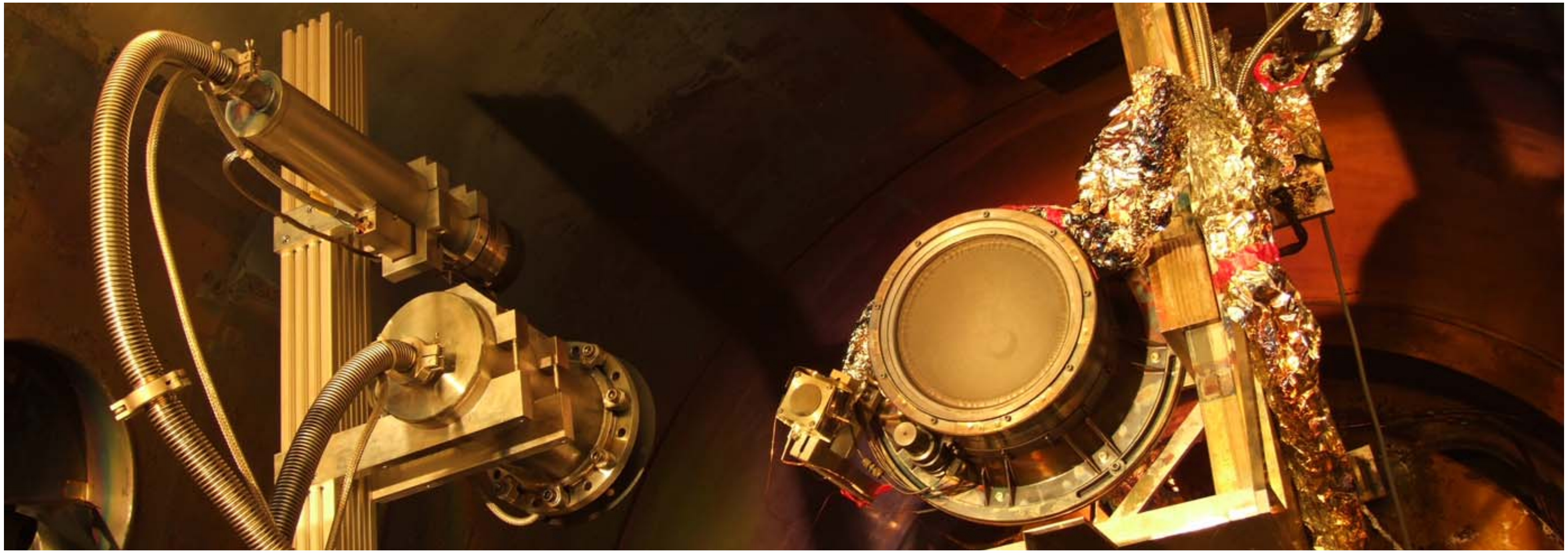

Final Presentation AEPD2: IOM Activities

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AO/1-7077/12/NL/EM

Final Presentation, ESA/ESTEC, December 14, 2017

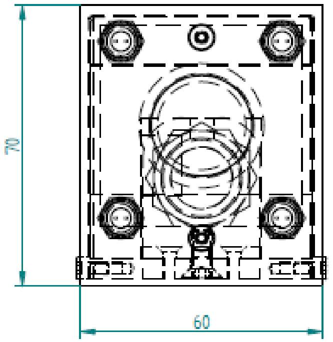
Outline

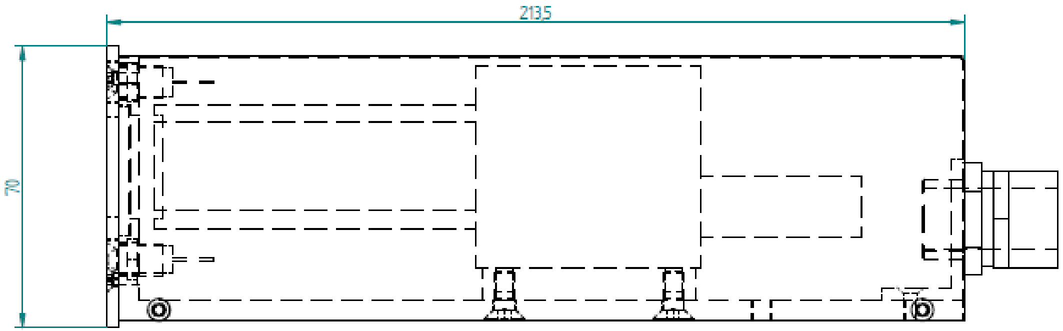
- Introduction
  - Tasks
- Diagnostic tools
  - Design
  - Performance characterization
- Results of test campaigns
  - RIT-µX
  - SPT-100ML
- Summary

Tasks

- Design, manufacturing, performance characterization of diagnostic tool
  - Telemicroscope
  - Triangular laser head
  - Pyrometer
  - Thermocamera
  - Retarding potential analyzer
  - Faraday probe
- Design, manufacturing, performance characterization of diagnostic system
- Perform and analyze test campaigns
  - Thrusters: RIT-µX (ArianeGroup), SPT-100ML (ICARE)
  - Facilities: Jumbo (JLU), MVTF

Telemicroscope: Design

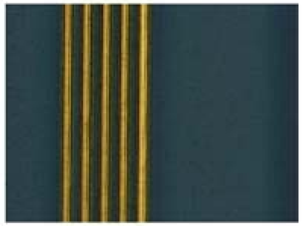




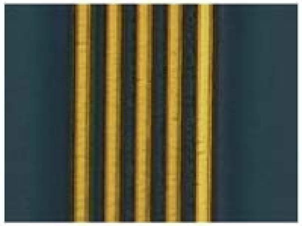
- Housing with graphite front plate and sapphire window
- 4 LEDs for object illumination
- Dimension 60 x 70 x 214 mm^3
- Operational test in air and in vacuum was performed successfully
- NOT specified for in-vacuum operation:
  Electronic parts had to be replaced
- Status: Ready for test campaigns

Telemicroscope: Performance characterization

Microscope image (lens 12.5x)

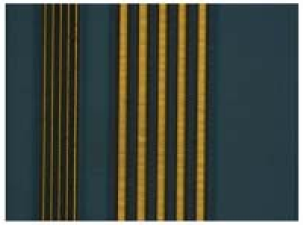


10 µm / 15 µm

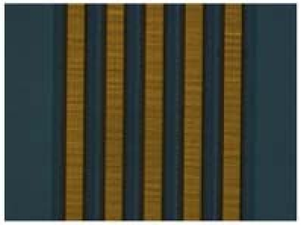


20 µm / 20 µm

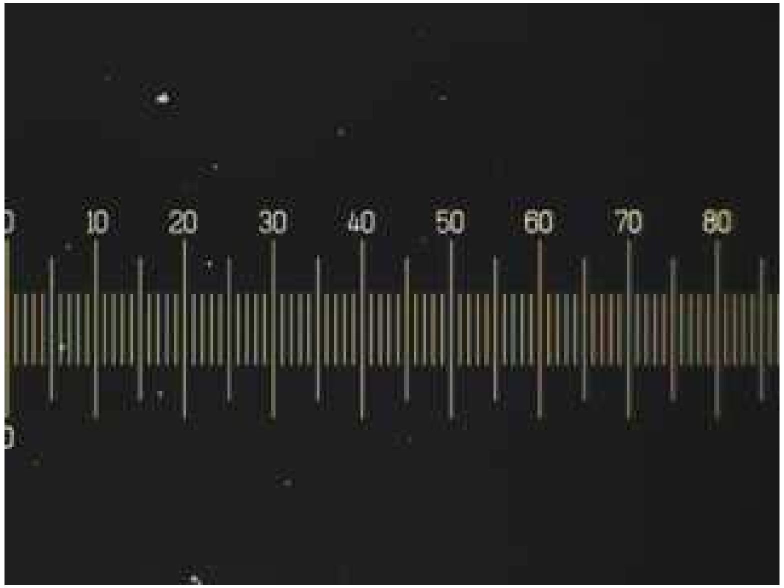
Microscope images (lens 3.5x)



50 µm / 50 µm

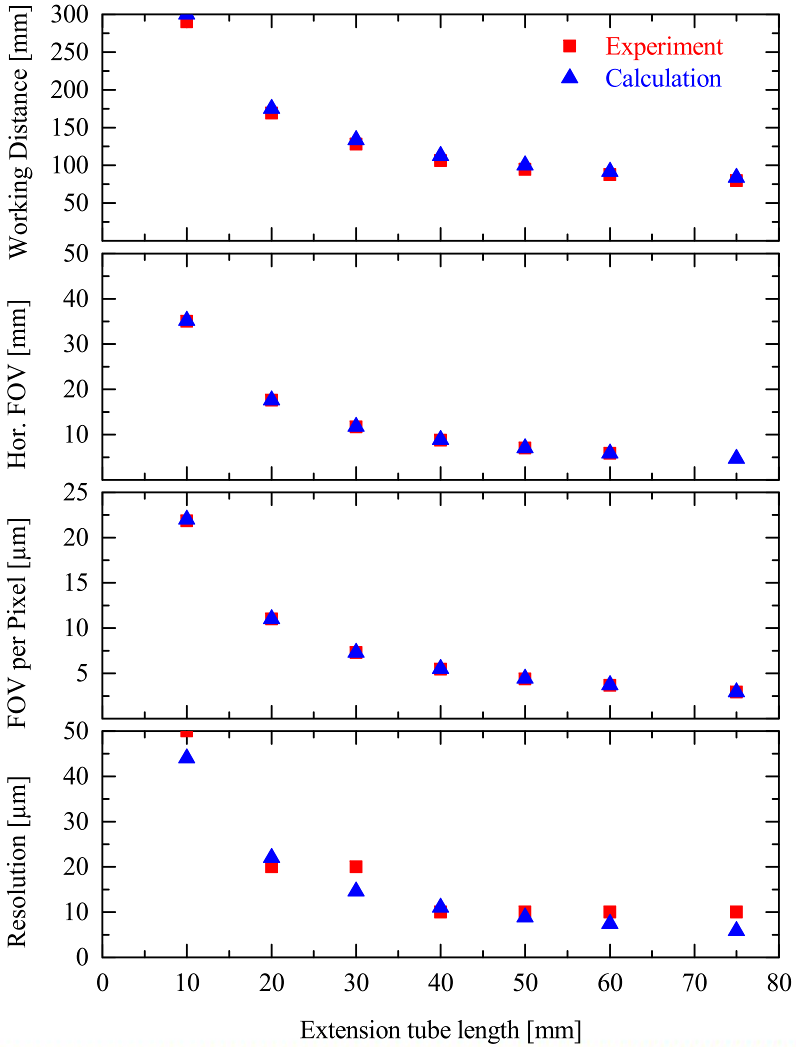


100 µm / 100 µm



- Calibration with test structures
  - Laser scribed line structures: characterization of lateral resolution
  - Graticule structure: image size and quality

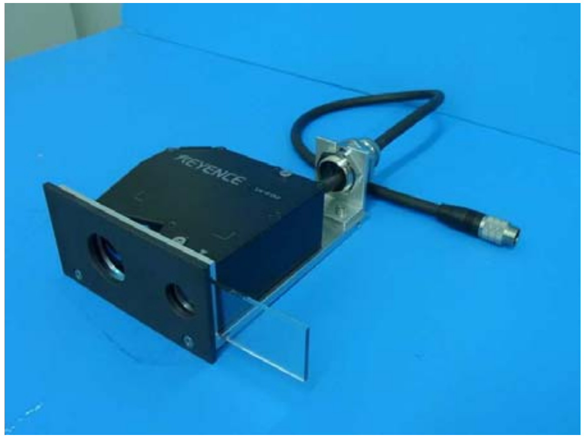
Telemicroscope: Performance characterization

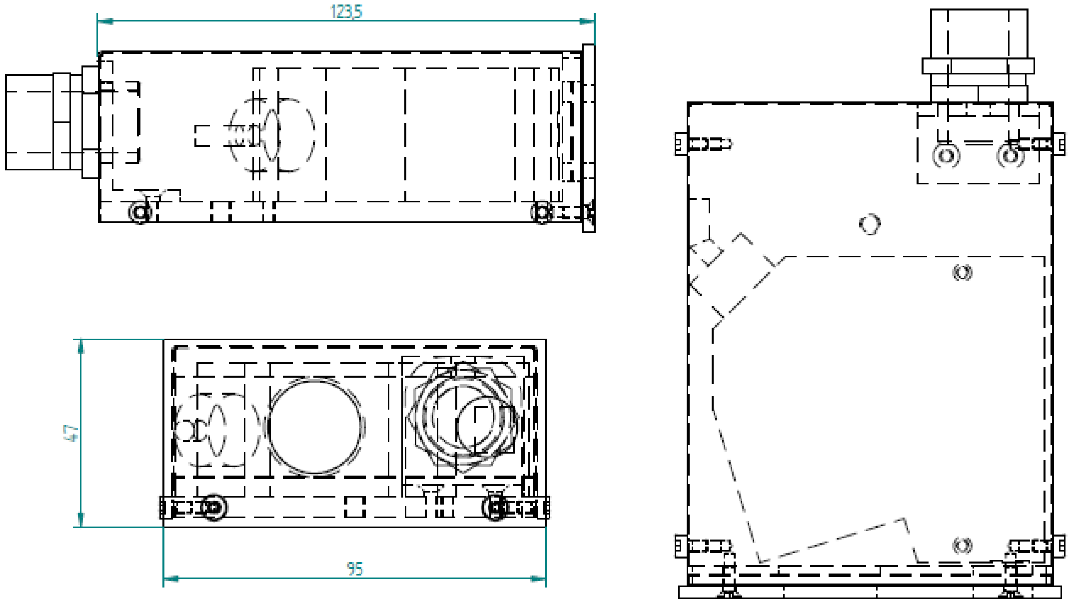


- Comparison of calculated performance data with experimental results (in dependence on extension tube length):
  - Working distance
  - Field of view
  - Lateral resolution
- Very good agreement

- Focal length: 50 mm
- Extension tube length: 40 mm
- Working distance: 112.5 mm
- Field of view: 8.75 x 6.56 mm^2
- Lateral resolution: < 10 µm

Laser head: Design

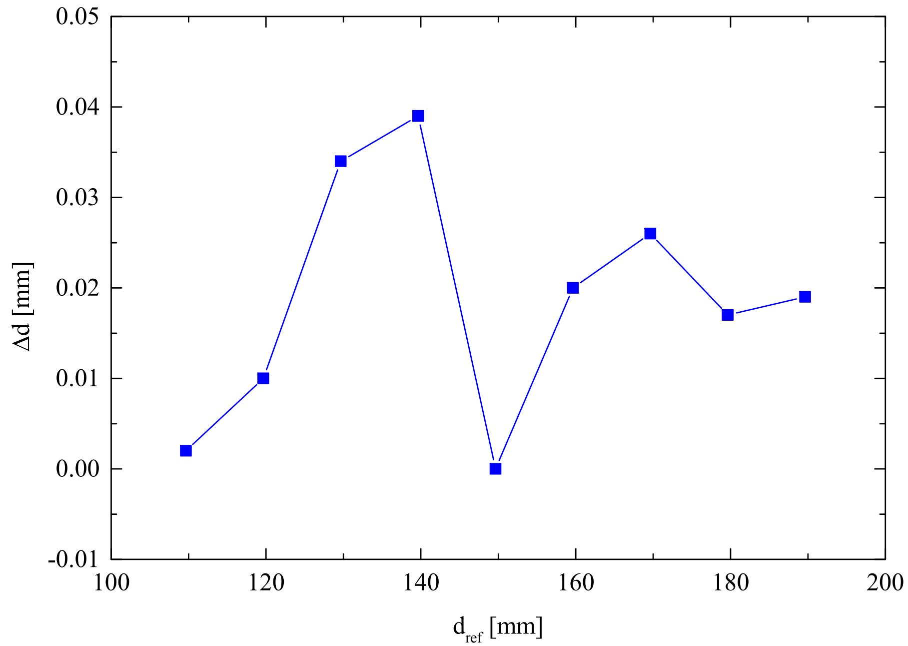


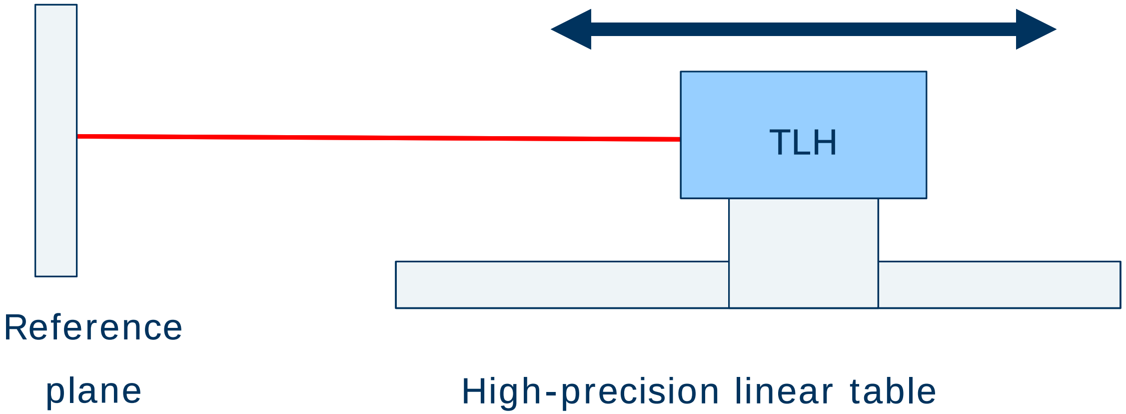


- Housing with graphite front plate and sapphire window
- Dimensions: 95 x 47 x 127 mm³
- Operational test in air and in vacuum was performed successfully
- NOT specified for in-vacuum operation:
  Electronic parts had to be replaced
- Status: Ready for test campaigns

