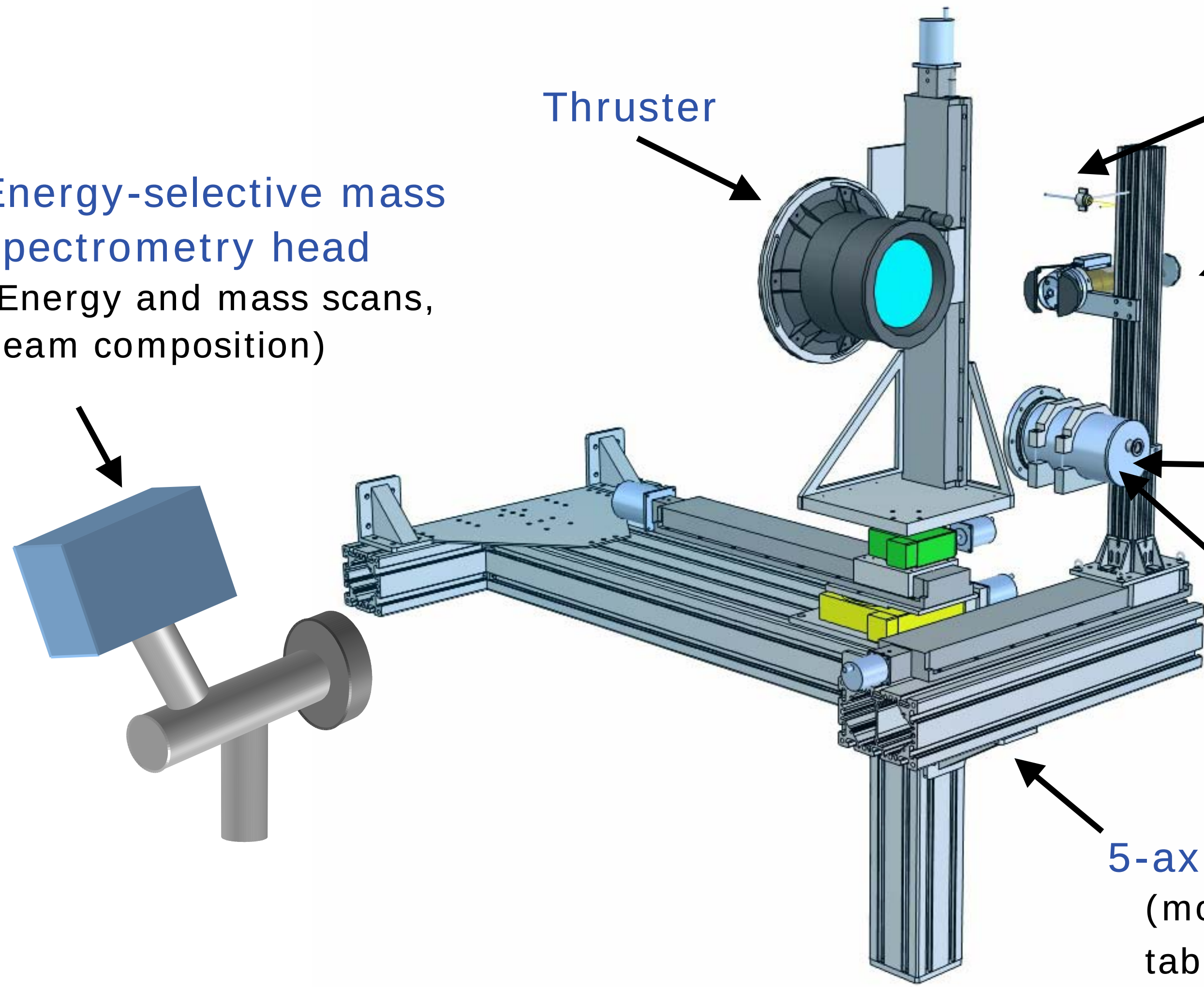
- Thruster needs to be tested on ground before flying into space
- Only in-situ characterization can tell, how thruster is operating while firing

3. Modeling

In-situ characterization can
- provide model input parameters
- validate modeling results

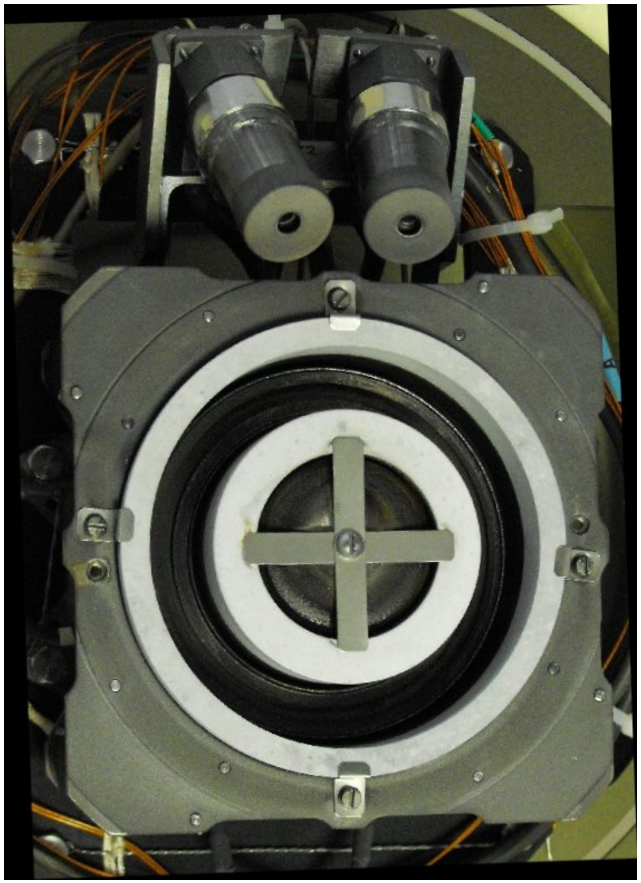
Our goal: Set up an advanced in-situ diagnostic system, which
- provides a comprehensive set of parameters
- can be used for different EP thruster types
- allows long-term testing

Diagnostic system setup



Test object: SPT-100D EM1 (Fakel)

Designed for high specific impulse

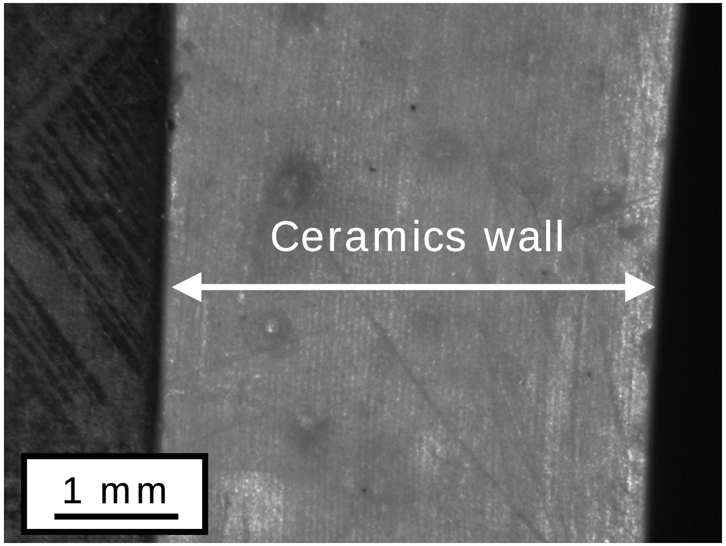


Discharge Voltage (V)	Discharge Current (A)	Discharge Power (W)
300	4.5	1350
500	3.7	1850
300	2.5	750
400	2.5	1000
500	2.5	1250
600	2.5	1500
700	2.5	1750
800	2.5	2000
750	2.6	1950

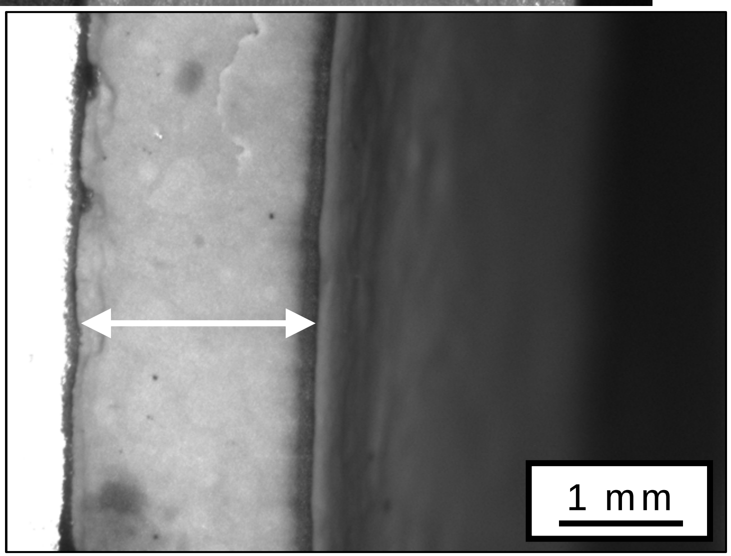
Total operation time for test campaign 280h

