

# International High Power Laser Ablation and Beamed Energy Propulsion Conference

Santa Fe, New Mexico, USA, April 21 – 25

## **Laser Propulsion Research Facilities at DLR Stuttgart**

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Eckel

Institute of Technical Physics, German Aerospace Center



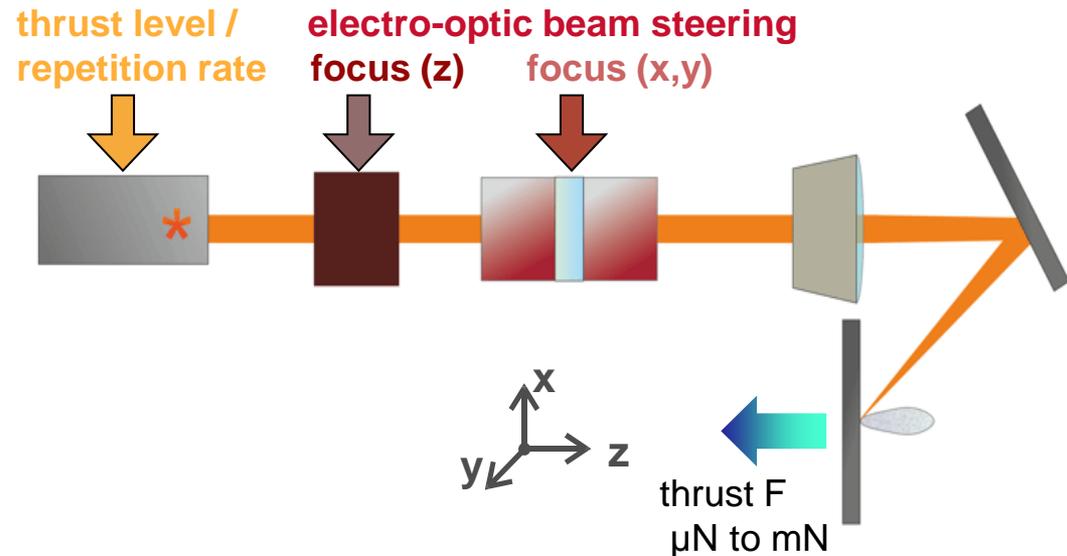
Knowledge for Tomorrow



# Motivation

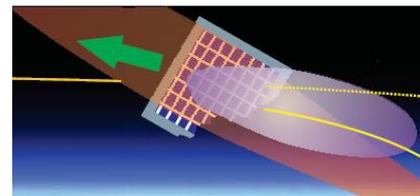
## microthrusters for future missions:

- $\mu\text{N}$  to  $\text{mN}$  thrust level with  $0.1 \mu\text{N}$  resolution
- thruster lifetime
- contamination issues
- no moving parts



## debris removal:

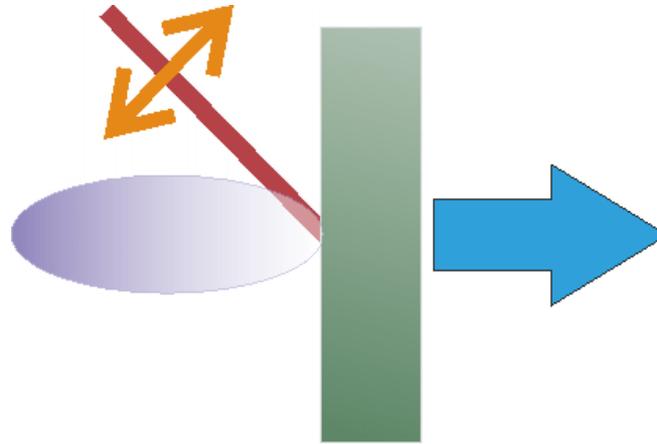
- reduce desorbitation time of known debris object by laser induced thrust



**for more information:** Thursday, 24 April 8:05, Dr. Bruno Esmler  
 “CLEANSPACE - Space Debris Removal by Ground Based Laser”