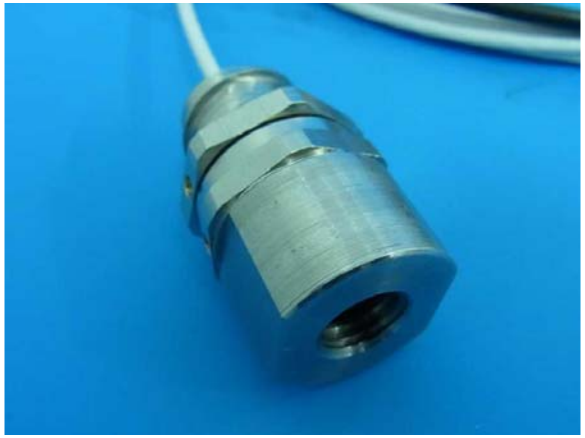
Laser head: Performance characterization

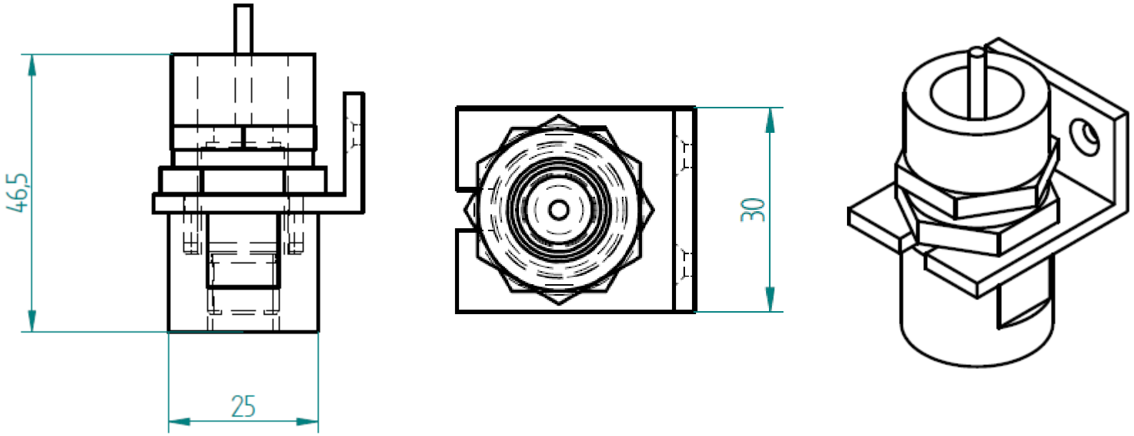
- Calibration using a high-precision linear table (positioning accuracy 10 µm)
- Relative distance measurement (with respect to reference plane)
- (Relative) distance accuracy: +/- 20 µm





Pyrometer: Design



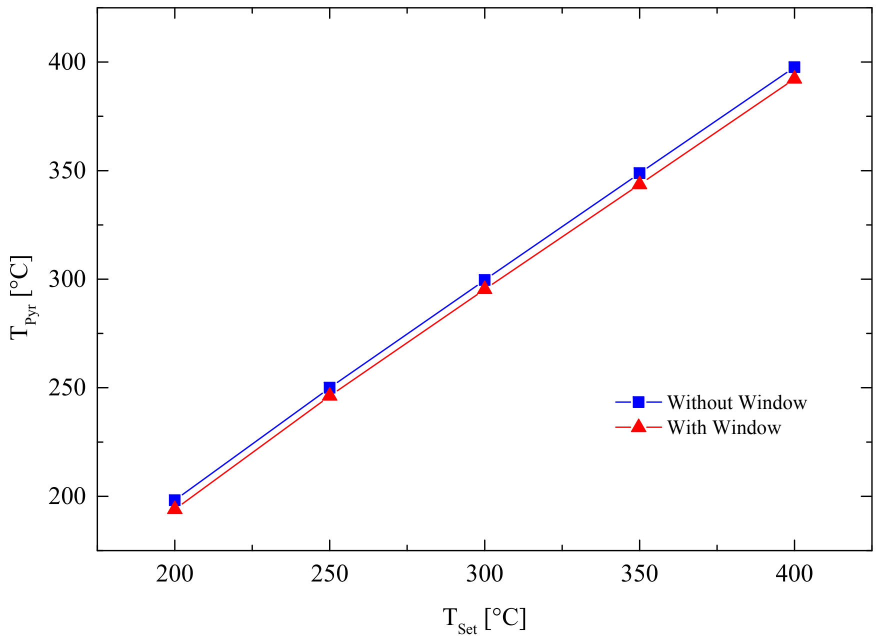


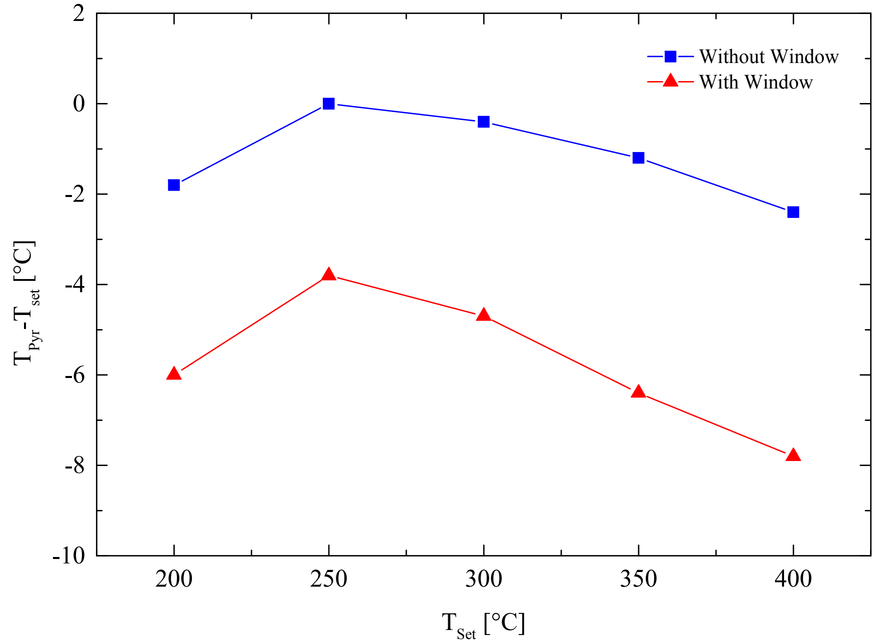
- Steel housing with sapphire window
- Dimension: Size 25 x 30 x 47 mm^3

  (compared to former AEPD-1: 300 mm / ∅ 200 mm cylinder)
- Operational test in air and in vacuum was performed successfully
- NOT specified for in-vacuum operation:

  Electronic parts had to be removed or replaced
- Status: Ready for test campaigns

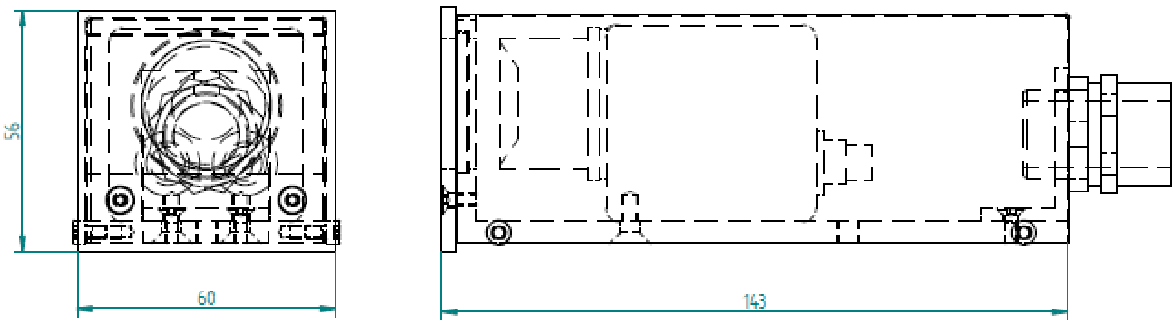
Pyrometer: Performance characterization





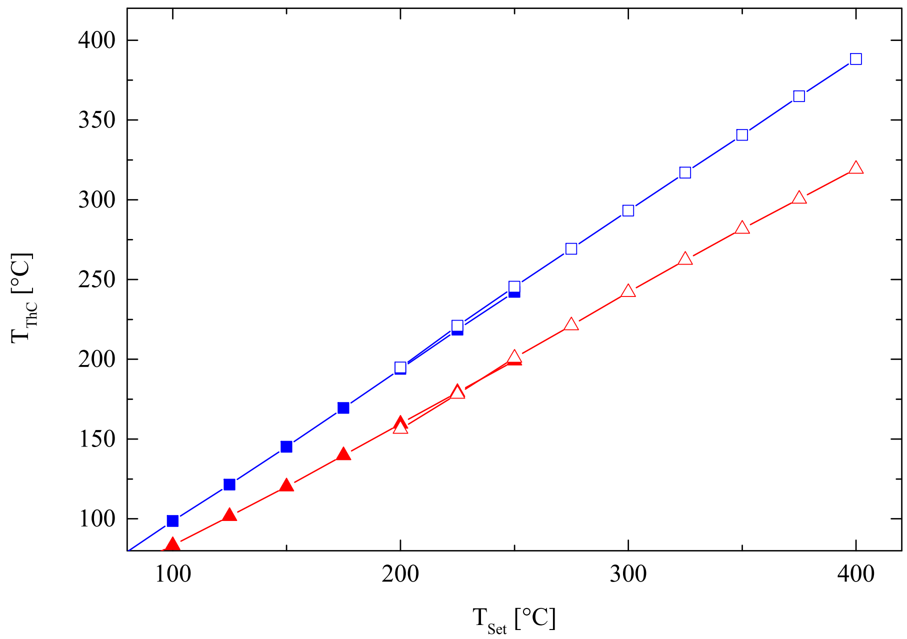
- Thermocalibrator Optris BR 400: T_{max} = 400°C; accuracy < 2°C
- Difference between set and measured temperature (w/o sapphire window): < 2°C
- Window effects need to be corrected

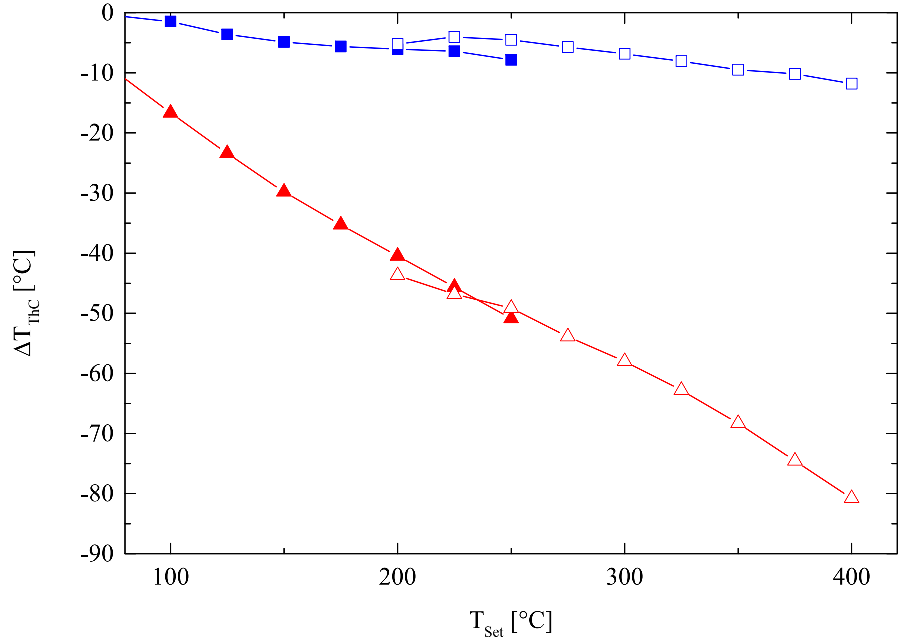
Thermocamera: Design



- Housing with graphite front plate and ZnS window
- Dimension: 56 x 60 x 143 mm³
  (AEPD-1: diameter 150 mm)
- Operational test in air and in vacuum was performed successfully
- NOT specified for in-vacuum operation:
  Electronic parts had to be replaced
- Status: Ready for test campaigns

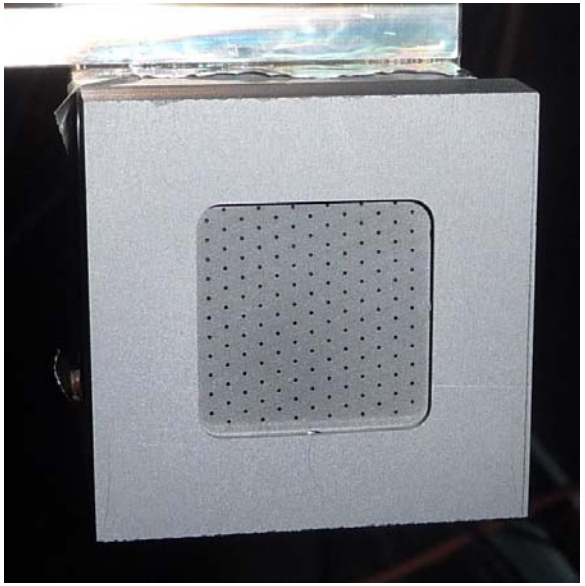
Thermocamera: Performance characterization