Further test object: Gridded ion thruster RIT-22
(see talk Mühlleithen 2009)

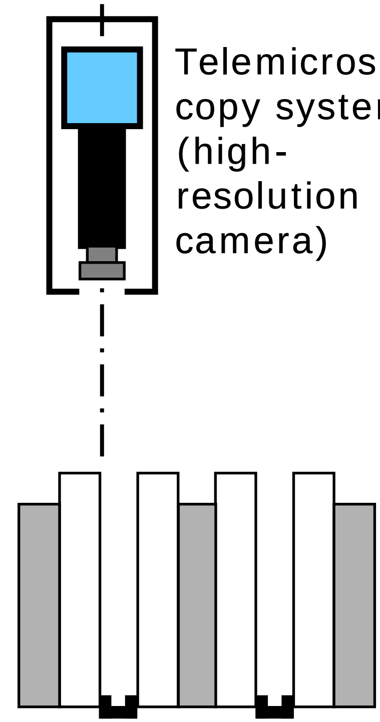
Telemicroscopy: Radial channel wall erosion



Start of test campaign



End of test campaign
(operation time ~280h)

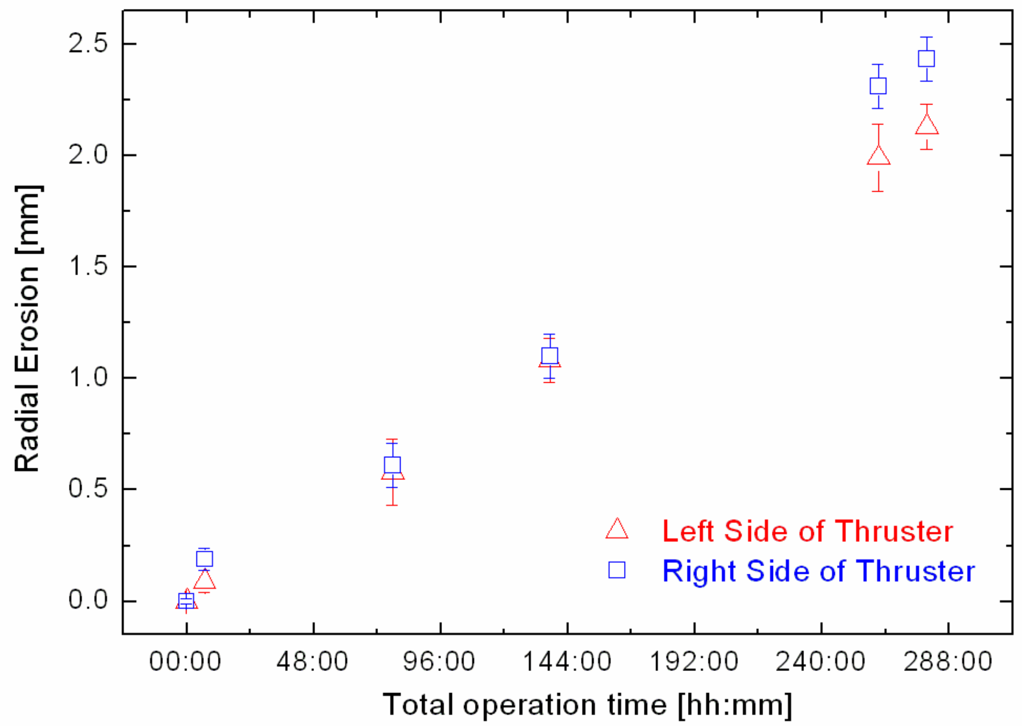


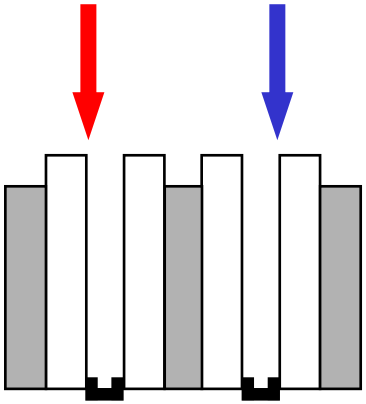
Telemicroscopy system (high-resolution camera)

Radial erosion can be clearly seen (~2.5 mm)

Telemicroscopy: Radial channel wall erosion

Radial Erosion, Outer Channel Wall Ceramics



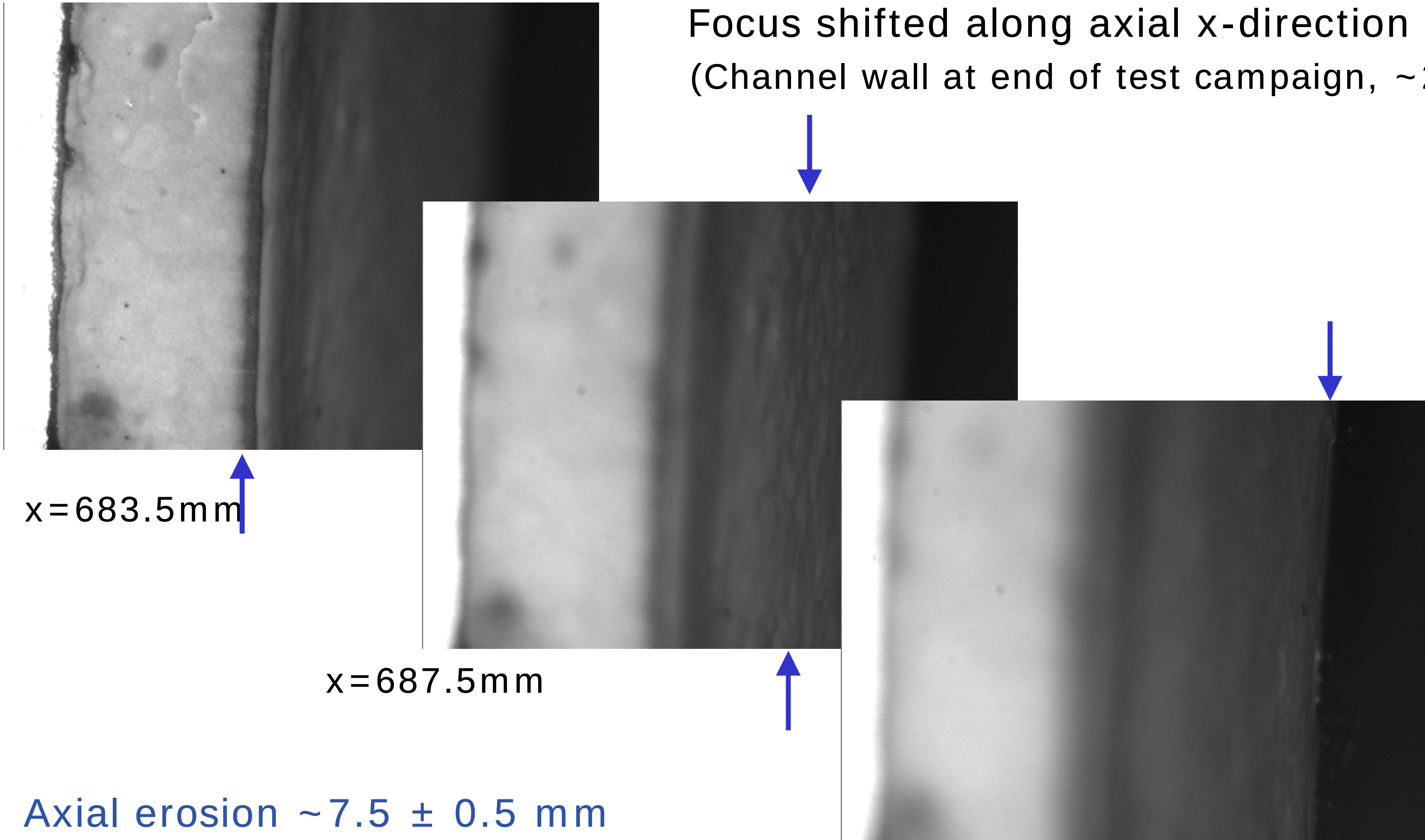


Linear increase of radial erosion with time

Telemicroscopy: Axial channel wall erosion

Focus shifted along axial x-direction

(Channel wall at end of test campaign, ~280h)