# Overview



## parameters

ablation scheme

target material

laser parameters

## figures of merit

imparted impulse

ablated mass

surface quality

plume characteristics

optimize

## experiment / theory

thrust measurement  
VLL

surface diagnostics  
VLL / IMD

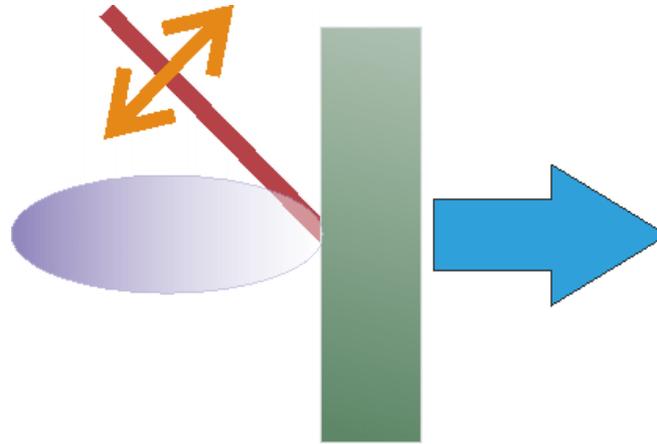
plasma diagnostics  
DSMC-PiC



Universität  
Stuttgart



# Overview



**for more information:**

Poster: „Open access tools“

Thursday, 24 April 9:15: „Overview of Laser Ablation Micropropulsion Research Activities at DLR Stuttgart“