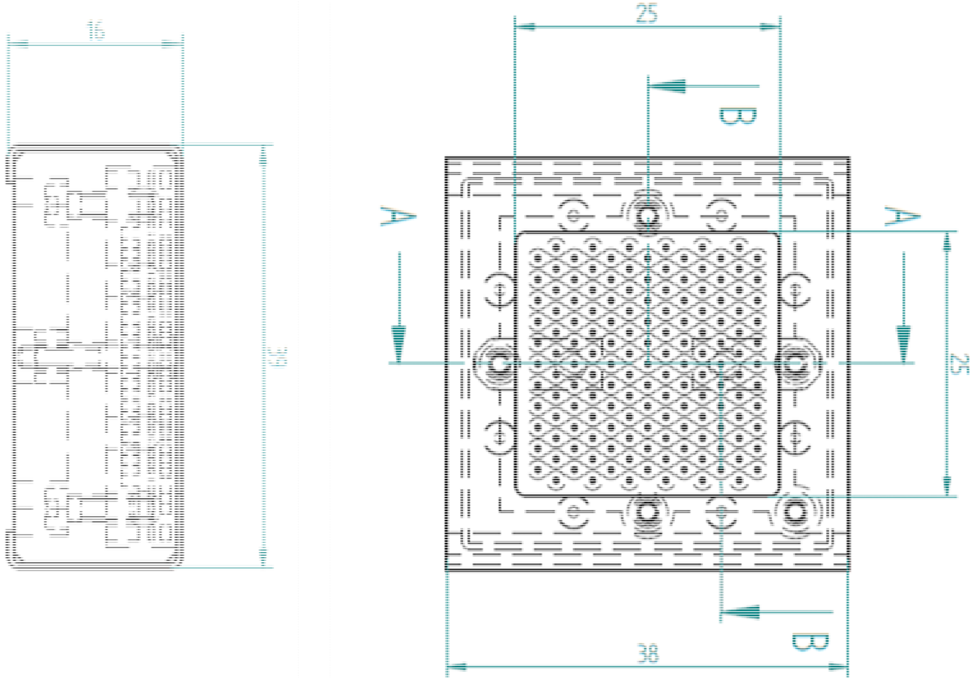




- Thermocalibrator Optris BR 400: T_{max} = 400°C; accuracy < 2°C
- Difference between set and measured temperature (w/o ZnS window): < 10°C
- Window effects need to be corrected

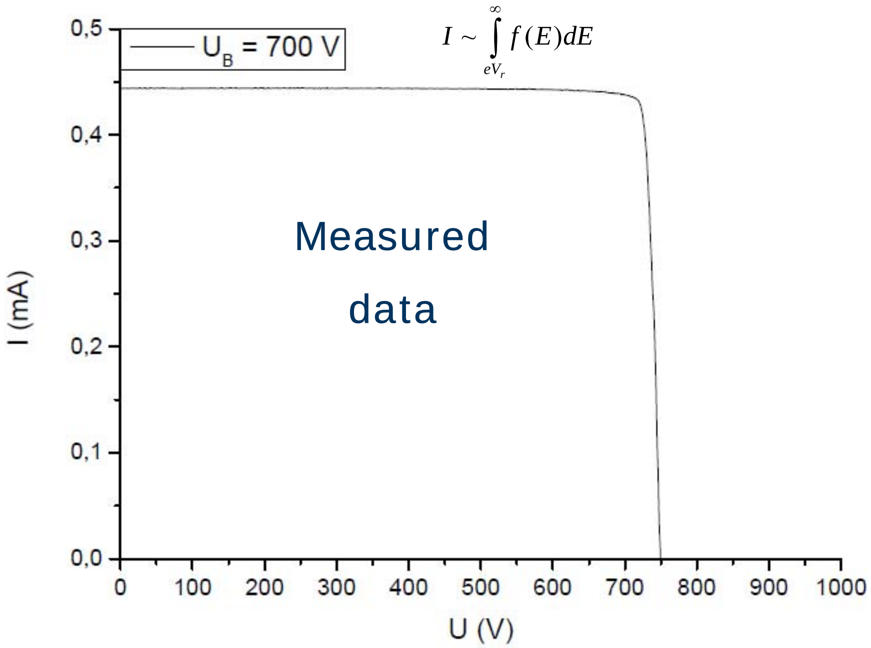
RPA: Design

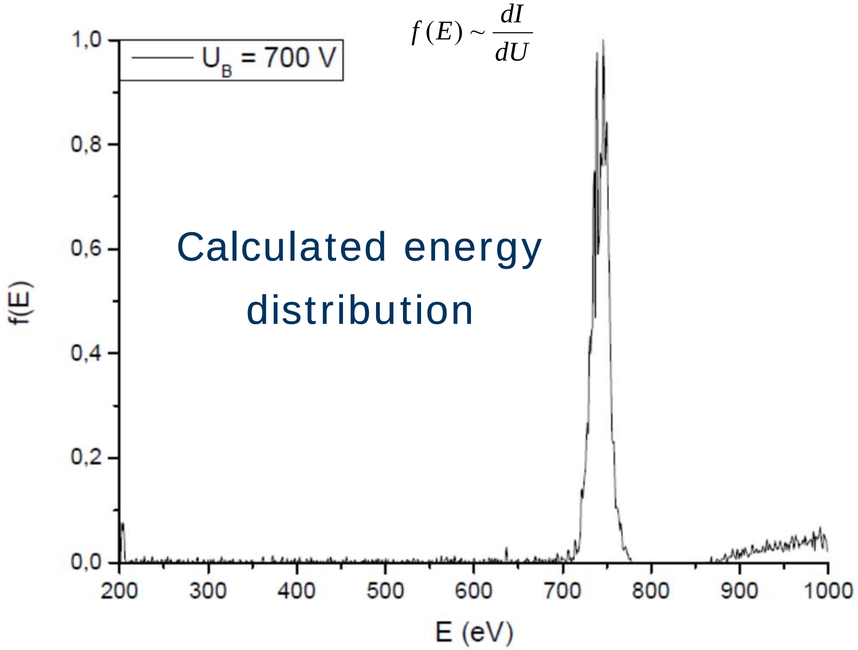




- Graphite grid: 149 holes, hole diameter 0.4 mm, hexagonally arranged
- Dimension: 38 x 39 x 16 mm^3
- Performance test of electronics was performed successfully
- Status: Ready for test campaigns

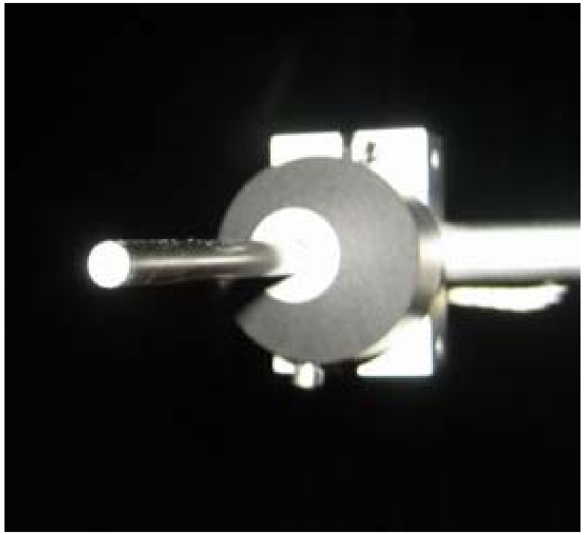
RPA: Performance characterization

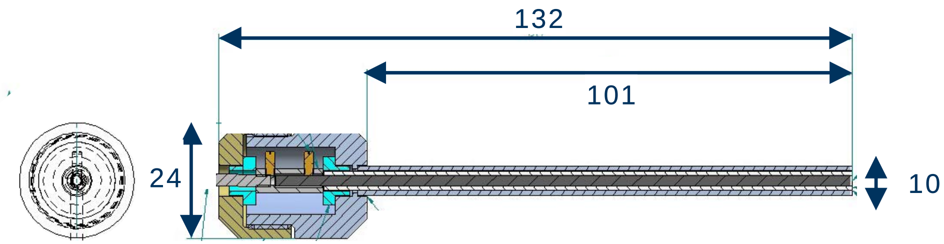


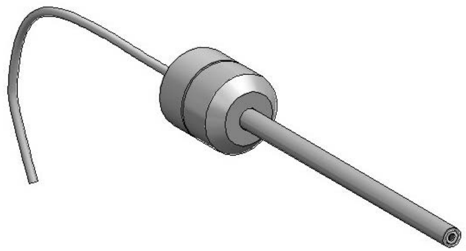


- RPA design is simulated by using IBSIMU software
- RPA was tested with ion beam source (IOM)
- Voltage measurement done using a calibrated instrument
- Comparison with ESMS in progress

Faraday probe: Design

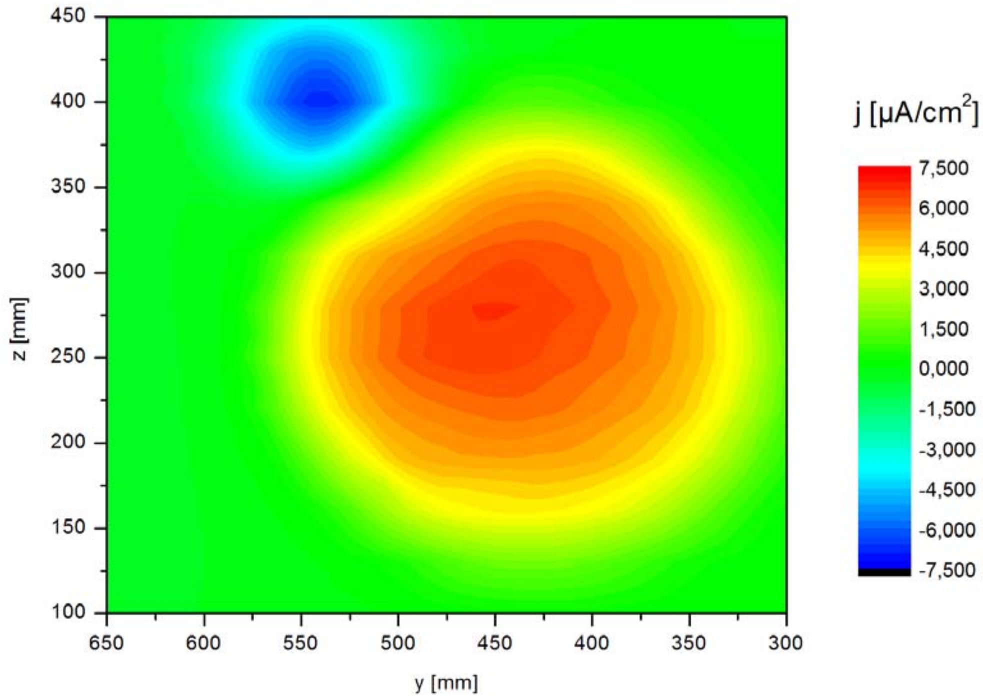






- Dimension: length 102 / 132 mm, diameter 6 / 24 mm
- Performance test of electronics was performed successfully
- Status: Ready for test campaigns

Faraday probe: Performance characterization



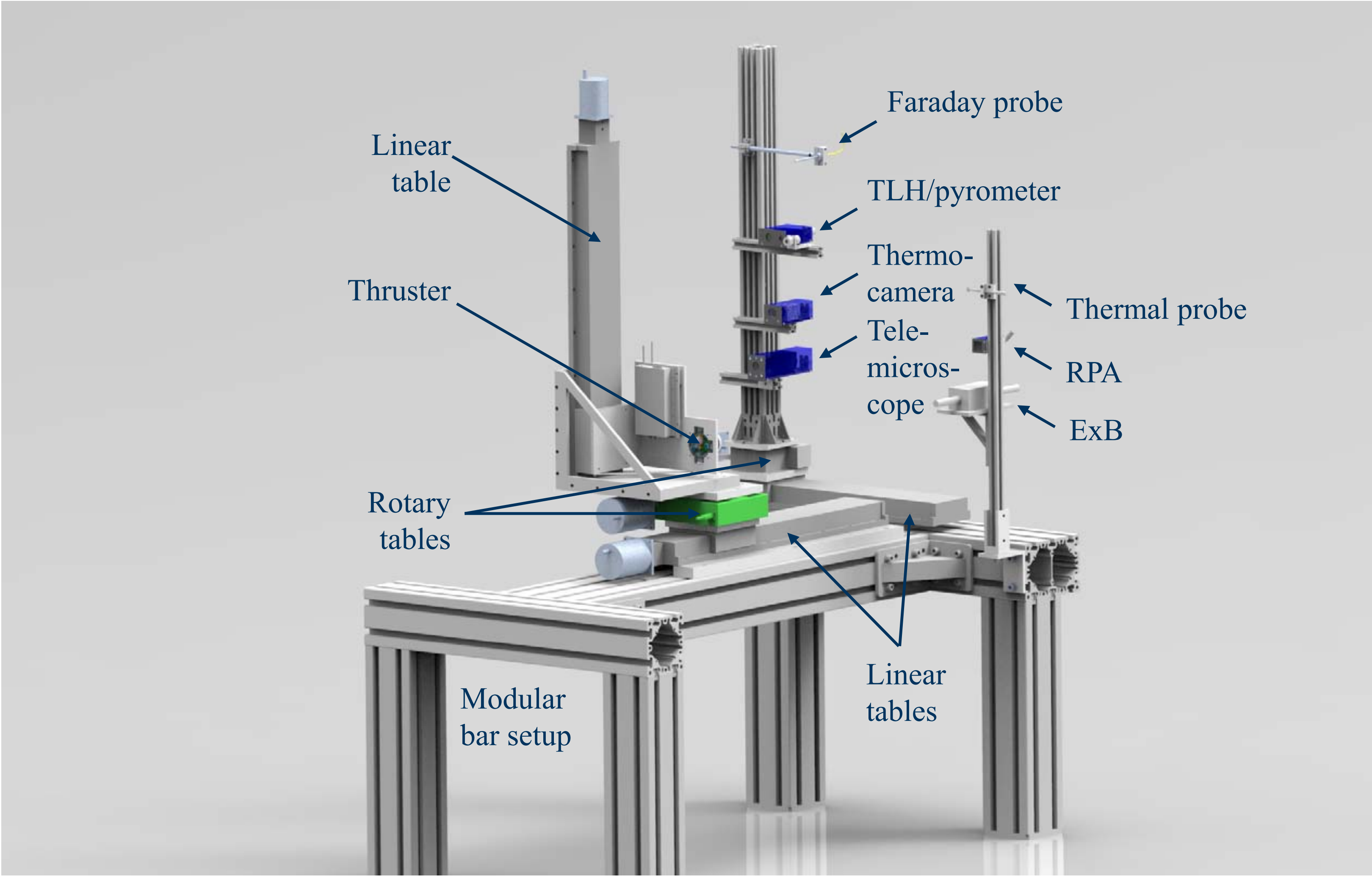
- Preliminary characterization done with RIT-22
- Current measurement calibrated with constant current source
- Current measurement employs an accuracy resistance
- Probe area is measured with calibrated vernier caliper