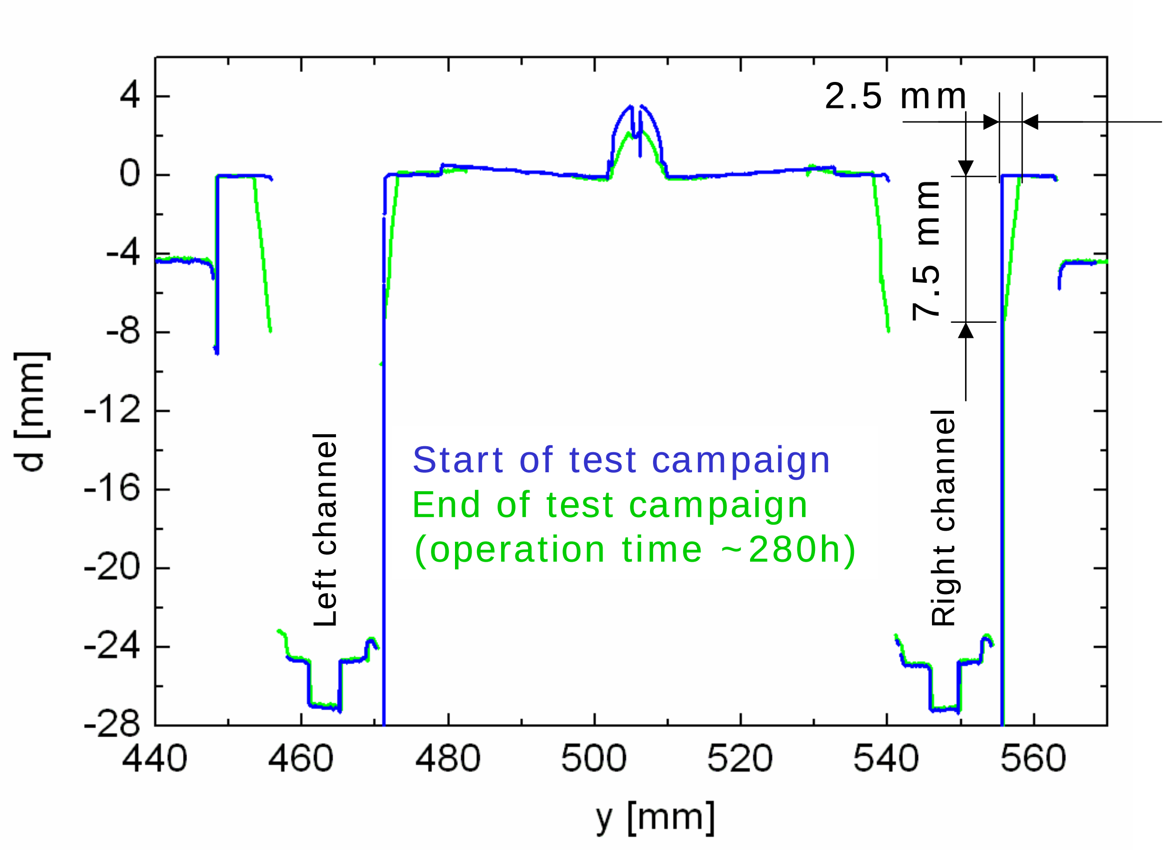
x=683.5mm

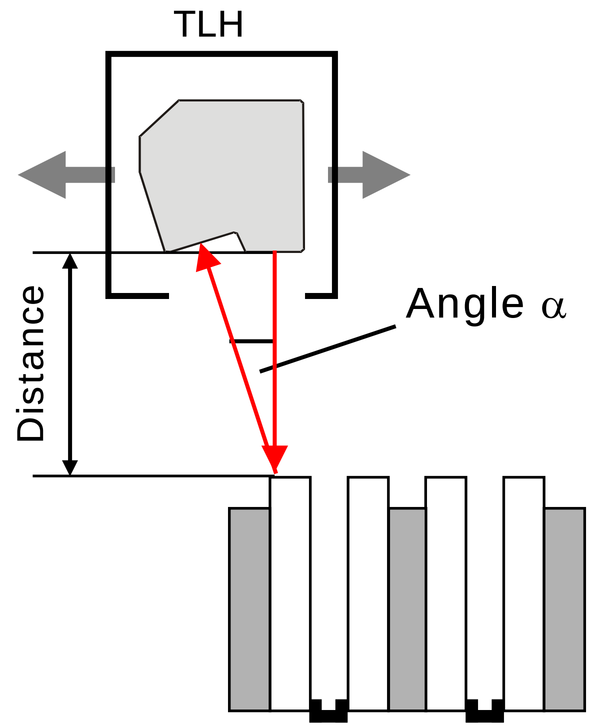
x=687.5mm

x=691.0mm

Axial erosion ~7.5 ± 0.5 mm

TLH: Line scans





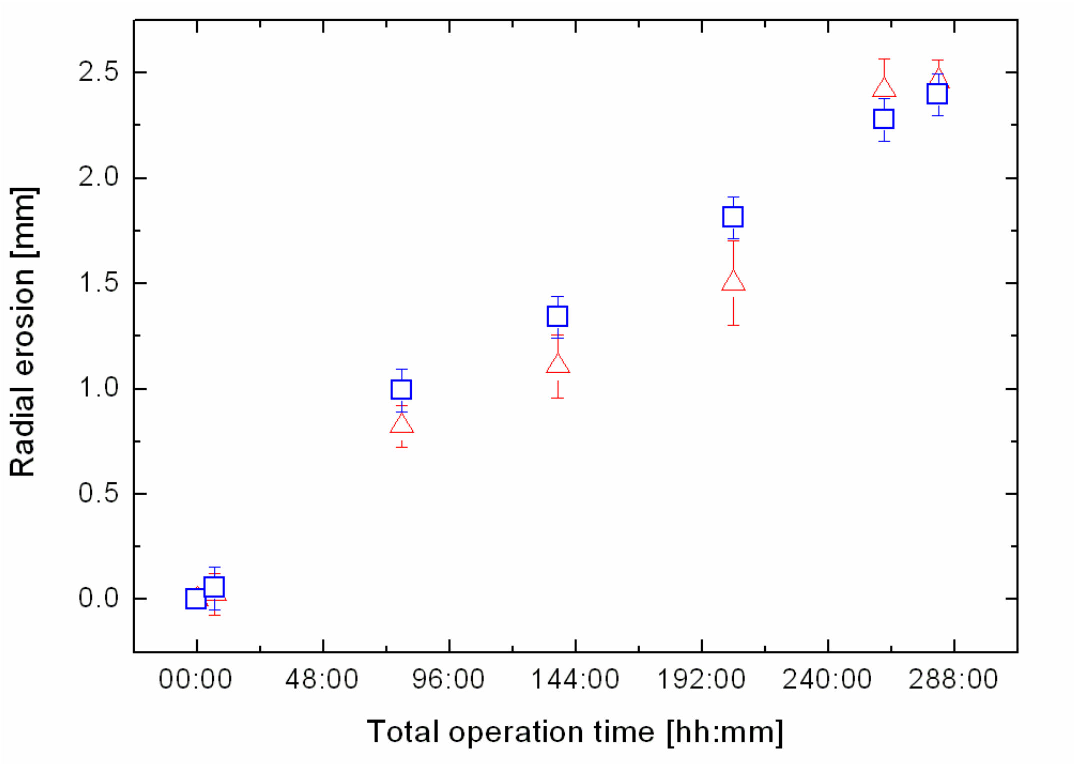
Left edges cannot be scanned completely (beam path of scattered light is blocked)

Radial erosion:2.5 mm

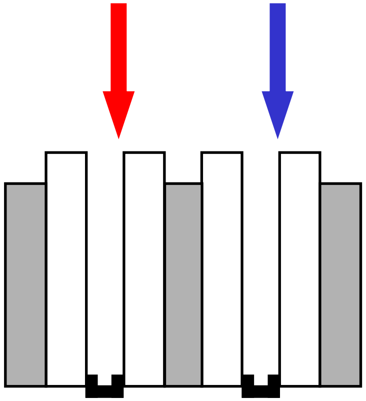
Axial erosion: 7.5mm

(Agreement with TMS)