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experiment / **theory**

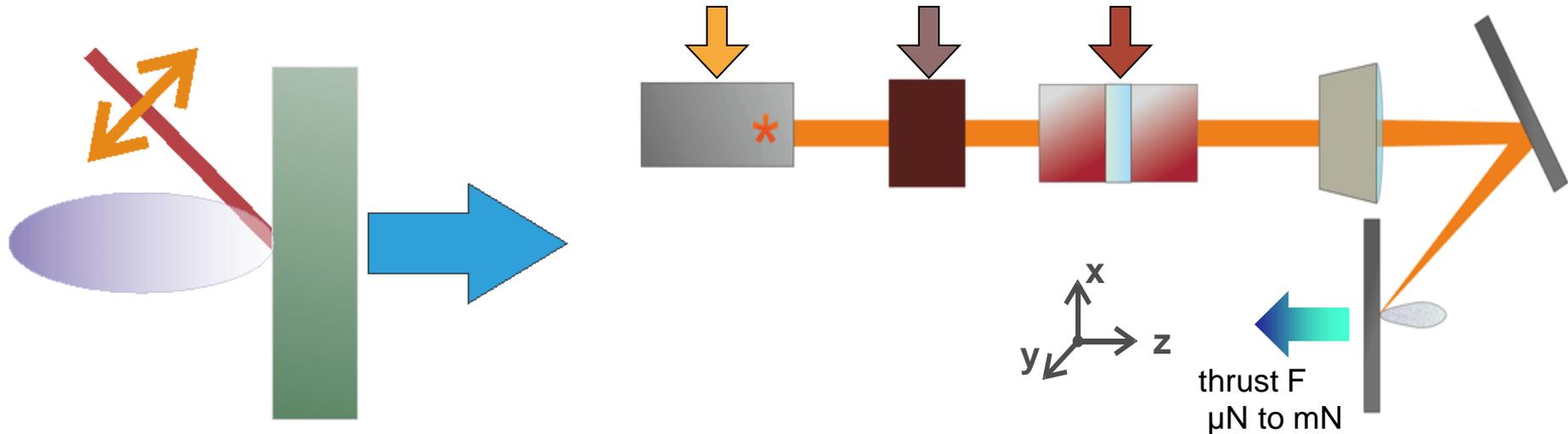
thrust measurement  
VLL

surface diagnostics  
VLL / IMD

plasma diagnostics  
DSMC-PiC



# Figures of Merit



## figures of merit

imparted impulse

ablated mass

surface quality

plume characteristics

$$I_{sp} = \frac{V_{jet}}{g}$$

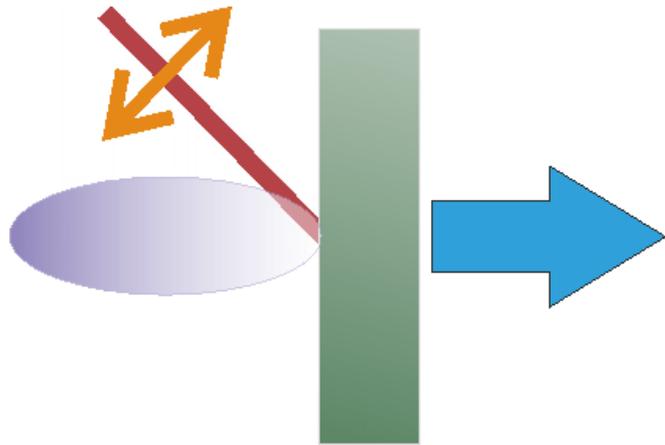
$$c_m = \frac{\Delta p}{E_L}$$

layer-by-layer ablation

lifetime/contamination issues/simulations



# Parameters

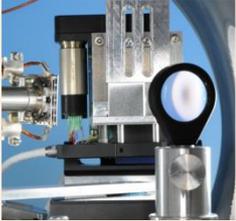
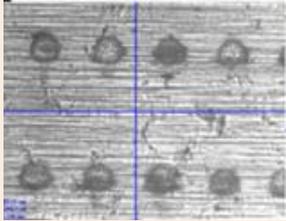