Connectors and vacuum feedthroughs: Status

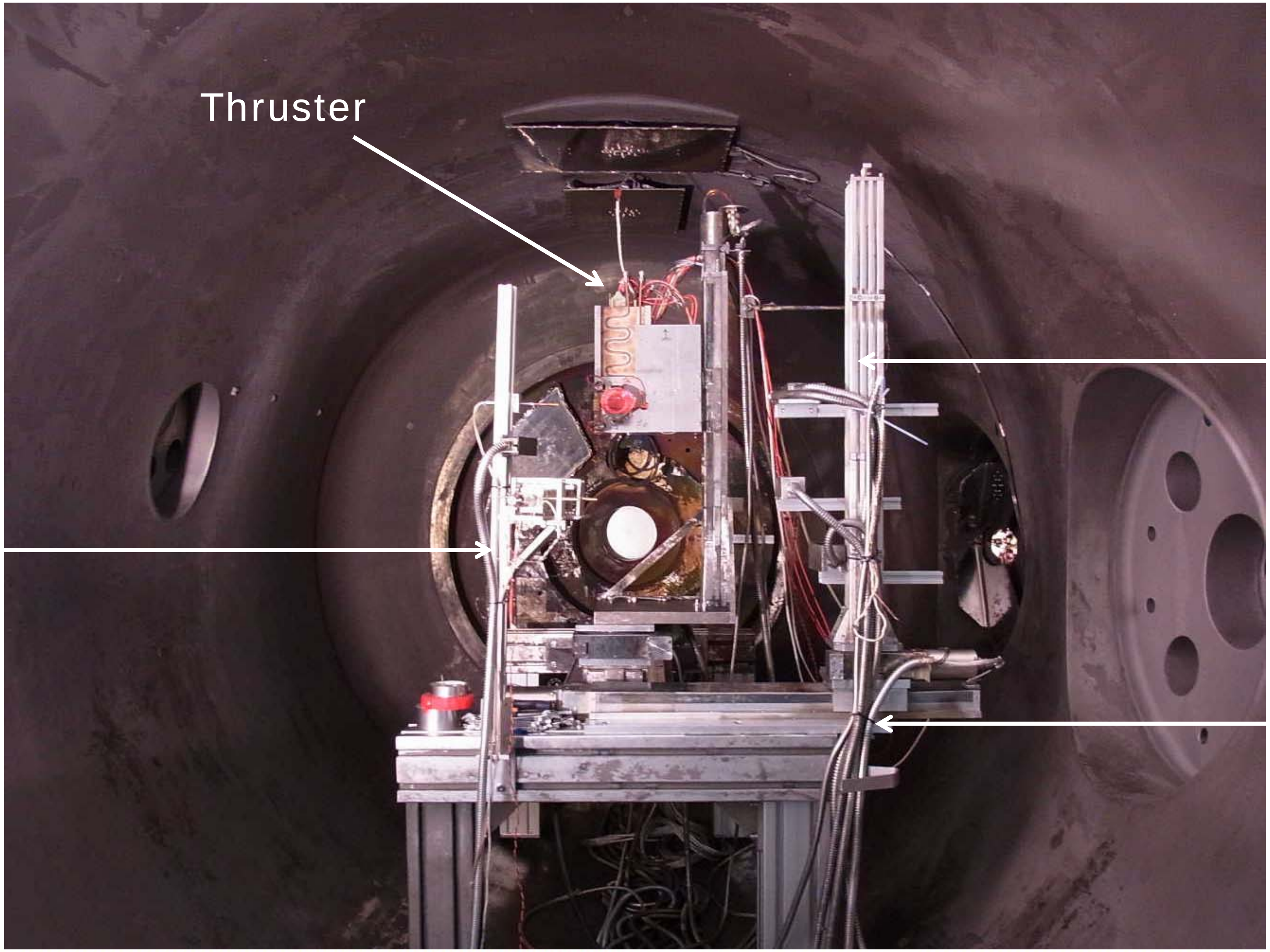
- USB connectors: Telemicroscope, pyrometer, thermocamera
- BNC connectors: RPA, Faraday cup
- Customized Lemo connector: TLH

- All feedthroughs (including connectors and cables) manufactured and assembled
- Operational tests in air and in vacuum were performed successfully
- Status: Ready for test campaigns

System setup with RIT-µX



System setup with RIT-µX (JLU Gießen)



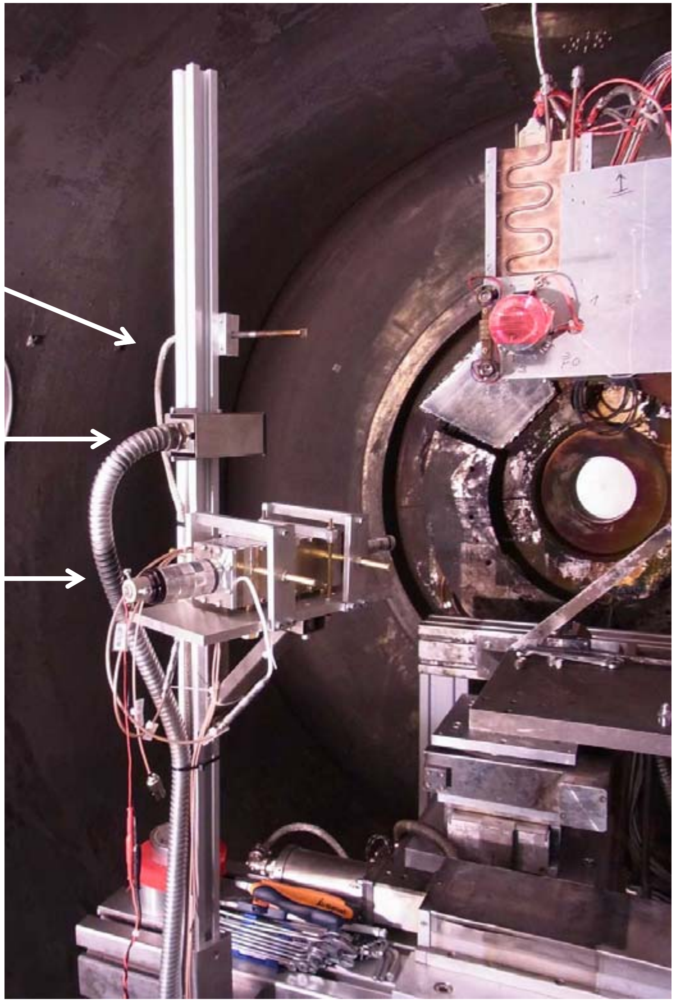
System setup (Diagnostic arms)

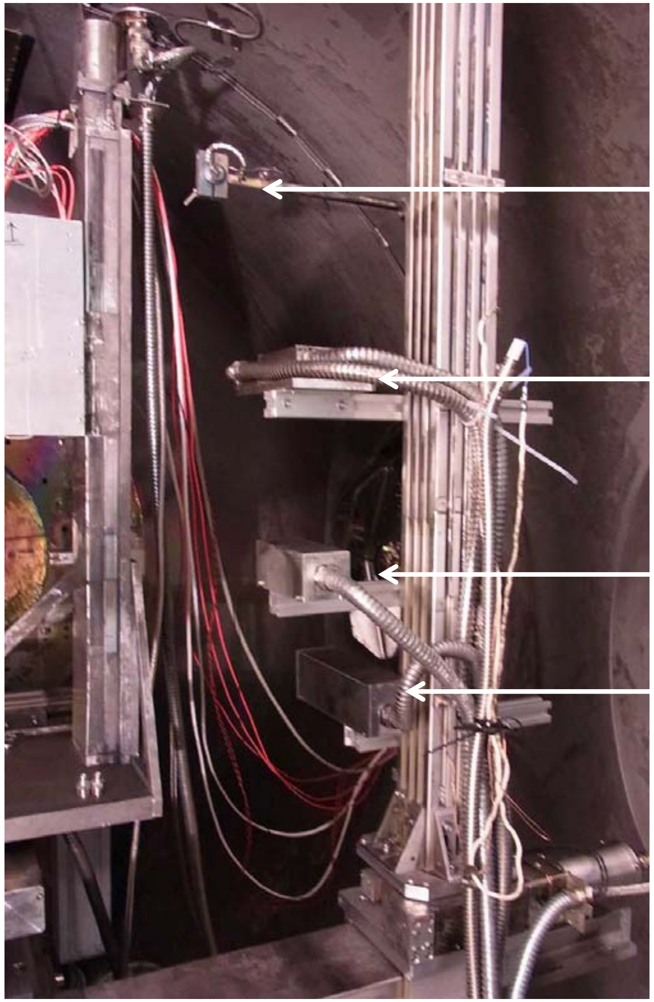
Thermoprobe
(CAU)

RPA

ExB
(Aerospazio)

Diagnostic
arm 1
(fixed)





Faraday probe

TLH/Pyrometer

Thermocamera

Telemicroscope

Diagnostic
arm 2
(y-axis)

List of performed measurements

	RIT-µX	SPT100-ML
Faraday probe	✓	✓
Retarding potential analyzer (RPA)	✓	✓
Pyrometer (Pyr)	Out of range	✓
Thermocamera (ThC)	✓	✓
Telemicroscope (TMS)	✓	✓
Triangular laser head (TLH)	✓	✓

RIT-µX: Operation points

Operation Point 1

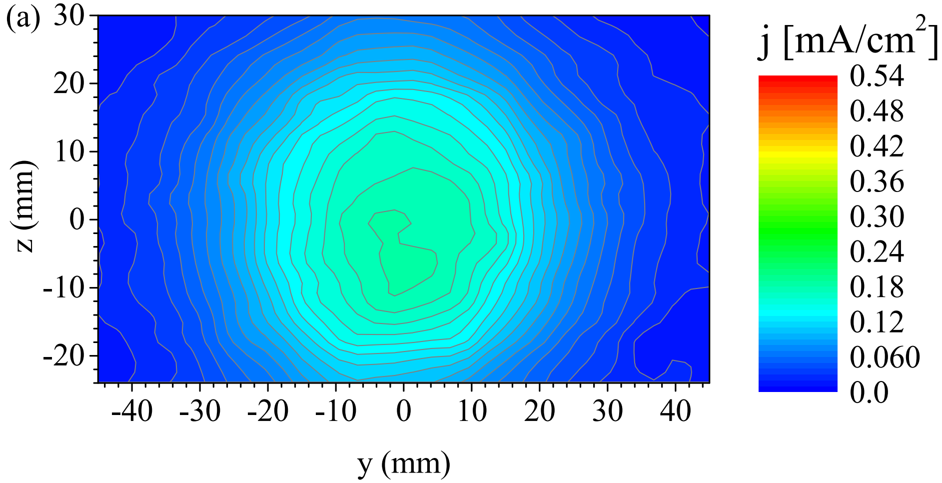
- Beam voltage: 1050 V
- Beam current: 4 mA
- Accelerator voltage: -200 V
- Nominal thrust: 210 µN

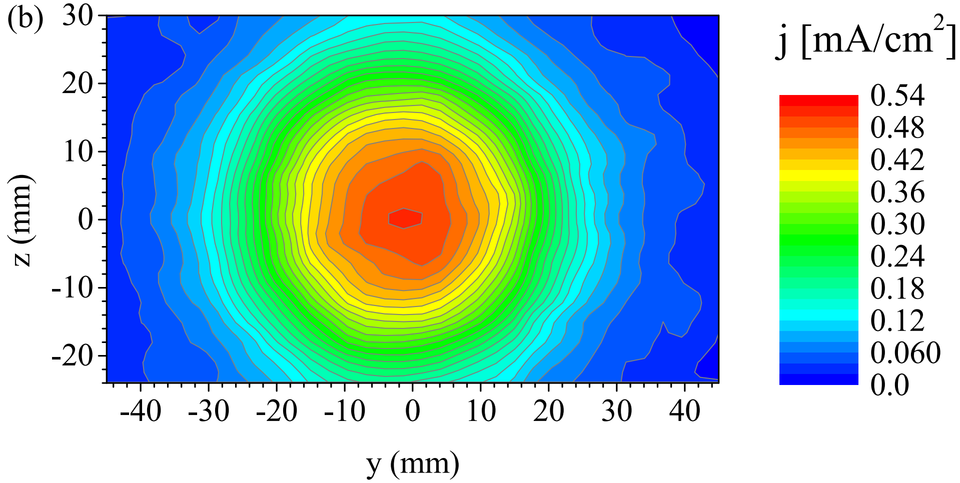
Operation Point 2

- Beam voltage: 1700 V
- Beam current: 8 mA
- Accelerator voltage: -250 V
- Nominal thrust: 540 µN

RIT-µX: Faraday probe

- Jumbo (JLU Gießen)
- Operation Point 1
- Operation Point 2



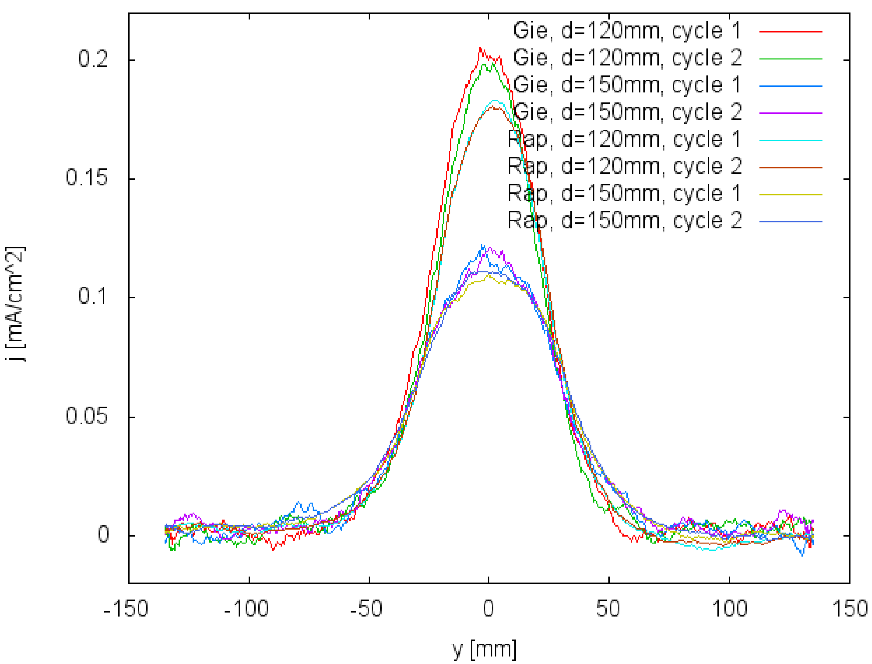


- j_{max} = 0.18 mA/cm² ± 0.02 mA/cm²
- FWHM = 48 mm ± 2 mm

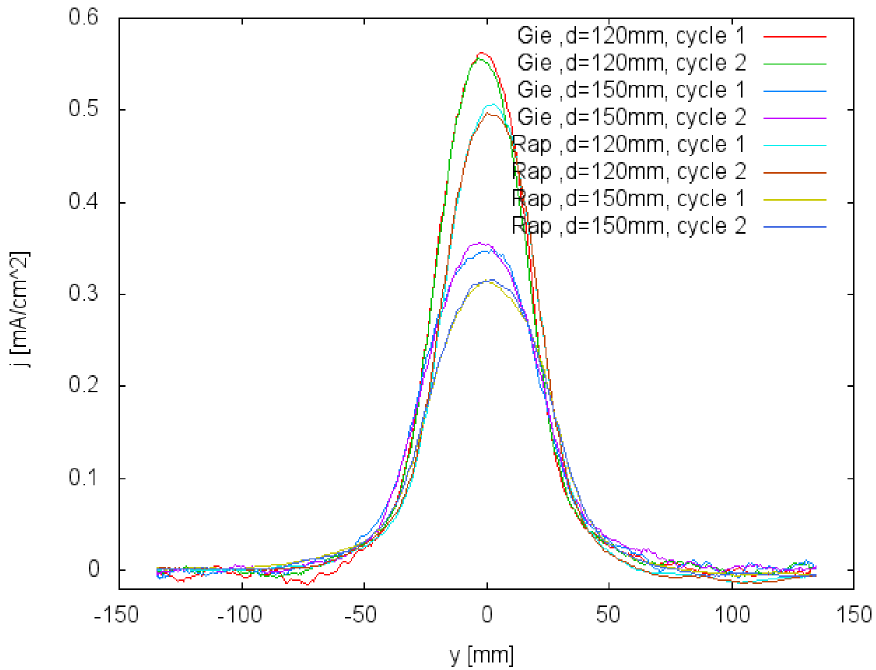
- j_{max} = 0.52 mA/cm² ± 0.04 mA/cm²
- FWHM = 41 mm ± 2 mm

RIT-µX: Faraday probe

- Operation Point 1



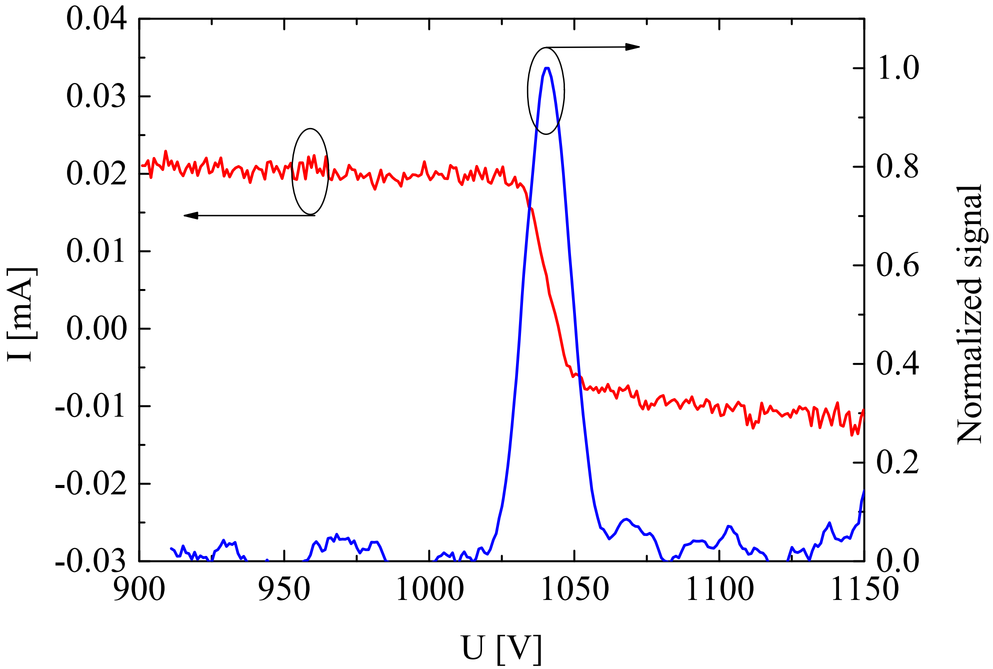
- Operation Point 2



- Scans at two distances: 120 mm / 150 mm
- Slightly higher current density in Jumbo (Gie) than in MVTF (Rap)
- FWHM very similar