TLH: Radial erosion

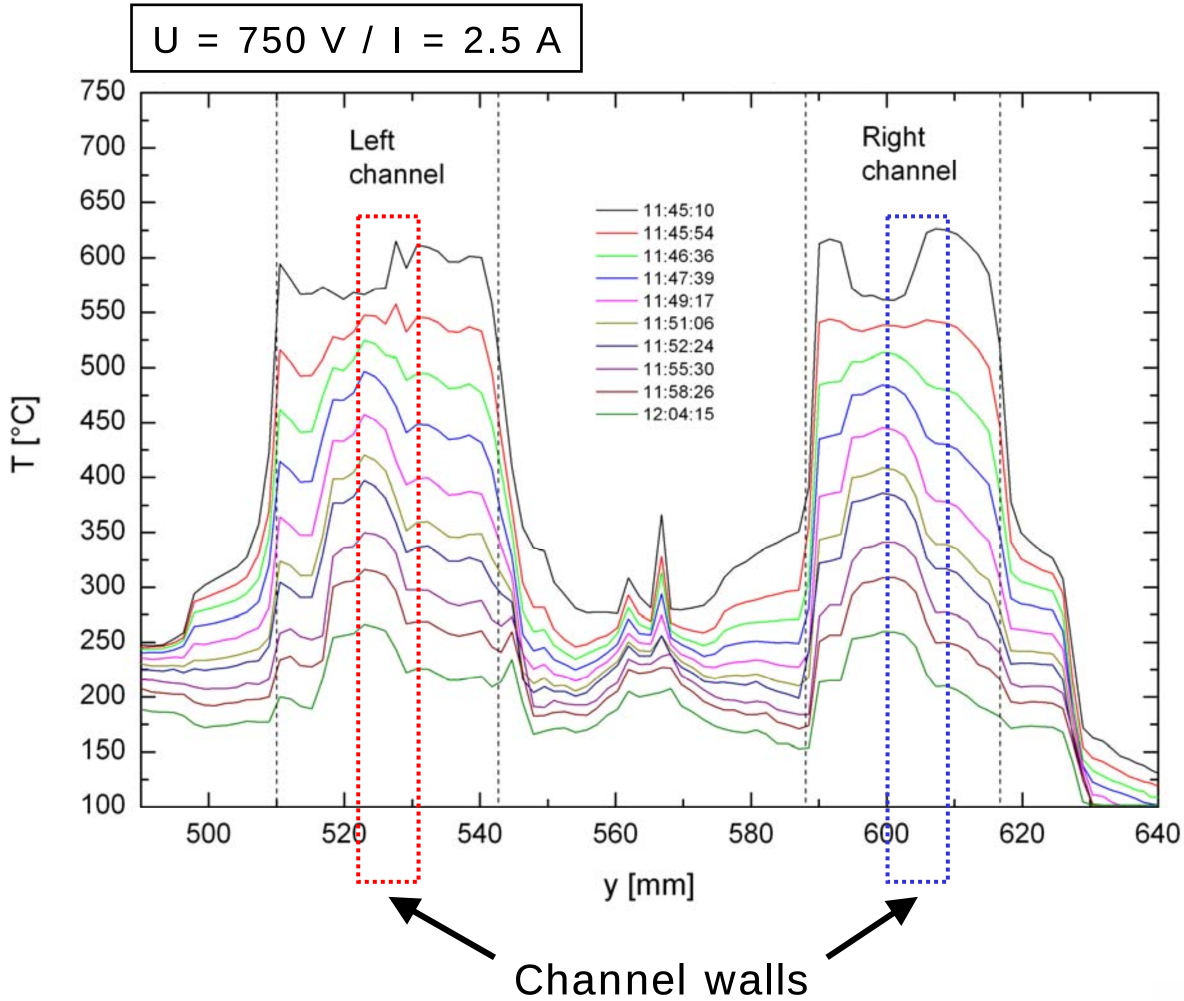


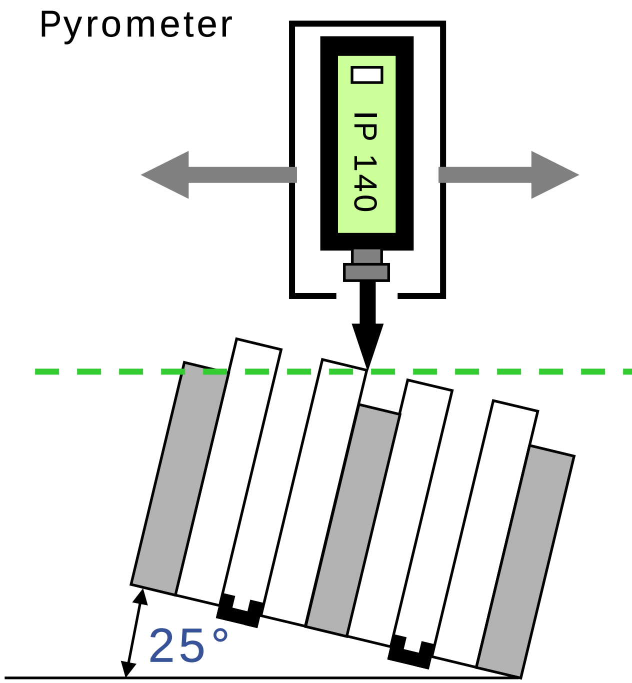
- Radial erosion increases linearly with increasing operation time
- Similar erosion values for all edges
- Absolute values depend on reference point



Pyrometer: Cool-down phase

Thruster tilted by 25°



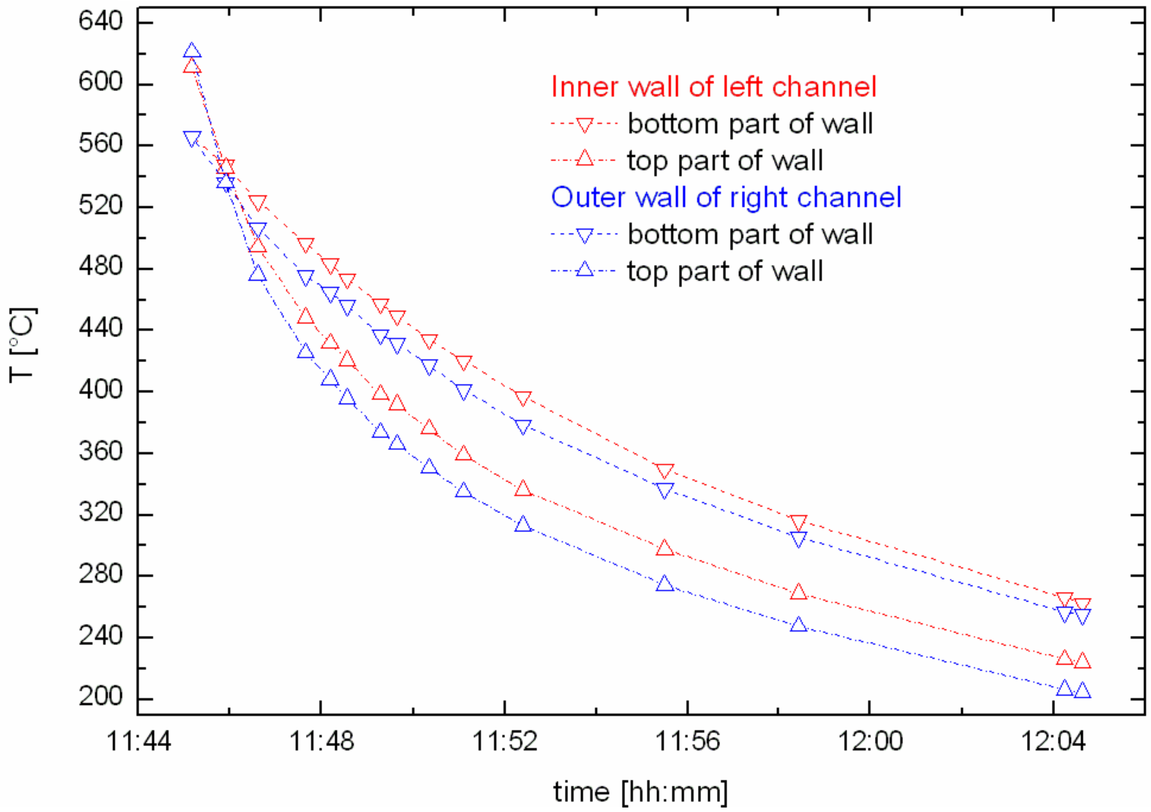


Systematic decrease of temperature with time

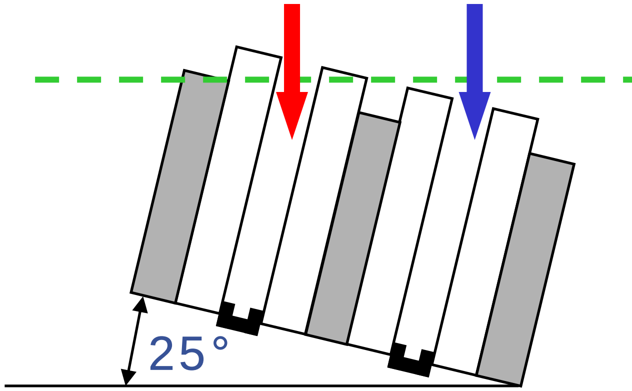
Pyrometer: Cool-down phase

Thruster tilted by 25°

U = 750 V / I = 2.5 A



Top part of channel wall
- is hotter at beginning
- cools down faster than bottom part