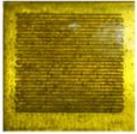
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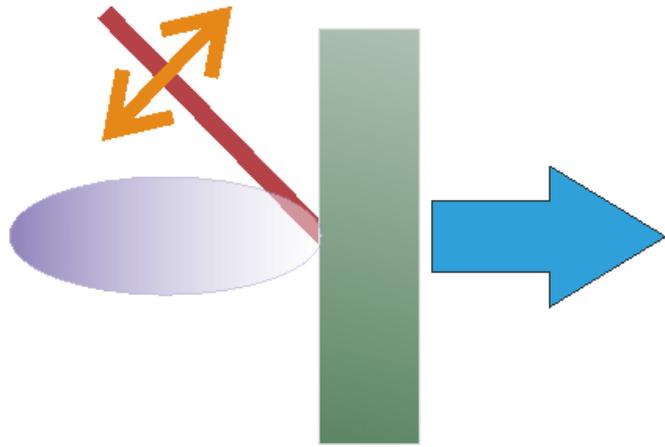
target positioning	galvo mirror beam-steering
	

<i>Microthrusters:</i> Al, Cu	<i>Debris:</i> Al, Si, Polyimide, Multi Layer		
			

pulse energy	<i>microchip lasers</i>	<i>Nd:YVO<sub>4</sub> slab laser</i>	
pulse length			
spot size			
polarization			
wavelength			
			



# Experimental Facilities

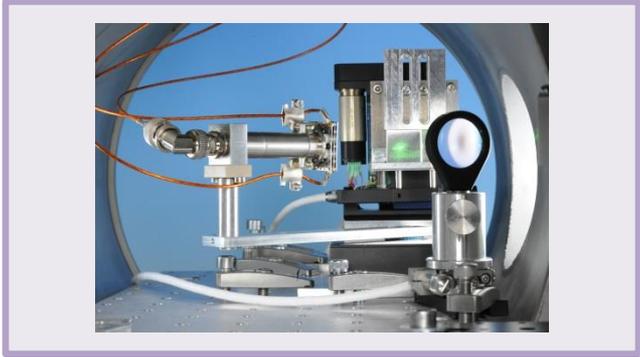
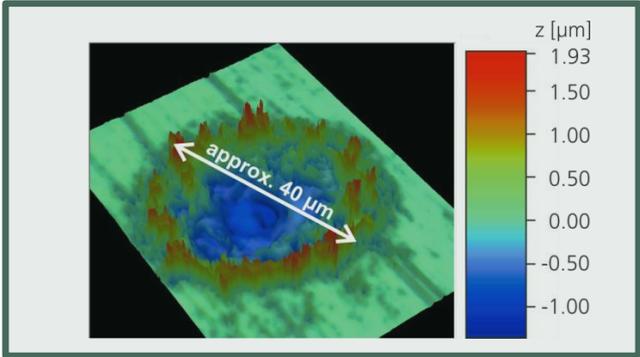
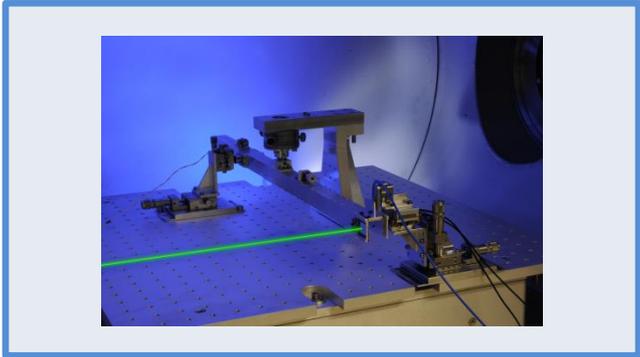