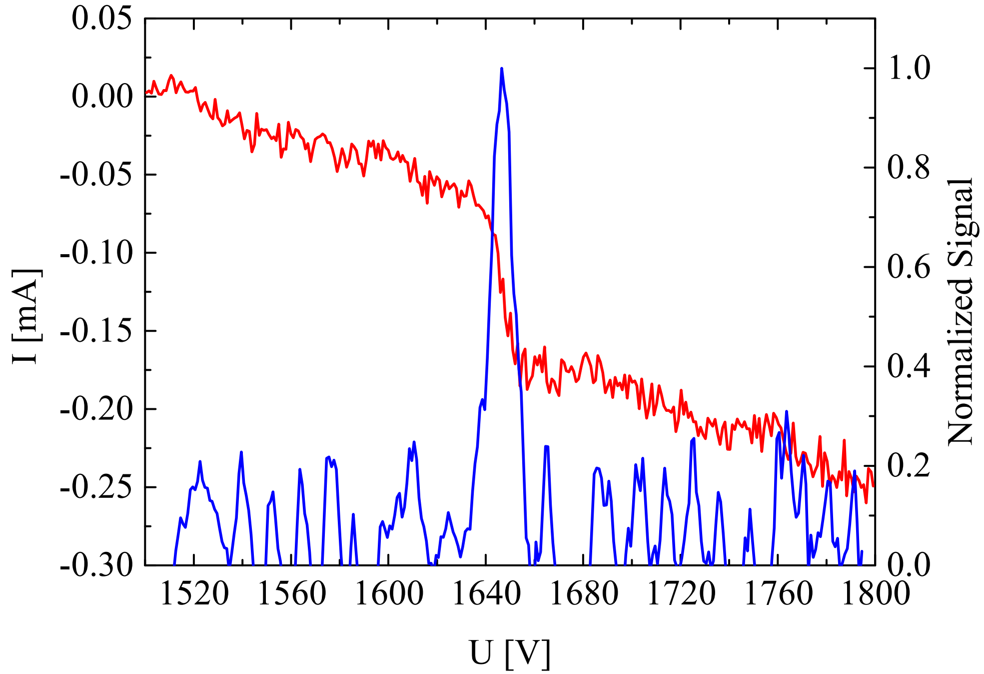
RIT-µX: RPA

- Operation Point 1



- E_{max} = 1041 eV ± 4 eV
- FWHM = 19 eV ± 1 eV

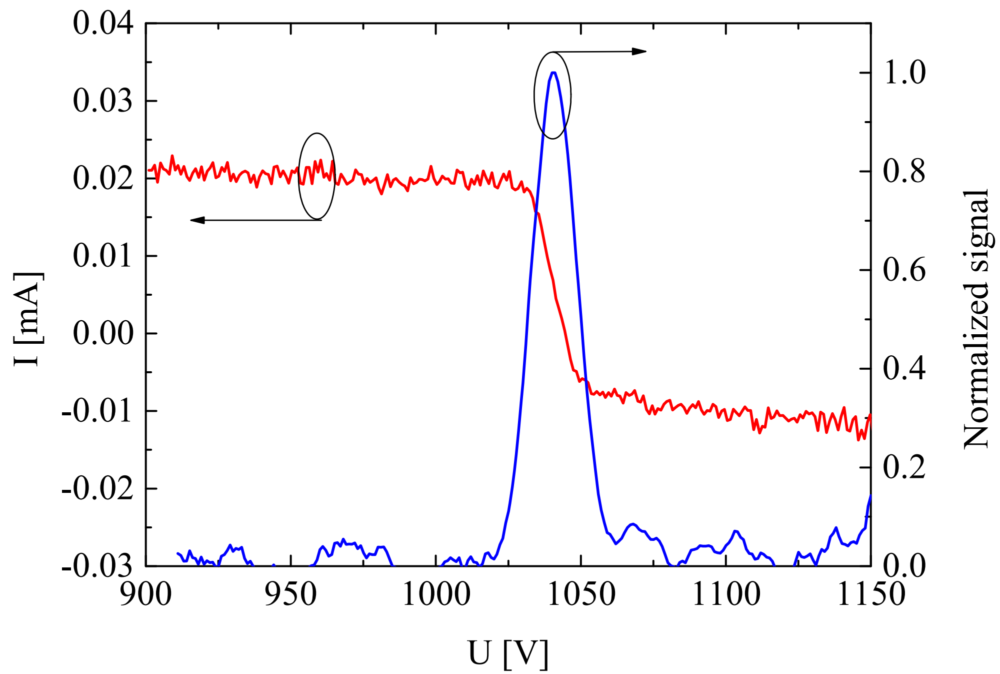
- Jumbo (JLU Gießen)
- Operation Point 2

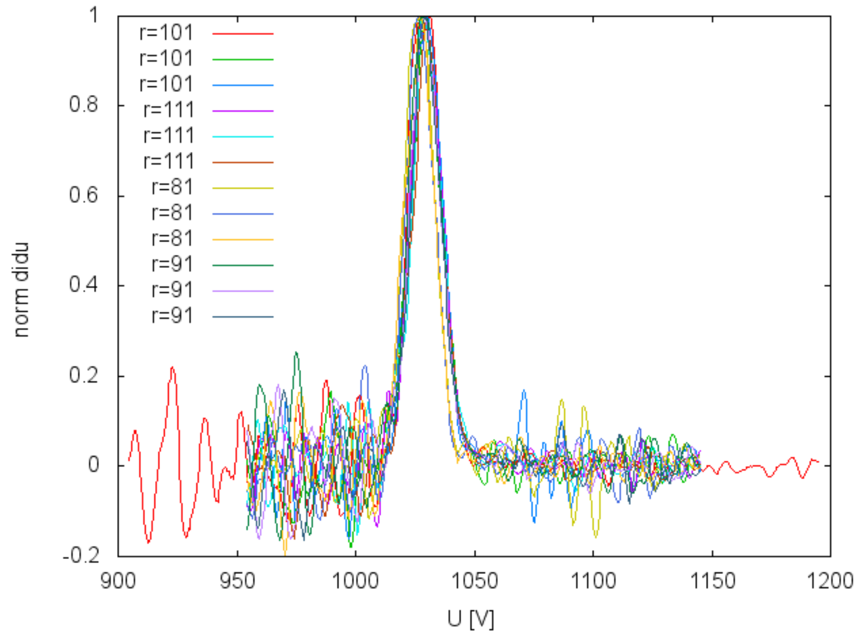


- E_{max} = 1647 eV ± 3 eV
- FWHM = 13 eV ± 1 eV

RIT-µX: RPA

- Operation Point 1
- Jumbo (JLU Gießen)
- MVTF (Aerospazio)





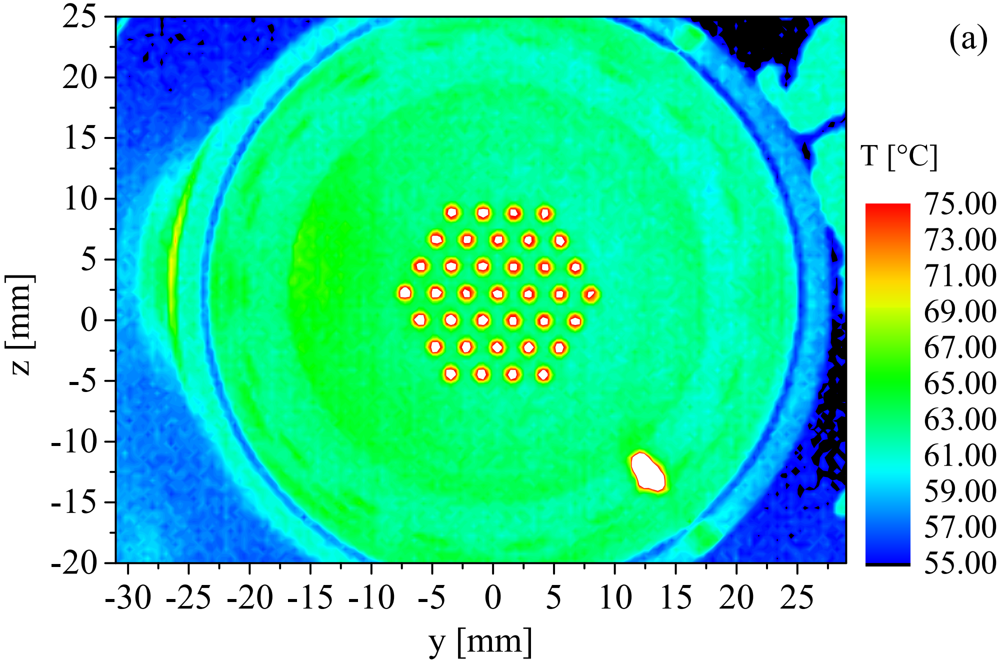
- E_{max} = 1041 eV ± 4 eV
- FWHM = 19 eV ± 1 eV
- E_{max} = 1037 eV ± 3 eV
- FWHM = 19 eV ± 1 eV

IOM

RIT-µX: Thermocamera

- Jumbo (JLU Gießen)

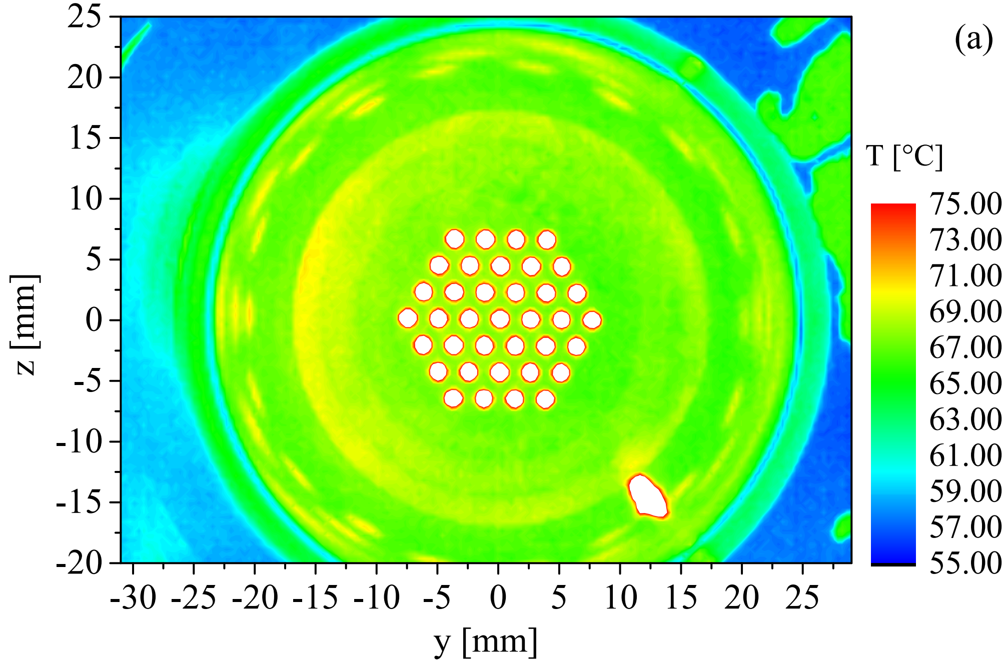
- Operation Point 1



- Grid temperature:

63° C ± 4° C

- Operation Point 2



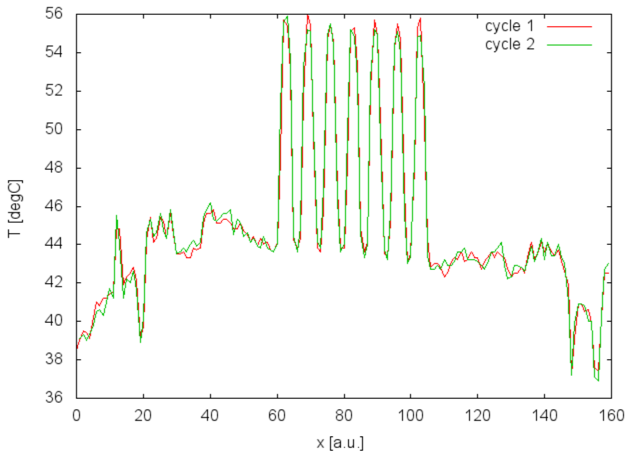
- Grid temperature:

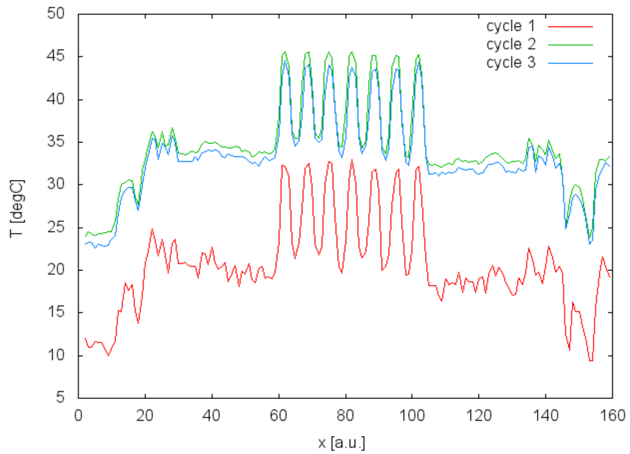
68° C ± 4° C

RIT-µX: Thermocamera

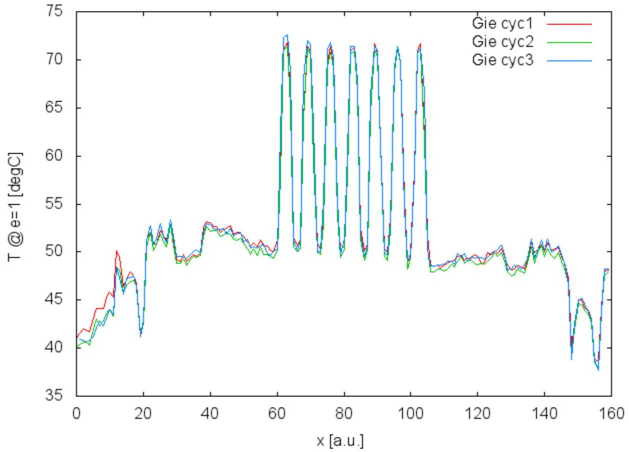
- Jumbo (JLU Gießen)
- MVTF (Aerospazio)