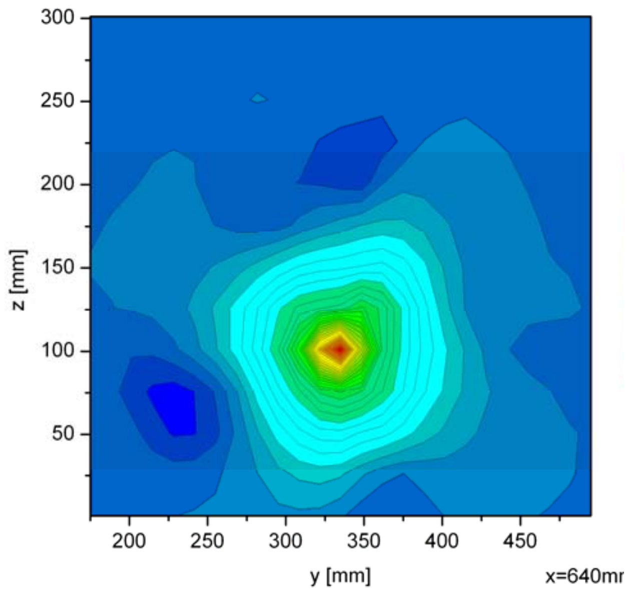


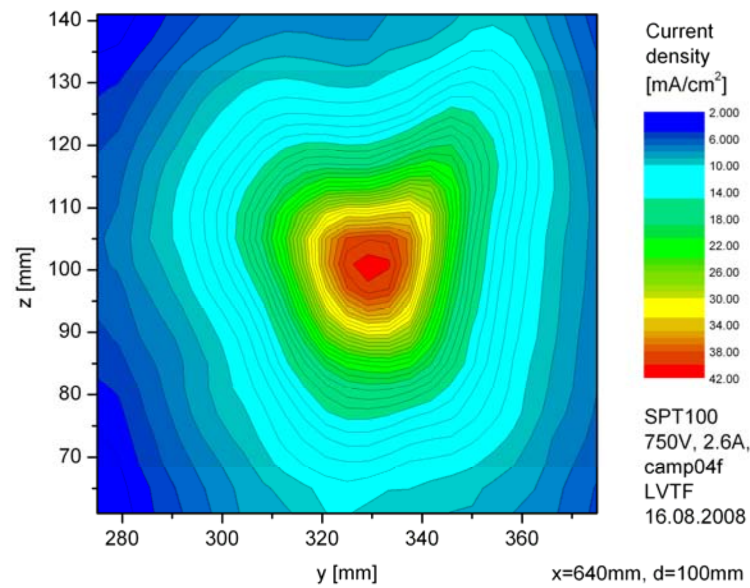
Outer wall of right channel cools down faster than inner wall of left channel

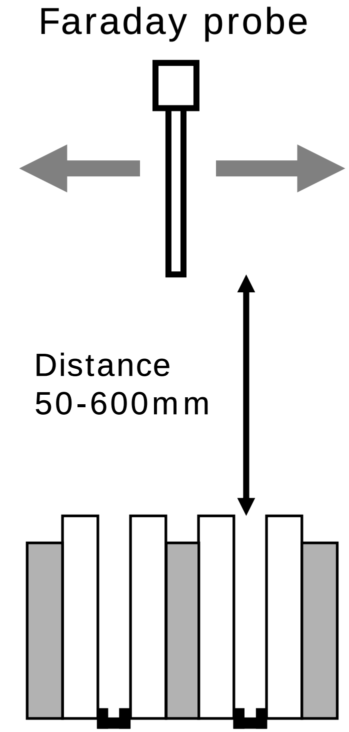
Faraday Probe: 2D Maps at distance 100 mm

Full map　　　　　Centre map

U = 750 V / I = 2.5 A







Beam looks (fairly) rotational symmetric

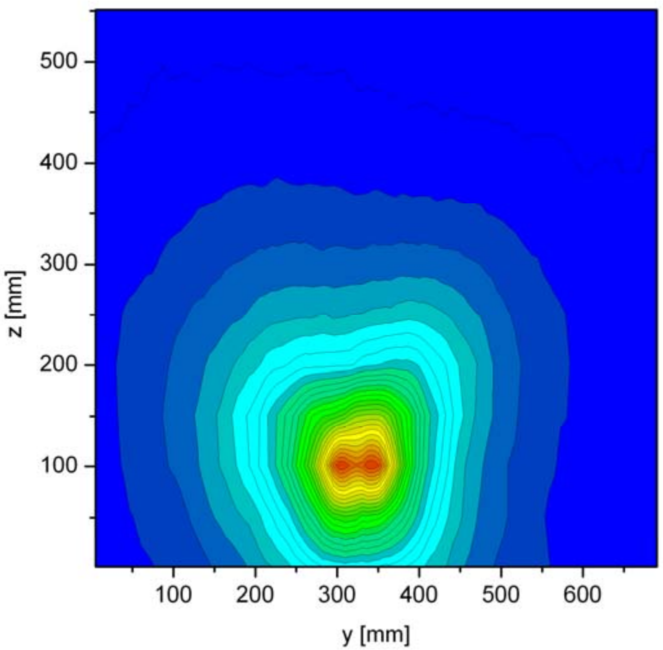
Beam focused (focal point at a distance of about 100 mm)

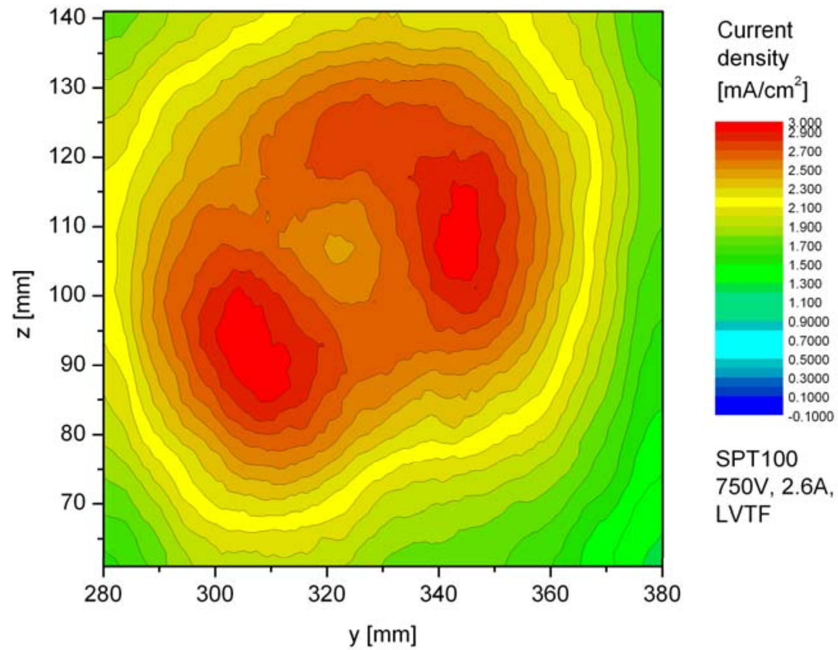
Faraday Probe: 2D Maps at distance 600 mm