experiment

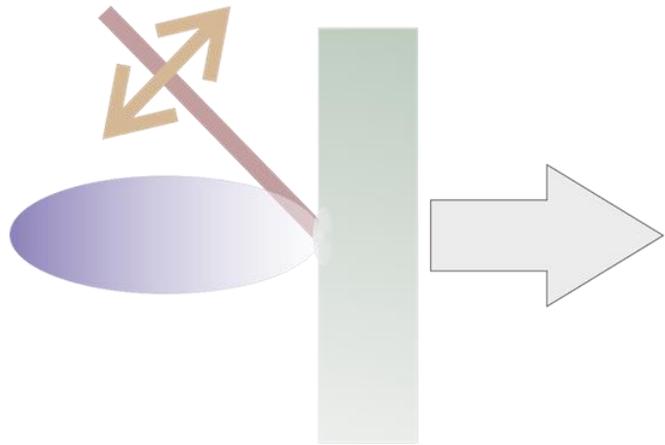
thrust measurement

surface diagnostics

plasma diagnostics



# Experimental Facilities – Plasma Diagnostics



experiment

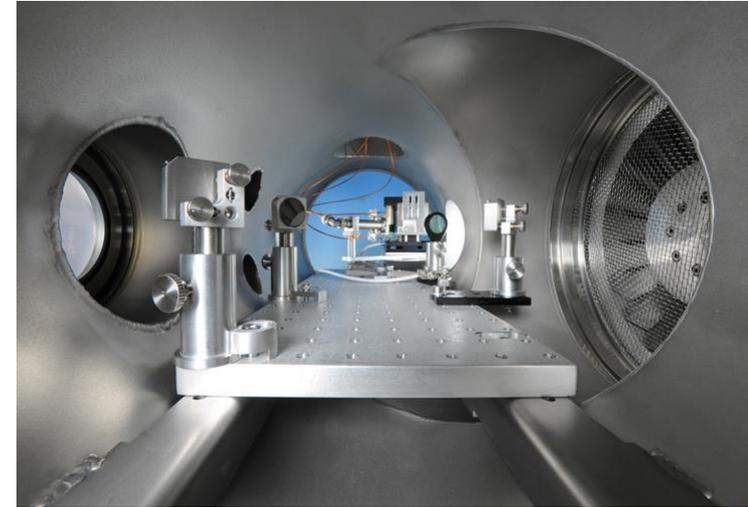
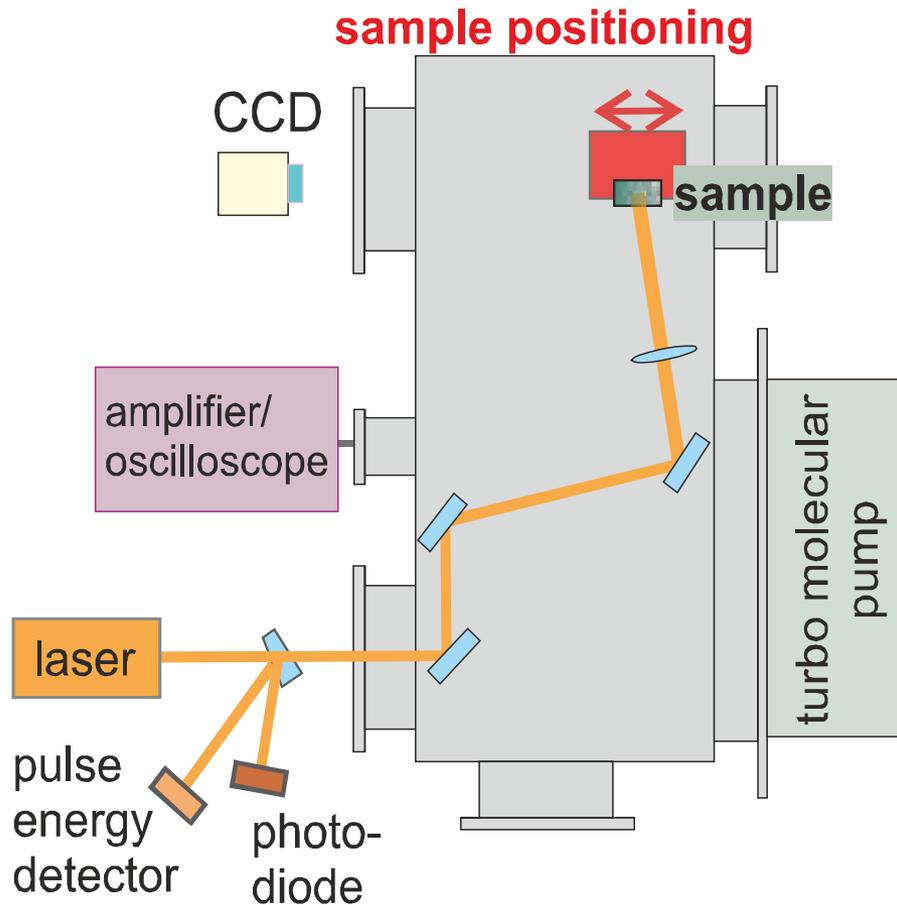