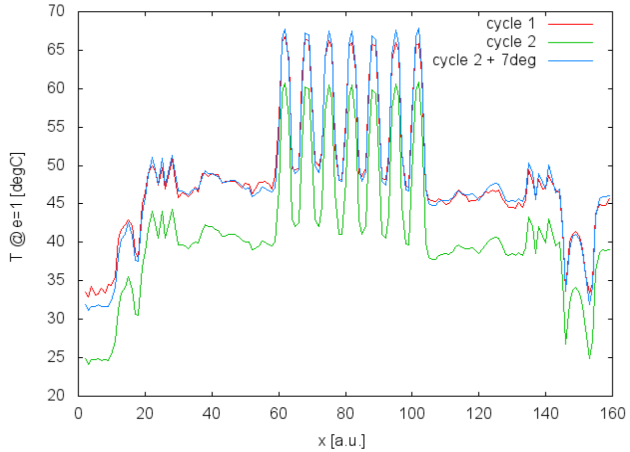
- Operation point 1





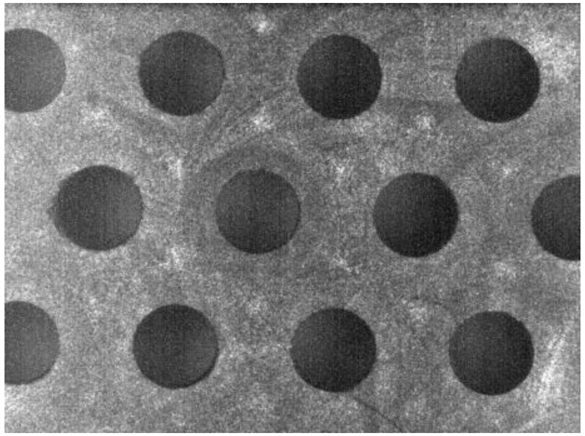
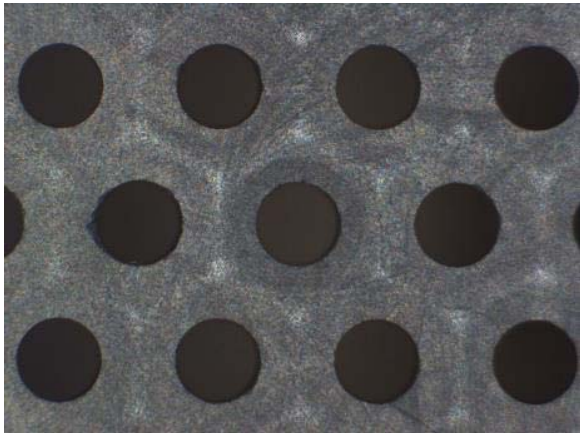
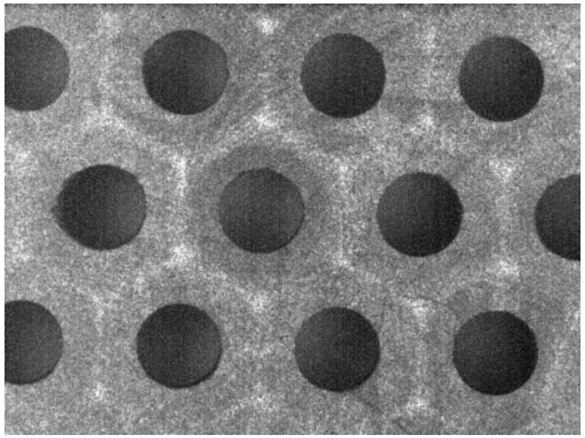
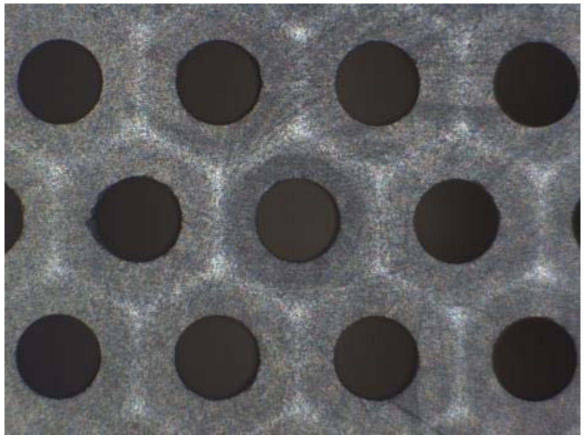
- Operation point 2





Influence from background temperature visible

RIT-µX: Telemicroscope

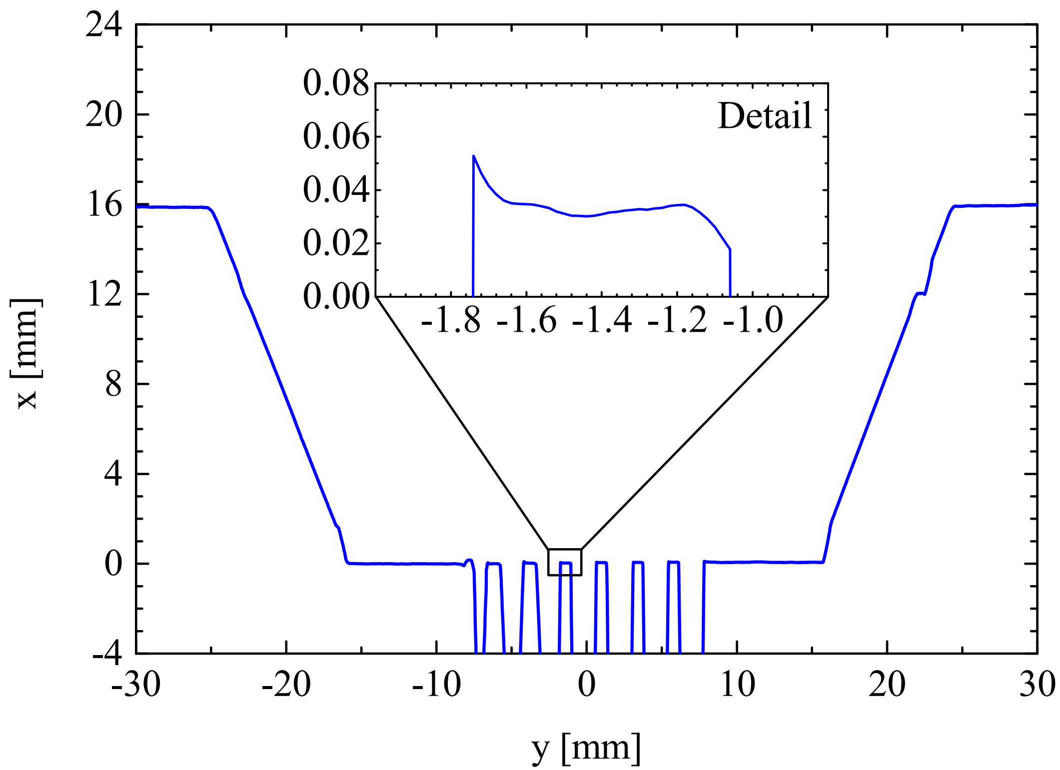
	Jumbo (JLU Gießen)	MVTF (Aerospazio)
Cycle 1		
Cycle 2		

Center hole diameter:

(1.27 ± 0.02) mm

RIT-µX: TLH

- Jumbo (JLU Gießen)



- Flat grid
- Measurement artifact at steep edges of grid holes (detail)

SPT100-ML: Operation points

Operation Point 1

- Anode voltage: 300 V
- Anodic mass flow: 3 mg/s
- Cathode mass flow: 0.5 mg/s
- Current: 2.5 A

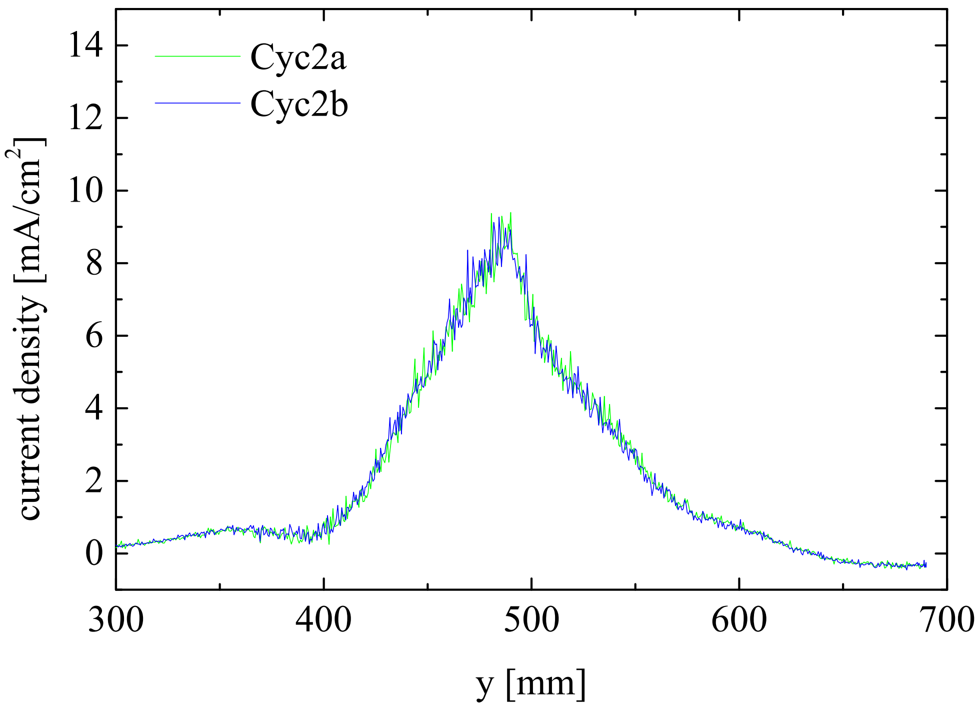
Operation Point 2

- Anode voltage: 300 V
- Anodic mass flow: 5 mg/s
- Cathode mass flow: 0.5mg/s
- Current: 4.5 A

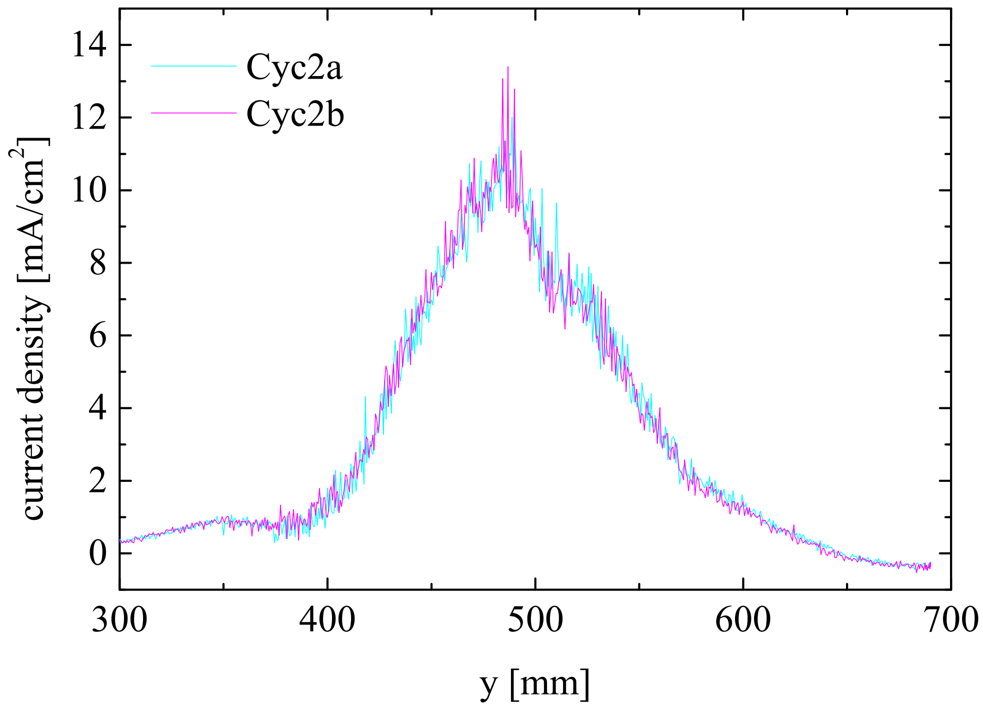
SPT100-ML: Faraday probe

- Jumbo (JLU Gießen)

- Operation Point 1



- Operation Point 2

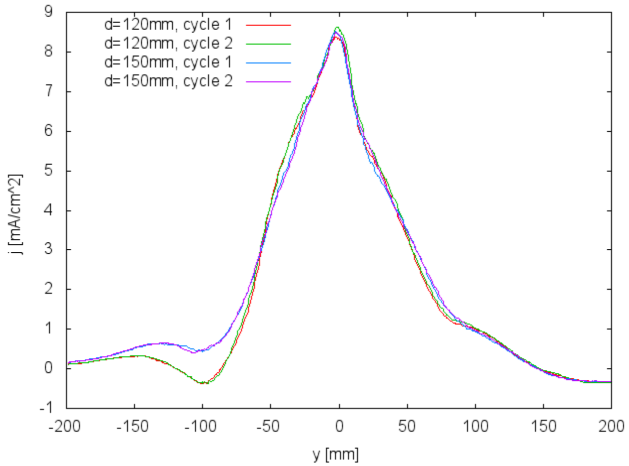


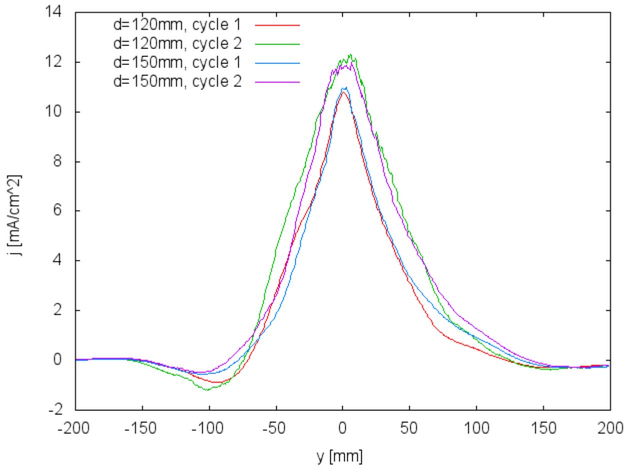
- Horizontal line scan across center of thruster
- Asymmetric beam profile, higher current density at operation point 2

SPT100-ML: Faraday probe

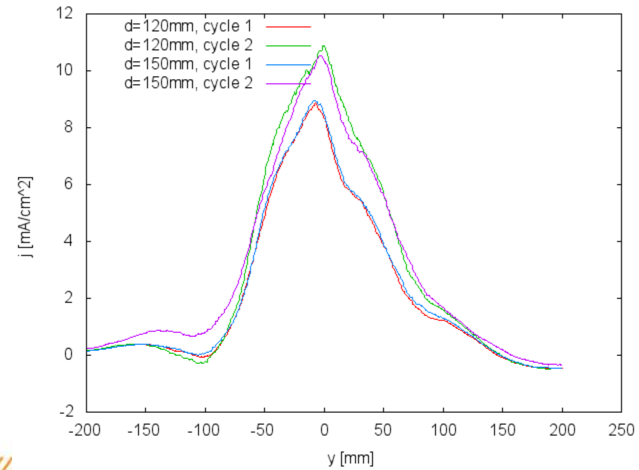
- Jumbo (JLU Gießen)
- MVTF (Aerospazio)