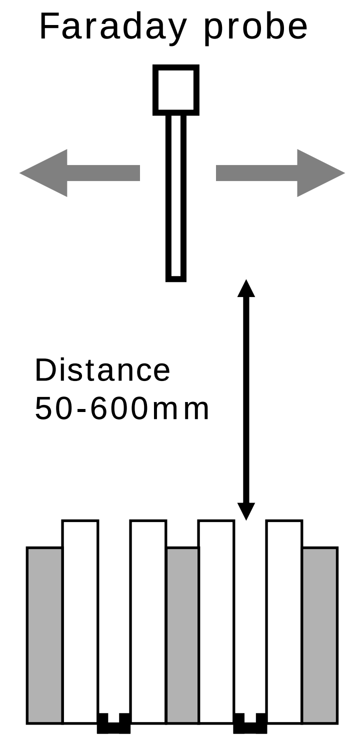
Full map

Centre map

U = 750 V / I = 2.5 A





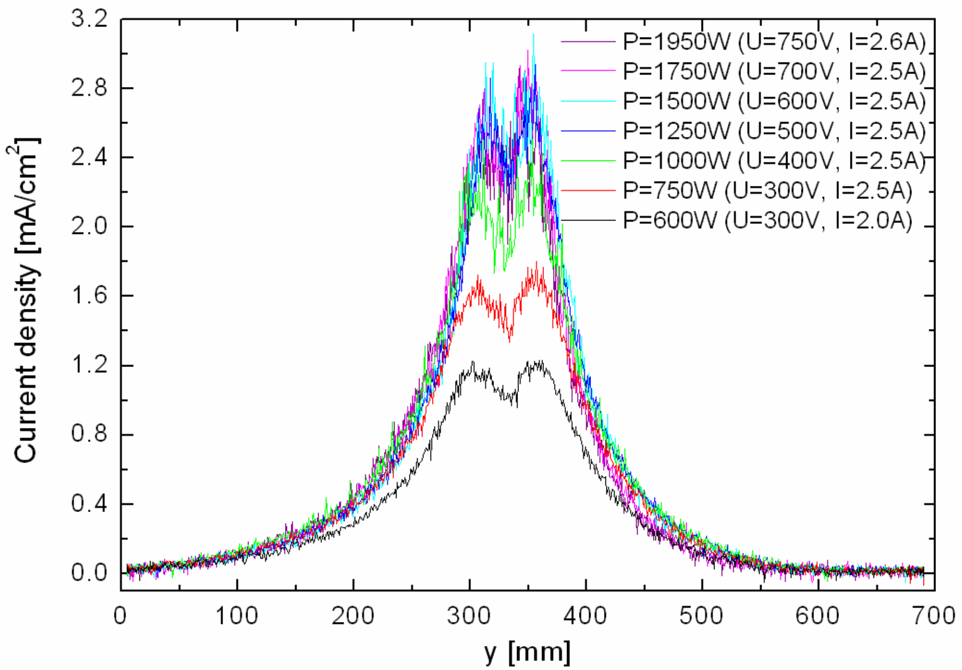


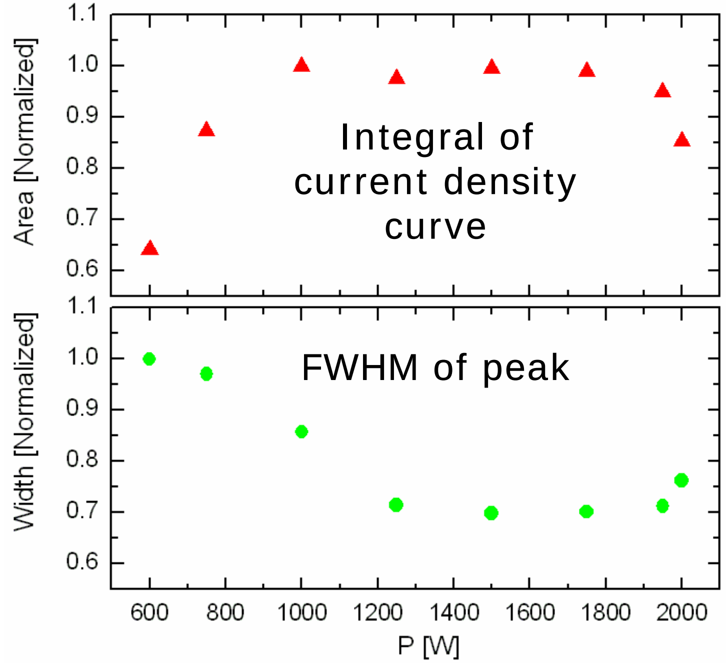
Beam is not rotational symmetric

(due to non-symmetric injection of electrons)

Faraday Probe: Centre scans at distance 600 mm

2D Faraday scans at different power levels

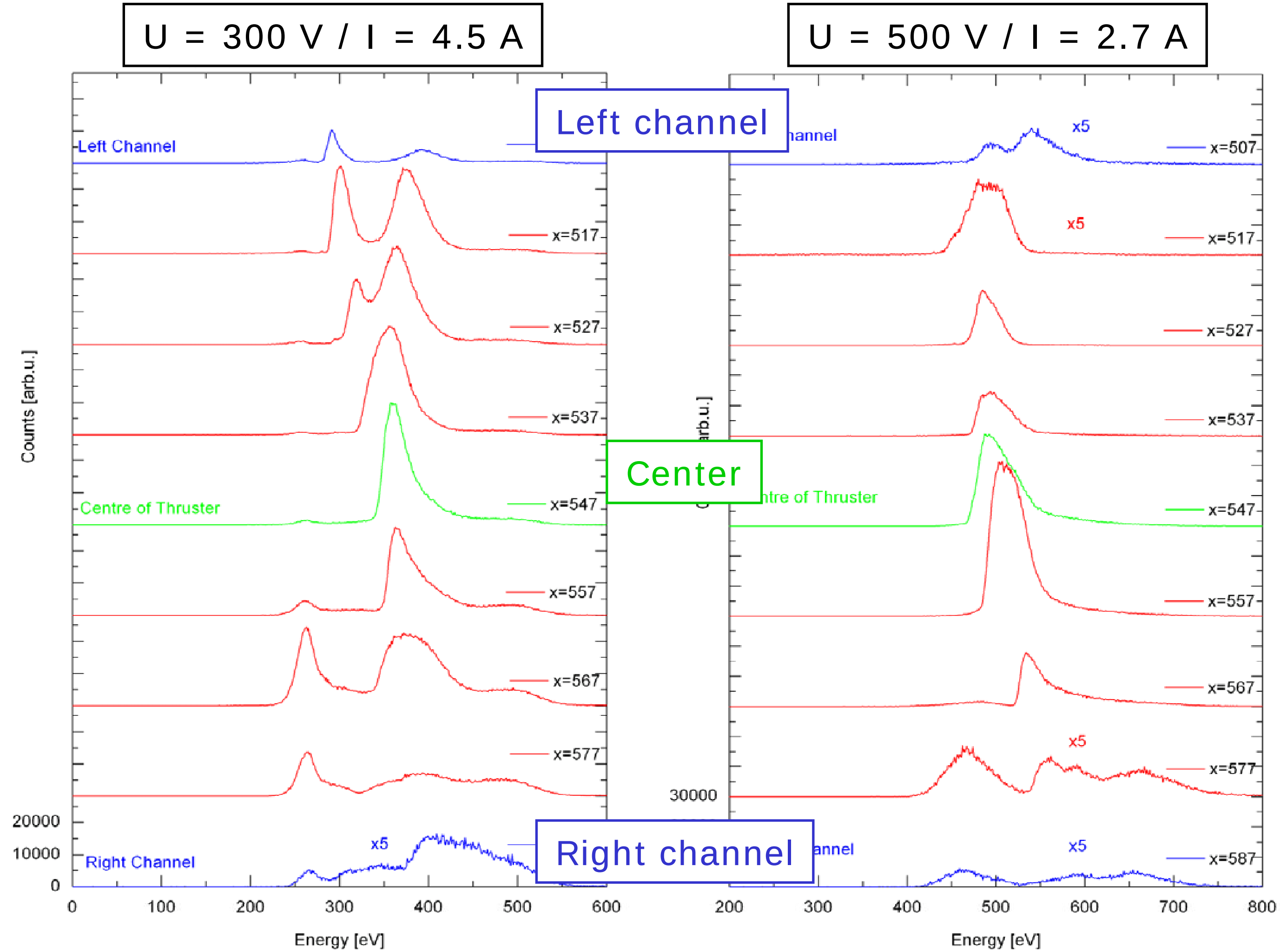


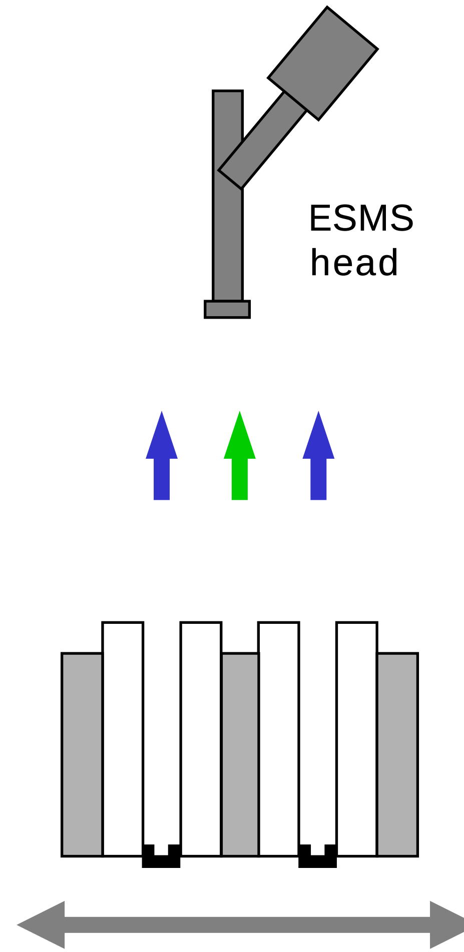


Current density maximum and FWHM minimum

for P > 1000 W

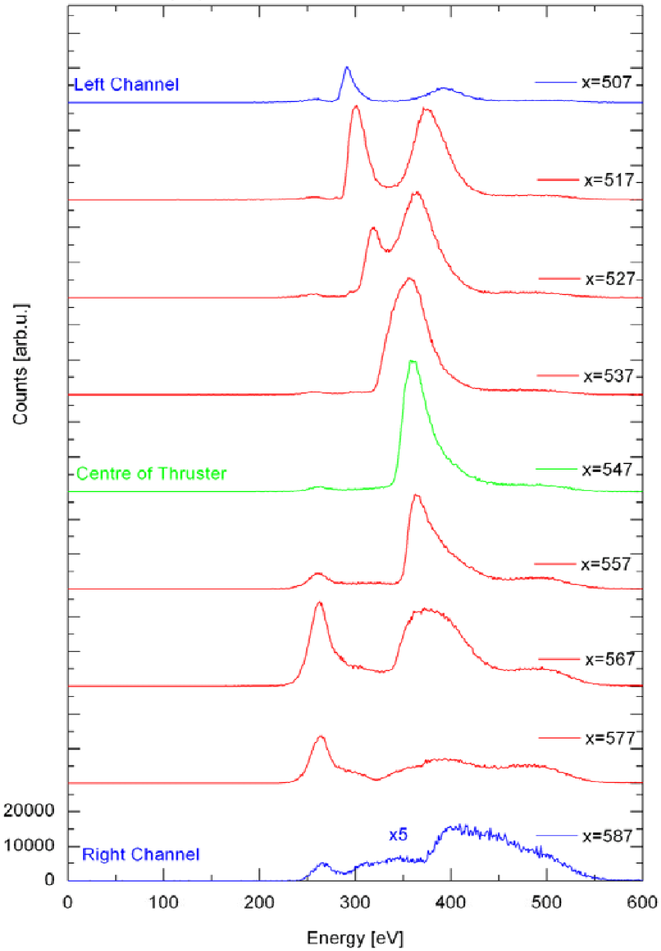
ESMS: Spatial energy scans $^{132}Xe^{+}$