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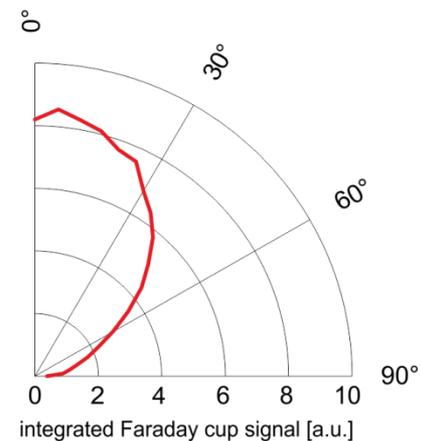
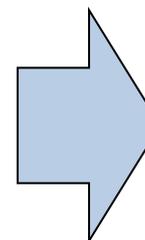
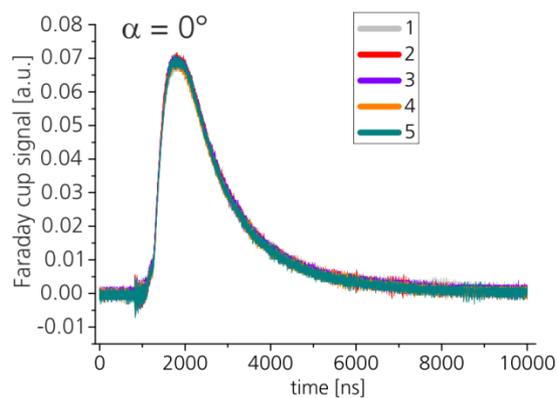
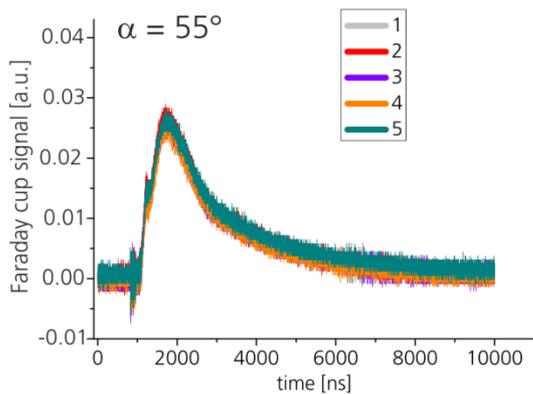
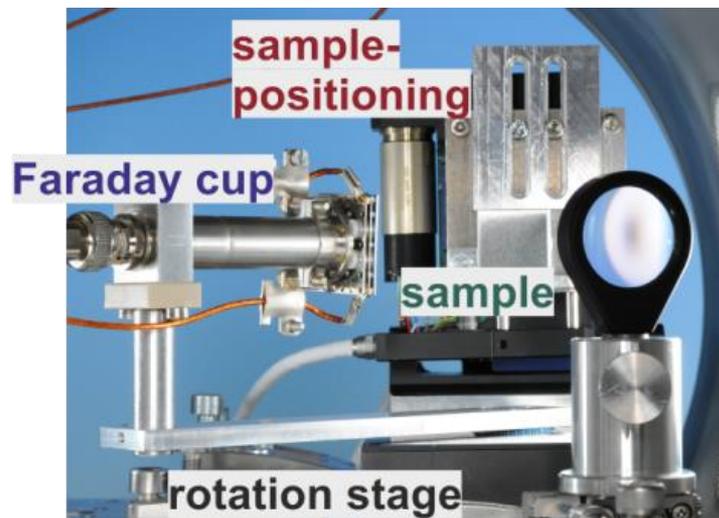
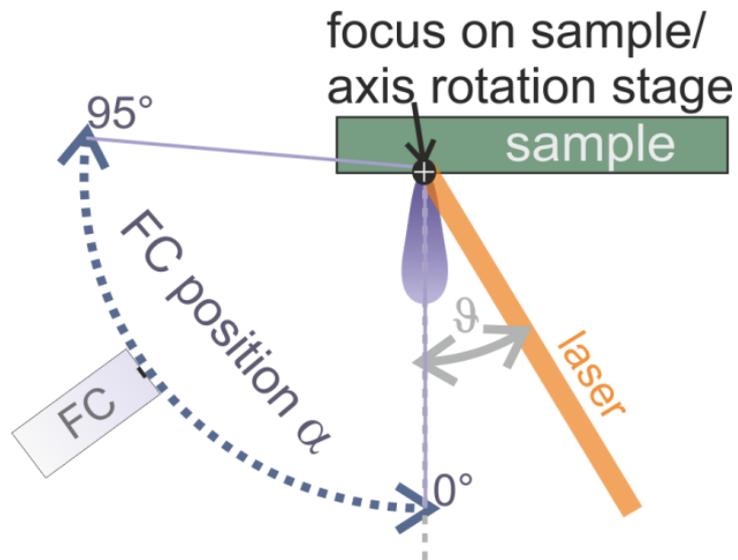
# Experimental Facilities – Plasma Diagnostics