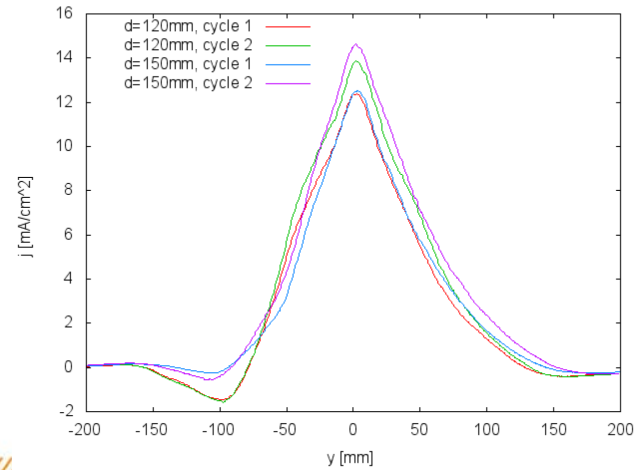
- Operation point 1





- Operation point 2

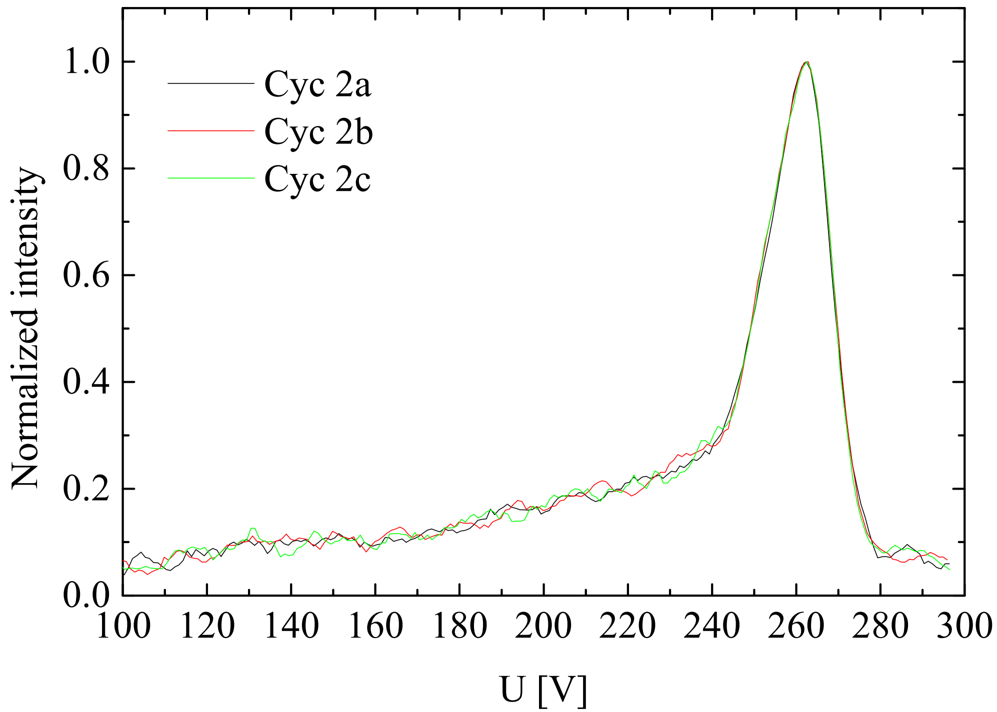




SPT100-ML: RPA

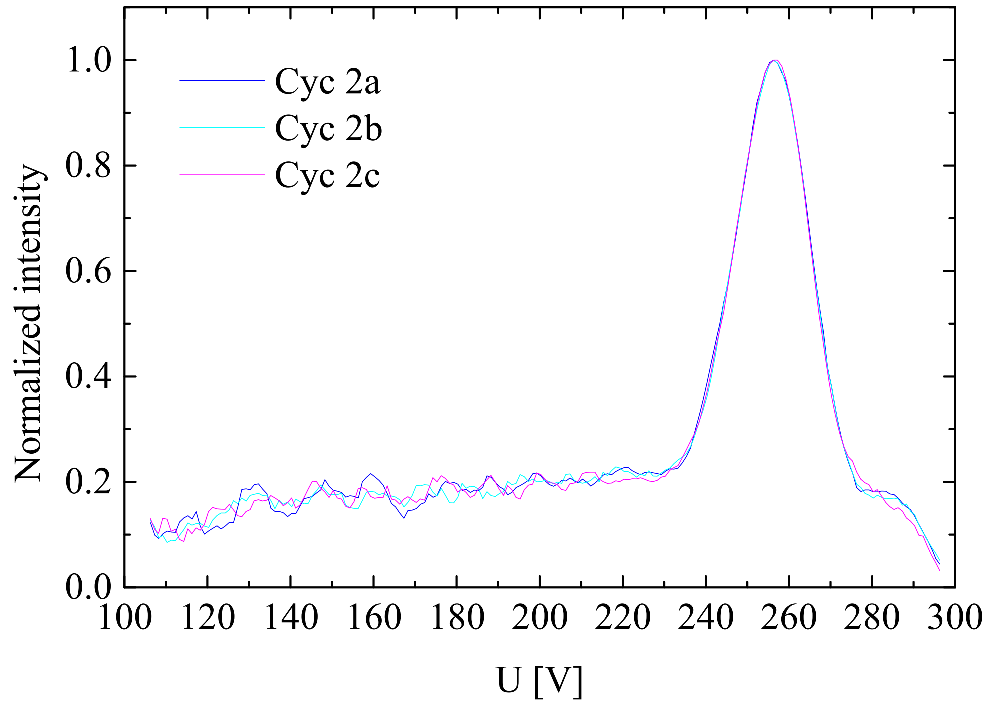
- Jumbo (JLU Gießen)

- Operation Point 1



- E_{max} = 261 eV ± 2 eV
- FWHM = 19 eV ± 2 eV

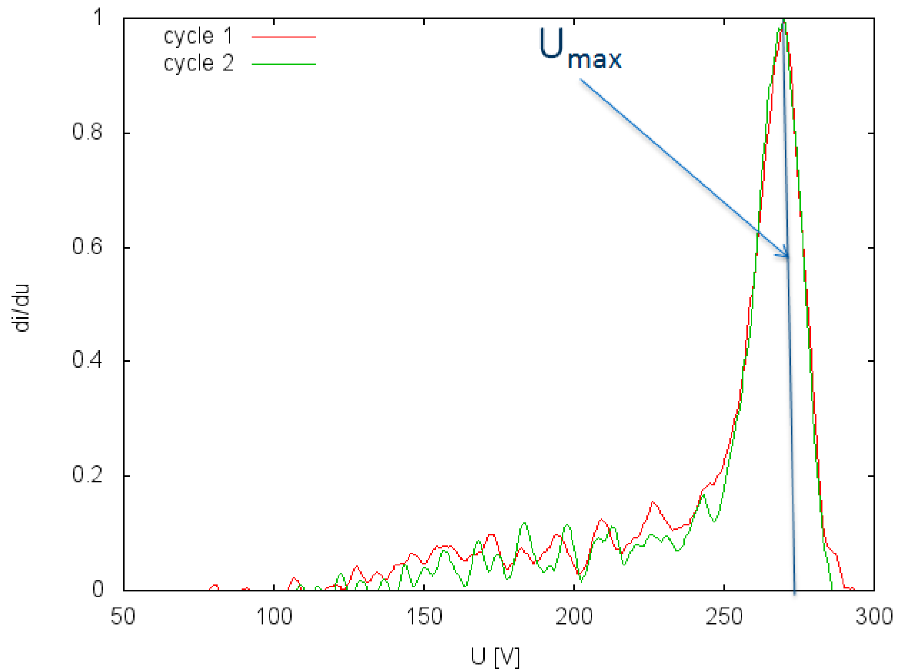
- Operation Point 2



- E_{max} = 257 eV ± 1 eV
- FWHM = 23 eV ± 1 eV

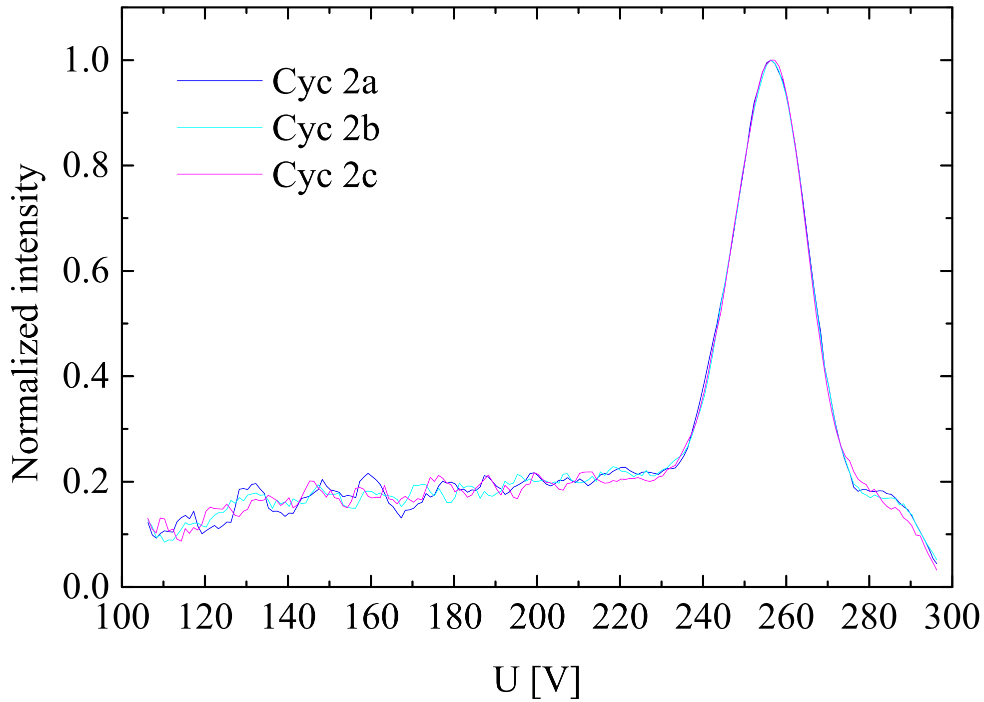
SPT100-ML: RPA

- MVTF (Aerospazio)



- E_{max} = 269 eV ± 2 eV

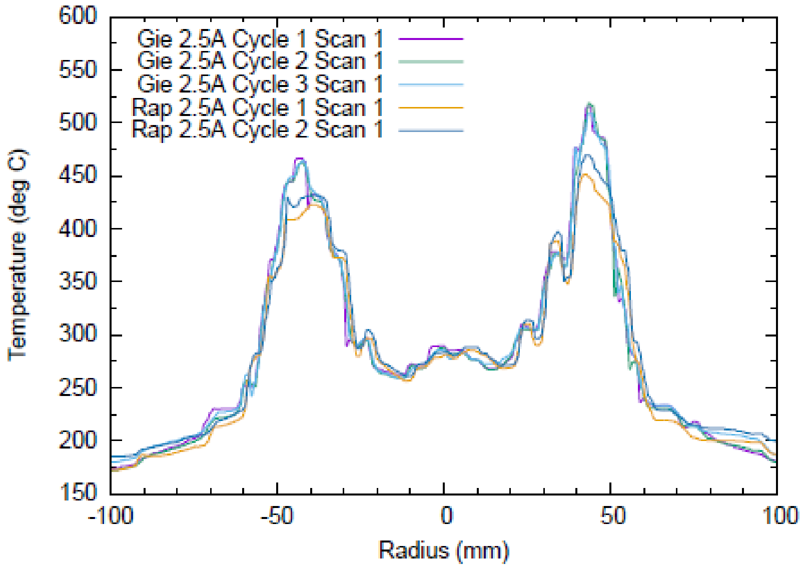
- Operation point 2
- Jumbo (JLU Gießen)



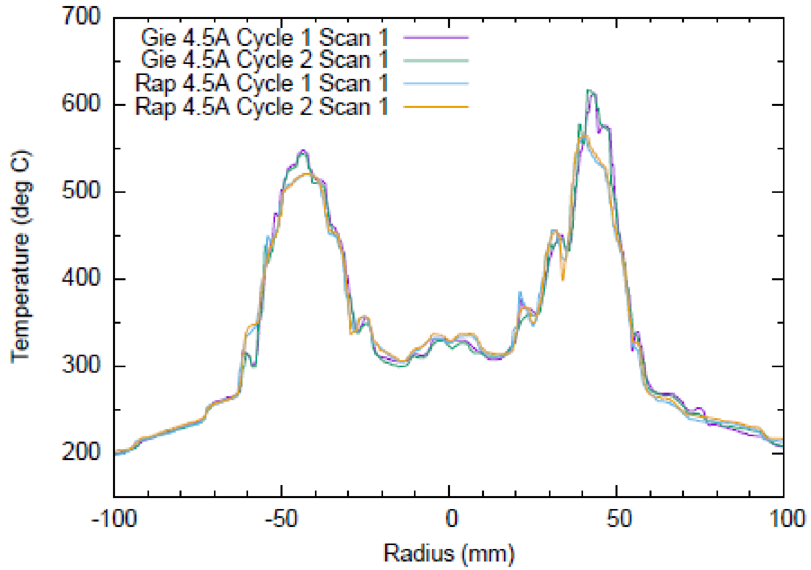
- E_{max} = 257 eV ± 1 eV

SPT100-ML: Pyrometer

- Operation Point 1



- Operation Point 2

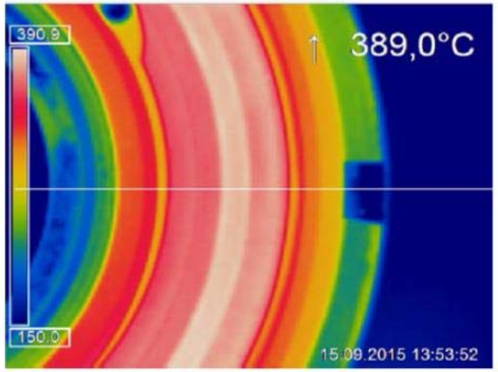


- Good agreement between Jumbo (Gie) and MVTF (Rap)
- Thruster temperature higher in operation mode 2 than in operation point 1