ESMS: Spatial energy scans $^{132}Xe^{+}$

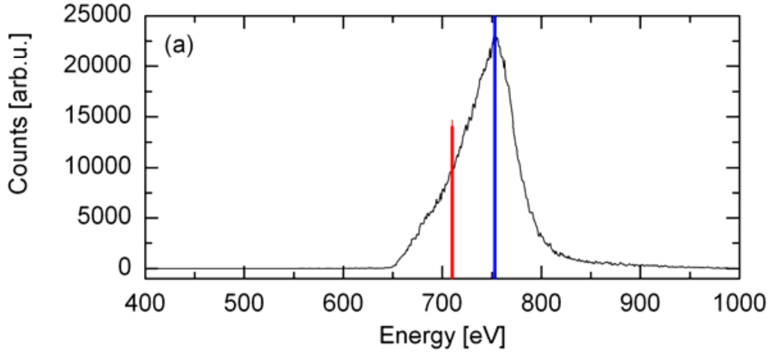
U = 300 V / I = 4.5 A



- Single peak structure dominating in the centre of the beam
- Multiple peak structure possible, especially above the plasma channels – potentials of ion creating zones must be different
- Ion energies can exceed the energy, which corresponds to the anode voltage, by up to 100 – 200 eV
- Similar behavior for different operation modes
- Non-symmetrical beam (agrees with Faraday maps)

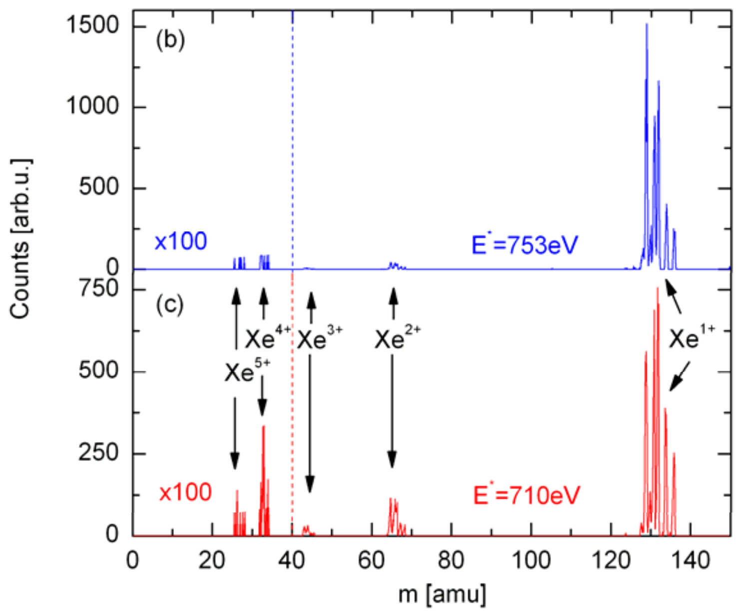
ESMS: Mass scans at different energies

U = 750 V / I = 2.5 A



Energy scan (in the centre of the beam)

- Broad, non-symmetric peak



Mass scans (at two different energies)

- Charge states 1-5 can be seen
- Fraction of multiple charged Xe ions changes with ion energy (and position) ➡ different e/m ratios result in different ion direction in the E and B –field of the thruster!

Summary

- In-situ EP diagnostic system designed, built and tested
- Successful test campaign with Hall Effect thruster SPT-100D EM1 at different operation modes, total operation time ~280h
- Diagnostic tools for mechanical (telemicroscopy, TLH), thermal (pyrometer), beam and plasma properties (Faraday probe, ESMS)
- Telemicroscopy system, TLH: radial and axial erosion of channel walls
- Pyrometer: temperature of channel walls
- Faraday probe: 2D current density maps, 3D plume plot possible
- ESMS: Energy and mass distribution, beam composition, multiple charged ions - helps to describe the basics of plasma and beam processes
- Modular setup, allows adaption to different facilities or other thruster types (e.g. Gridded ion thruster RIT-22, see paper IEPC-2009-160), and integration of new diagnostic heads (e.g. thermocamera, thrust balance)

Acknowledgements

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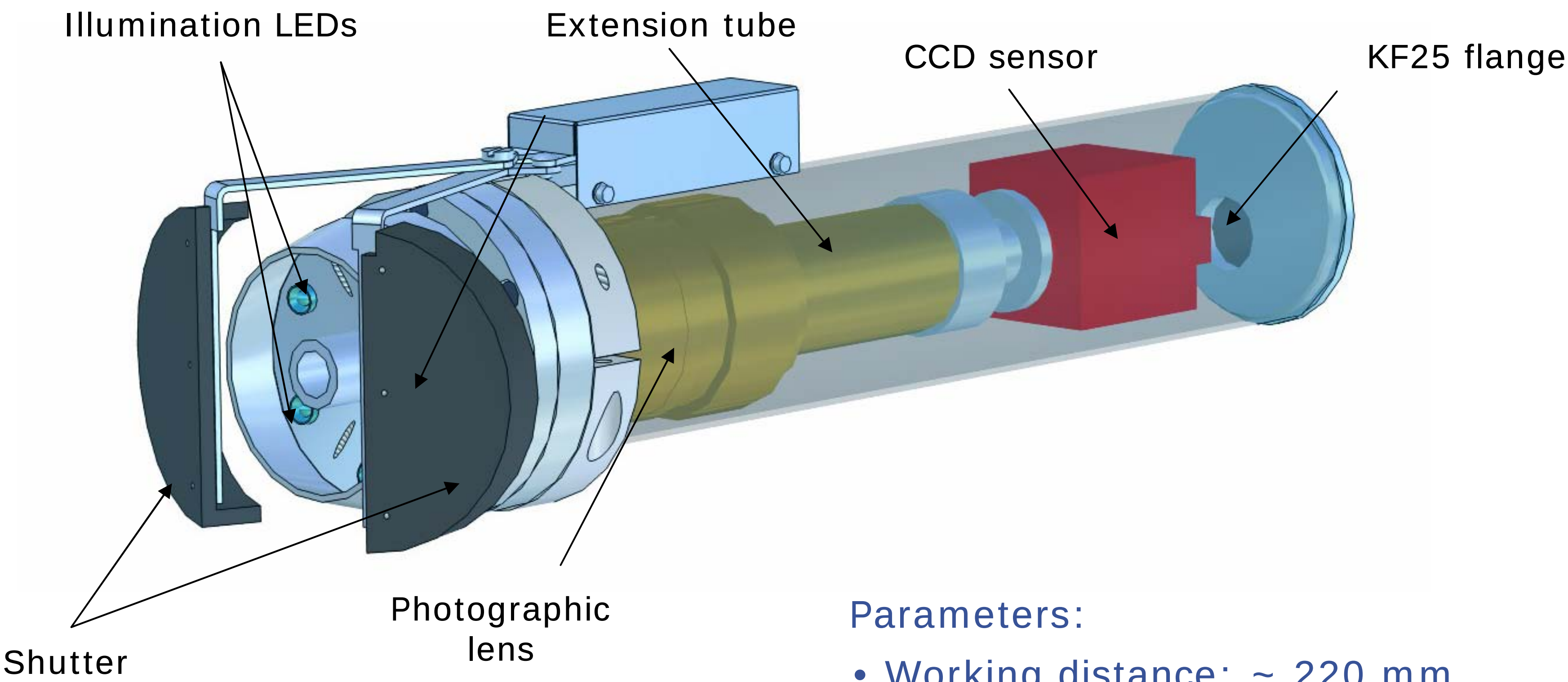
Team at Aerospazio	Test facility operation and support
P.-E. Frigot, J. Gonzalez del Amo (ESA)	Project-coordinators

Financial support: ESA/ESTEC Contract No. 20461/06/NL/CP

Thank you for your attention

Telemicroscopy system setup



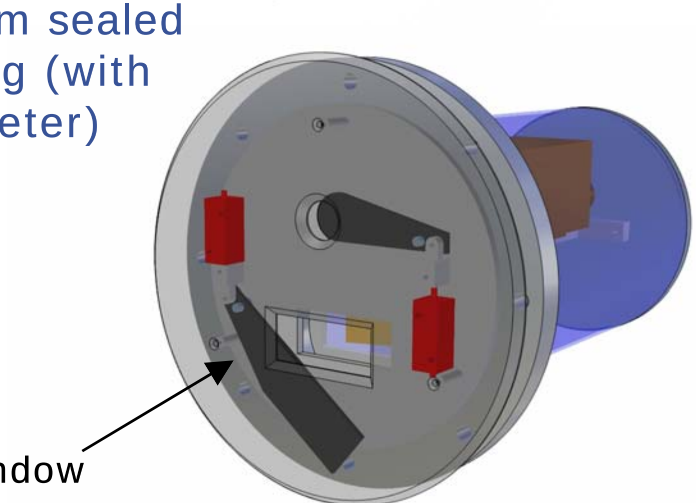
Parameters:
- Working distance: ~ 220 mm
- Field of view: ~ 5.8 x 4.3 mm^2
- Lateral resolution: ~0.01 mm
- Depth of field: ~ 0.3-0.5 mm