- 35 l vacuum chamber (0.6 m x 0.25 m  $\varnothing$ )
- 15 m<sup>3</sup>/h scroll pump and 1550 l/s N<sub>2</sub> turbomolecular pump
- $< 5 \cdot 10^{-6}$  mbar
- microchip lasers: 1 mJ @ 1 ns and 80  $\mu$ J @ 500 ps

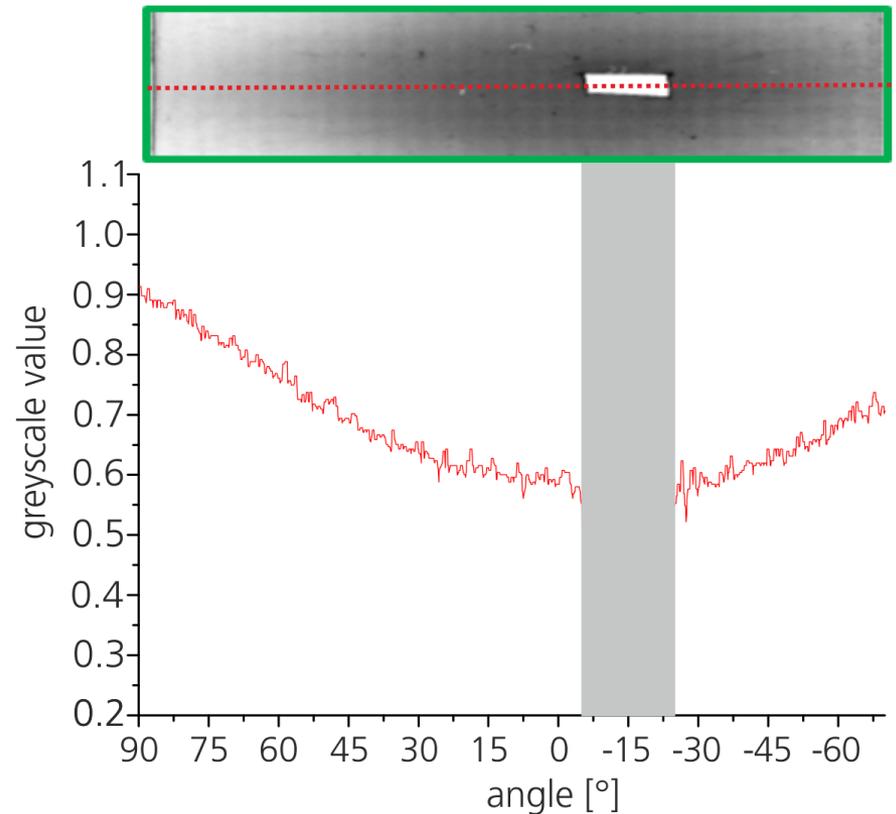
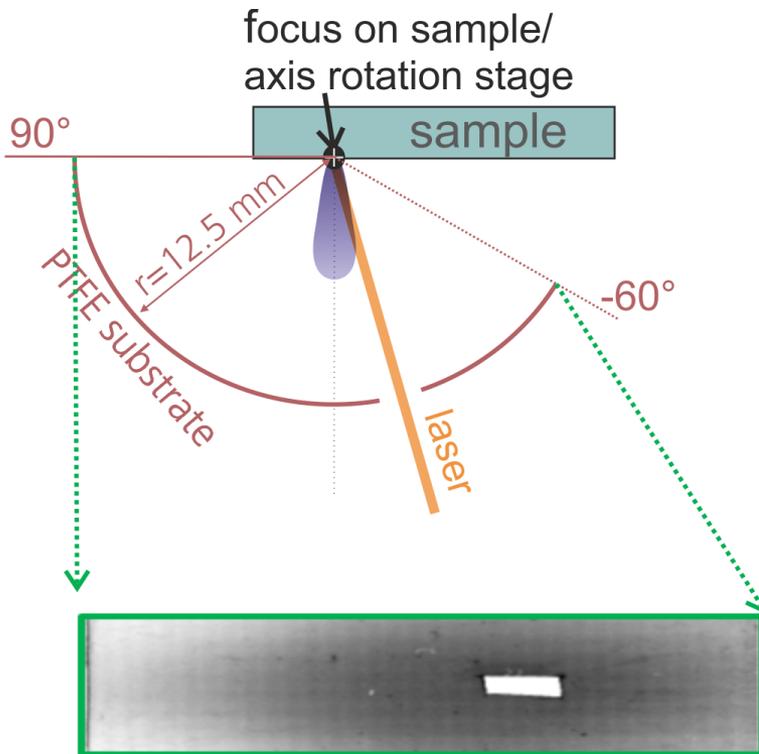


# Experimental Facilities – Plasma Diagnostics

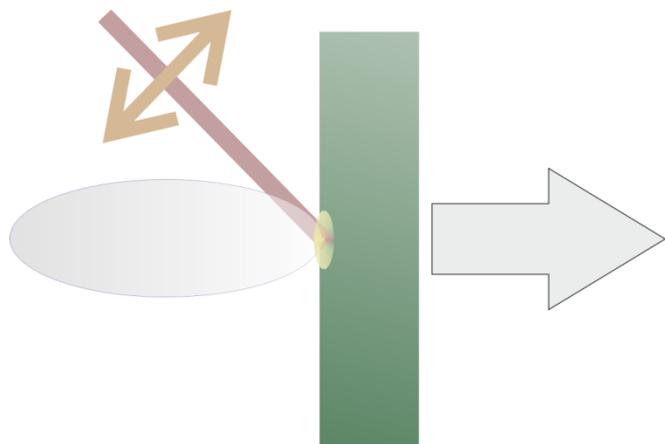


# Experimental Facilities – Plasma Diagnostics

- PTFE foil coating from 300,000 shots at same parameters (Al, 500 ps, 71.7  $\mu\text{J}$ )
- scanner with a transmitted light unit (Epson V700)