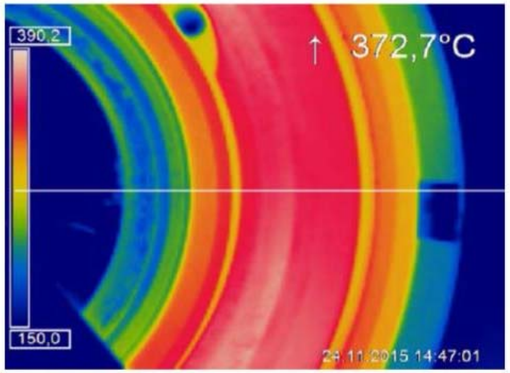
SPT100-ML: Thermocamera

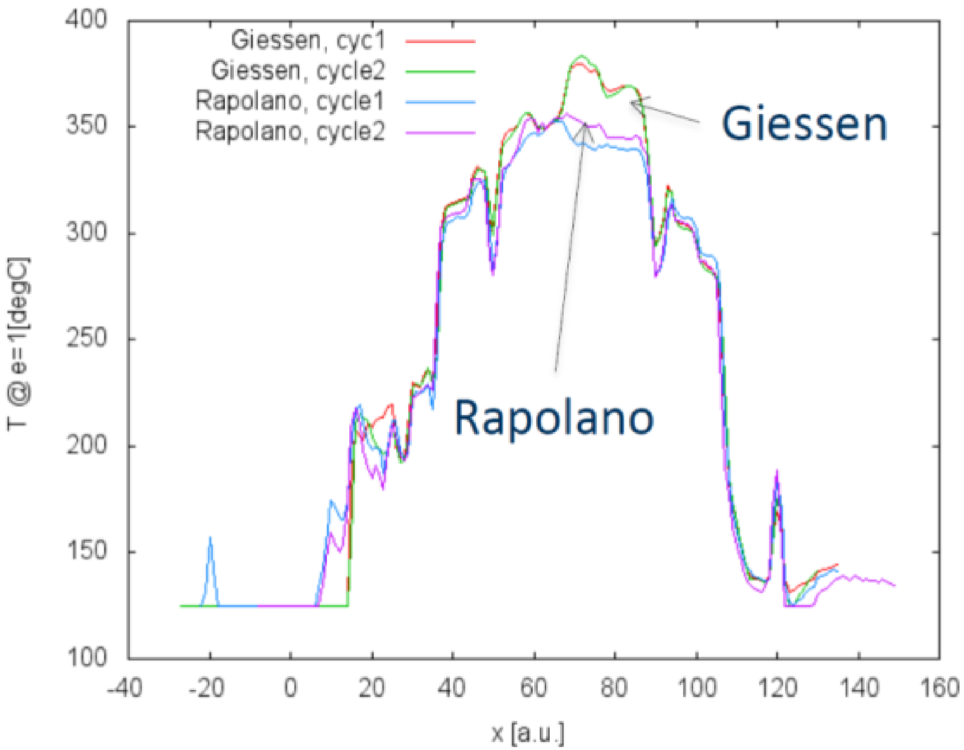
- Operation Point 1, right channel

Giessen JUMBO



Rapolano MVTF

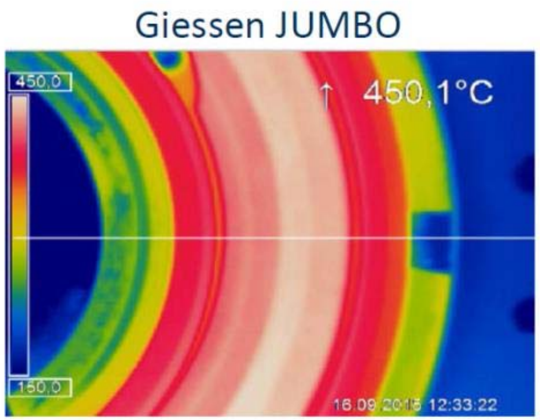


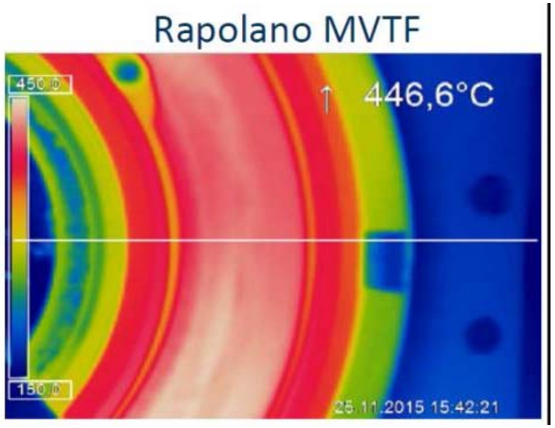


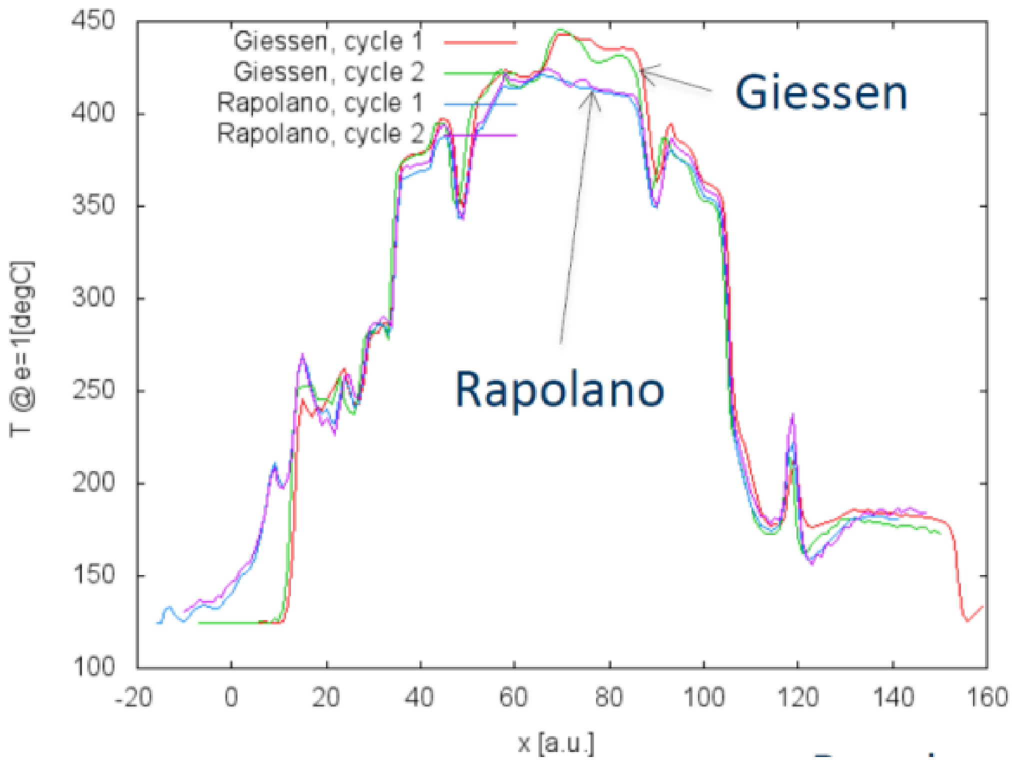
- Good agreement between Jumbo (Giessen) und MVTF (Rapolano)
- Differences in linescans are not artifacts (see images)

SPT100-ML: Thermocamera

- Operation Point 2, right channel





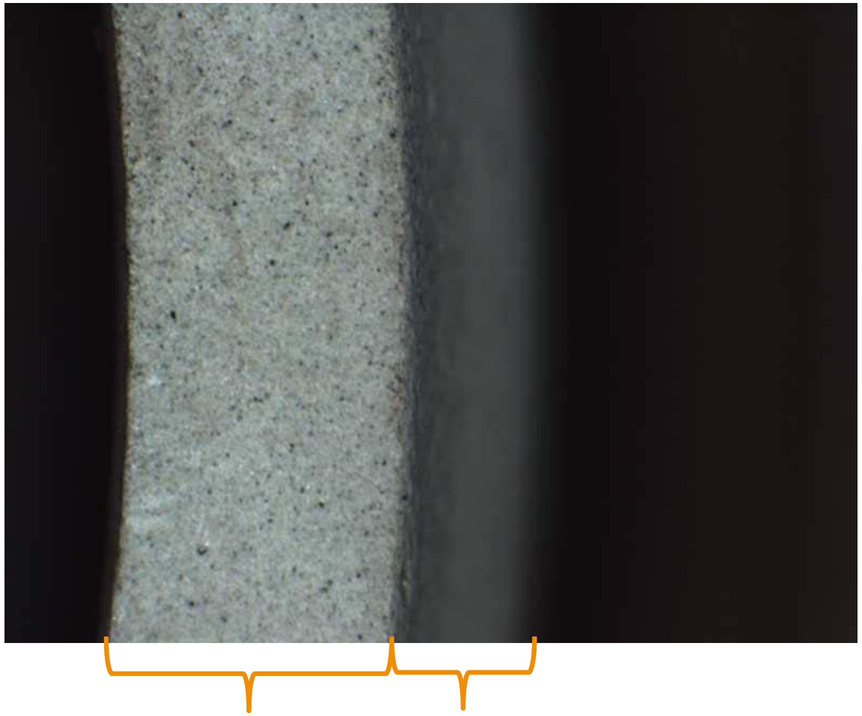


- Good agreement between Jumbo (Giessen) und MVTF (Rapolano)
- Differences in linescans are not artifacts (see images)

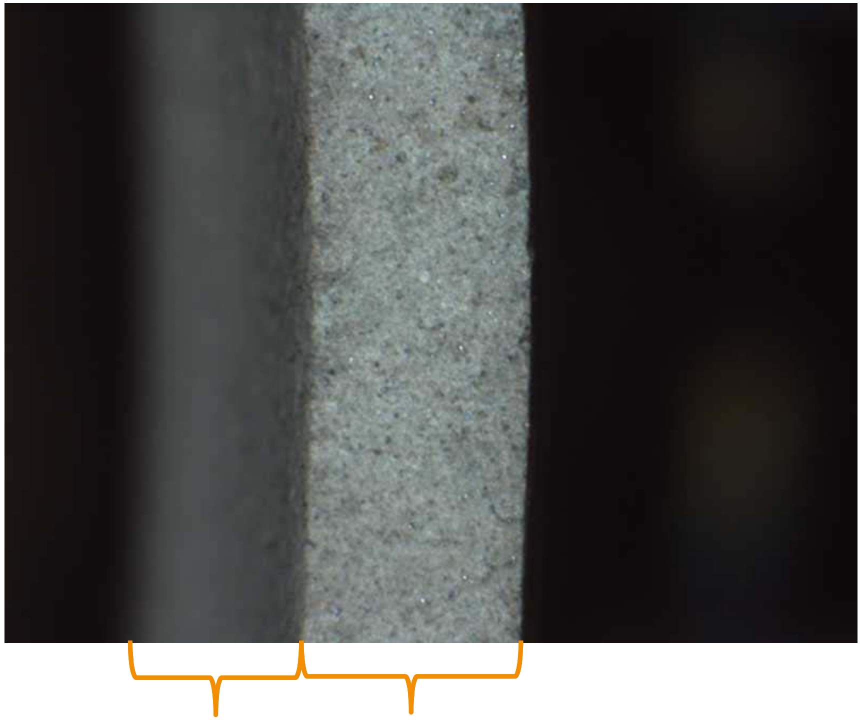
SPT100-ML: Telemicroscope

- Jumbo (JLU Gießen)

- Inner ceramic wall



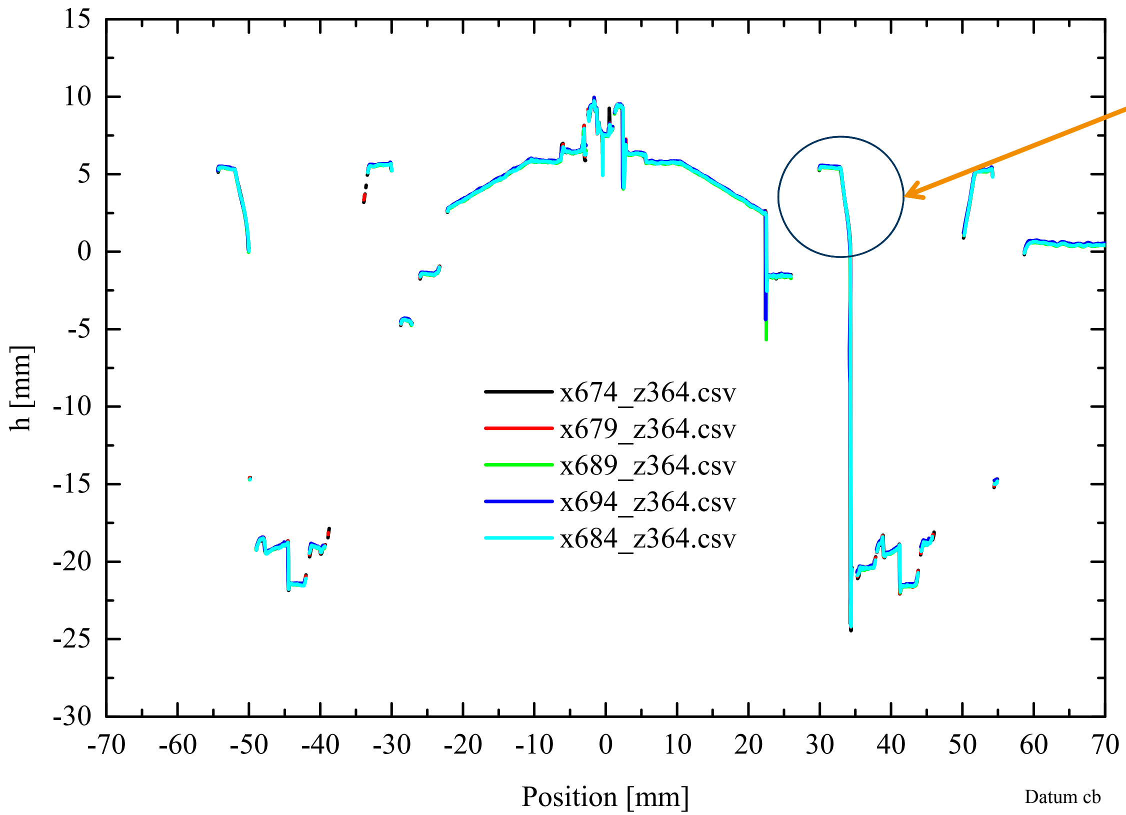
- Outer ceramic wall



- Top edge of channel walls already eroded (axial erosion ~ 4.5 mm ± 1.0 mm)

SPT100-ML: TLH

Jumbo (JLU Gießen)

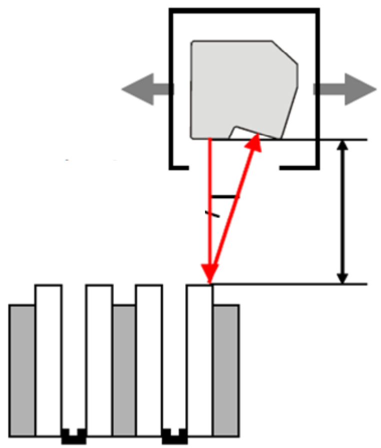


Radial erosion:

1.5 mm ± 0.2 mm

Axial erosion:

4.9 mm ± 0.5 mm



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Summary

- AEPD2 system design, manufactured and tested
- Diagnostic tools developed and performance evaluated
  - Optical measurements: telemicroscope, triangular laser head
  - Temperature measurements: pyrometer, thermocamera
  - Particle beam measurements: retarding potential analyzer, Faraday probe, active thermal probe
- System operated well at all test campaigns
  - Jumbo (JLU Gießen): RIT-µX & SPT-100ML
  - MVTF (Aerospazio): RIT-µX & SPT-100ML
- In general very good reproducibility of results within the same facility
- Comparison of results between different facilities shows “facility effects”, for example from background temperature and pressure
- Deeper understanding the facility effects requires further studies
- For better quantification, window effects (Pyr, ThC) need to addressed in more detail

Appendix

Telemicroscope: Sources of uncertainty

- Vacuum (lack of convection)
  - Can affect operation of electronics (maximum temperature 85° C), no problems encountered in test campaign ✓
- Rise of temperature due to interaction with energetic particle beam
  - Thermal expansion of mechanical parts, e.g. extension tube length, minimal effect on performance and can be examined by calculation ✓
- Contamination by sputtered material:
  - Can affect image quality, protect window if not in operation ✓
- Setup:
  - Window in image path: no effect detected ✓

Laser head: Sources of uncertainty

- Vacuum (lack of convection)
  - Can affect operation of electronics (maximum temperature 85° C), no problems encountered in test campaign ✓
- Rise of temperature due to interaction with energetic particle beam
  - Thermal expansion of mechanical parts, e.g. window, can be examined by calculation (expected to be negligible) ✓
- Contamination by sputtered material:
  - Can affect signal intensity, no problems encountered in test campaign ✓
- Setup:
  - Window effect: relative distance changes are measured accurately ✓

Pyrometer: Sources of uncertainty

- Vacuum (lack of convection)
  - Can affect operation of electronics (maximum temperature 85° C), no problems encountered in test campaign ✓
- Rise of temperature due to interaction with energetic particle beam
  - Thermal expansion of mechanical parts expected to be negligible ✓
  - Heated window can affect results: to be examined by calculation
- Contamination or erosion by sputtered material:
  - Can affect window and, hence, signal intensity: needs to be tested in additional test campaign, can be examined by calculation and experiment ✓
- Test object:
  - Emissivity error: to be examined by calculation and experiment ?
- Setup:
  - Window effect: experiment and/or calculation ✓

Thermocamera: Sources of uncertainty

- Vacuum (lack of convection)
  - Can affect operation of electronics (maximum temperature 85° C), chip temperature can be read out from software ✓
- Rise of temperature due to interaction with energetic particle beam
  - Thermal expansion of mechanical parts expected to be negligible ✓
  - Heated window can effect results: to be examined by calculation
- Contamination by sputtered material:
  - Can affect window and, hence, signal intensity: needs to be tested in additional test campaign, can be examined by calculation and experiment ✗
- Test object:
  - Emissivity error: to be examined by calculation and experiment ?
- Setup:
  - Window effect: experiment and/or calculation ✓

RPA: Sources of uncertainty

- Vacuum (lack of convection)
  - No effect, electronics outside vacuum ✓
- Rise of temperature due to interaction with energetic particle beam
  - Thermal expansion of grids: can be examined by calculation, influence on measured ion energy expected to be small ✓
- Contamination by sputtered material:
  - No effect expected ✓
- Electronics (measurements and/or manufacturer's data):
  - High voltage power supply ✓
  - Isolation amplifier
  - Measurement resistor
  - Data acquisition module

Faraday probe: Sources of uncertainty

- Vacuum (lack of convection) ✓
  - No effect, electronics outside vacuum
- Rise of temperature due to interaction with energetic particle beam ✓
  - Thermal expansion of measurement area:
    can be examined by calculation, expected to be negligible
- Contamination by sputtered material: ✓
  - No effect expected
- Electronics (measurements and/or manufacturer's data) and setup: ✓
  - Measurement area
  - Measuring resistor
  - Data acquisition card
  - Cable and feedthrough