Vacuum sealed housing of telemicroscopy system (TMS)

Triangular laser head (TLH)

Keyence LK-G 152

Vacuum sealed housing (with Pyrometer)



TLH window with shutter

Triangular laser head (TLH) parameters:

- Working distance : 150 ± 40mm
- Axial resolution : < 0.001 mm
- Diameter laser spot: 0.12 mm

Measurement options:

- Horizontal and vertical scans

Intended Tasks:

- Radials and axisl channel wall erosion

Pyrometer setup

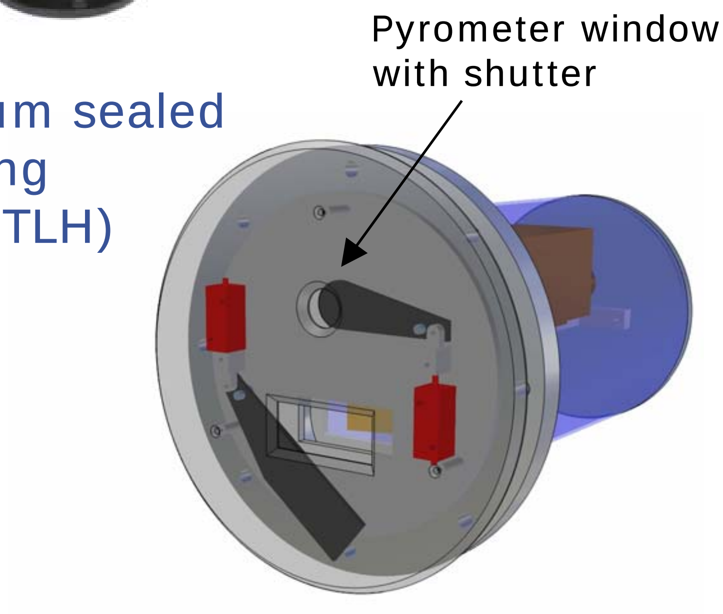
Impac IP140

Source: Impac Infrared GmbH

Pyrometer parameters:

- Temperature range: 100 - 700 °C
- Accuracy: 2 - 3 °C
- Working distance : ~ 150 mm
- Spot size in focus: ~ 1.5 mm

Vacuum sealed housing (with TLH)



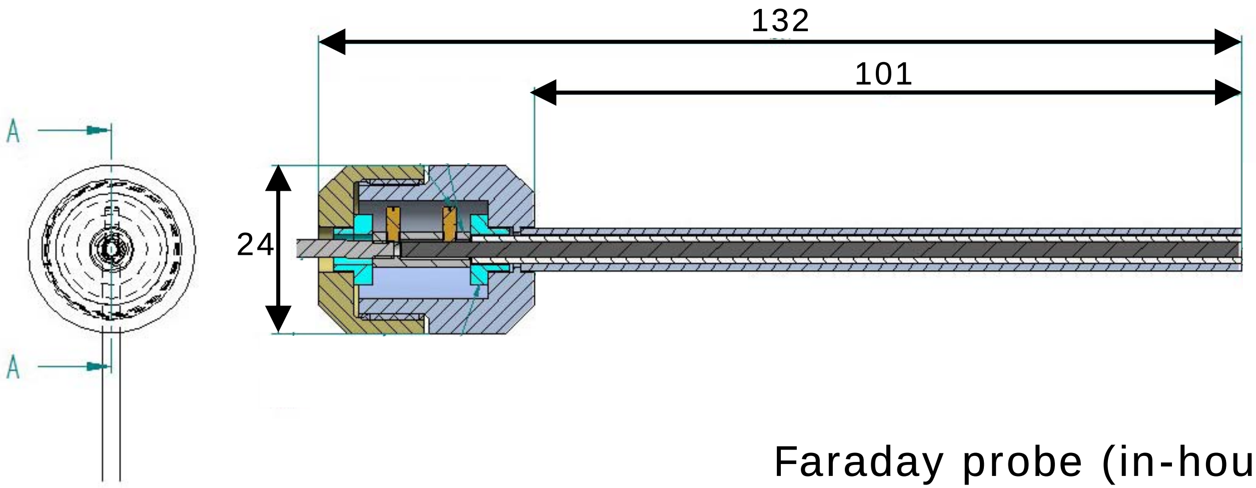
Measurement options:

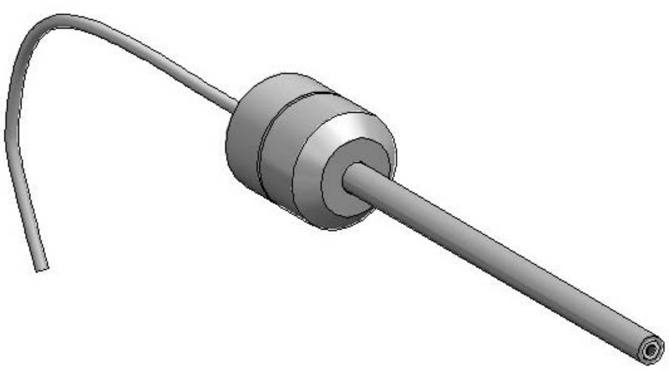
- Temperature line scans

Intended Tasks:

- Temperature of ceramics channel walls (SPT)

Faraday probe

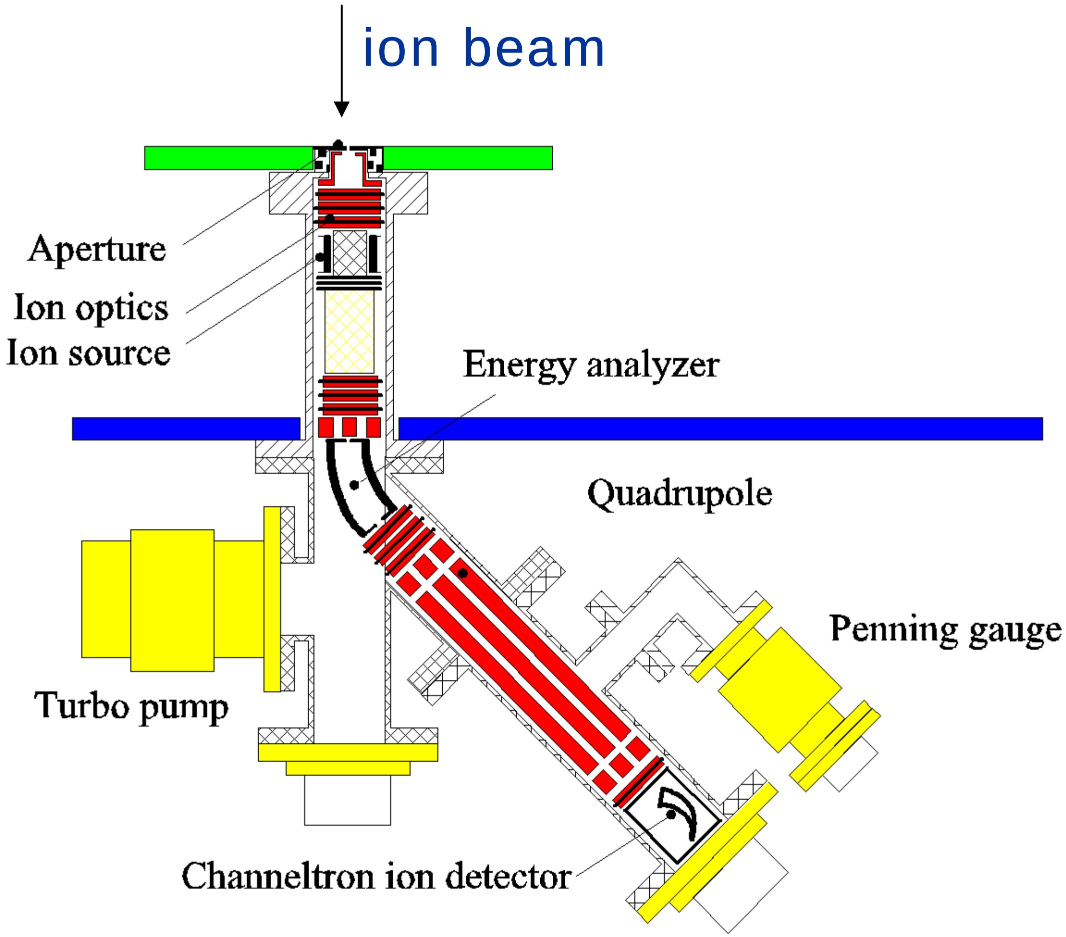




Faraday probe (in-house built):

- cup-diameter 2 mm
- shielded by a stainless steel cylinder
- covert by a graphite sputter shield
- cable inside support frame
- ion current density range up to 40 mA/cm^2

Energy-Selective Mass Spectrometer



HIDEN EQP 300

- Mounted to chamber wall
- Aperture diameter 200 µm
- Mass range 0 … 300 amu
- Mass resolution 1 amu
- Energy range up to 5 keV
- Energy resolution 0.5 eV