# Experimental Facilities – Surface Diagnostics

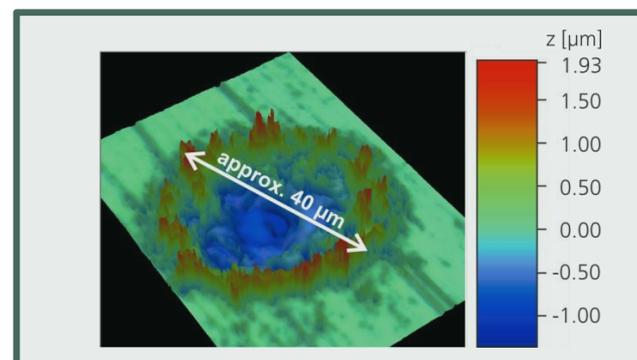


experiment

thrust measurement

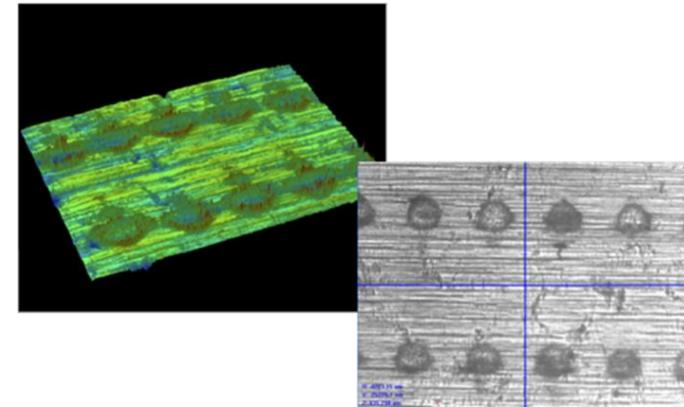
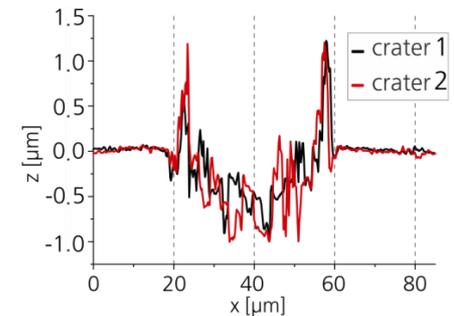
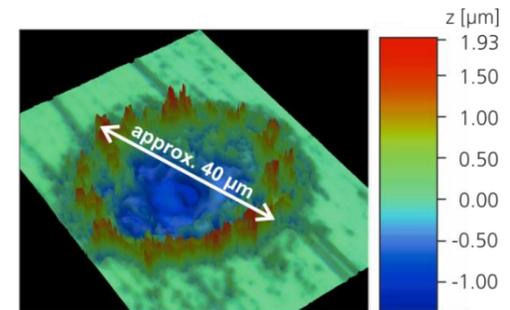
surface diagnostics

plasma diagnostics

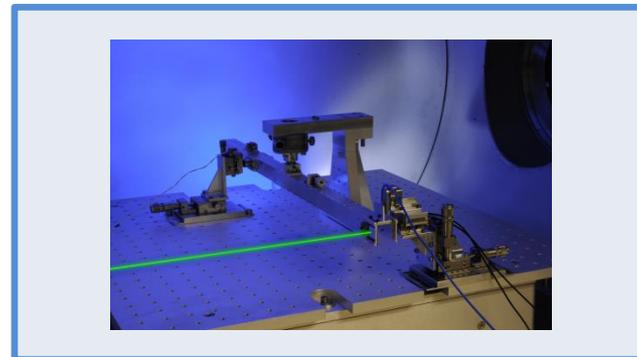
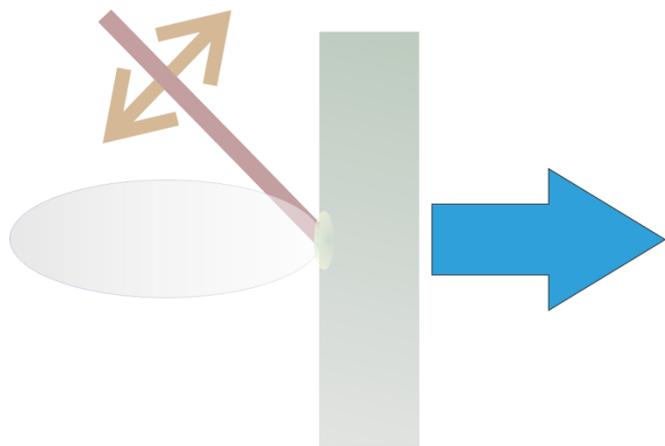


# Experimental Facilities – Surface Diagnostics

- commercial white light interferometer (Veeco NT9100)
- 3D crater geometry measurements → ablated mass
- target surface roughness
- positioning and adjustment:
  - positioning of the targets in the focus
  - step size for target positioning/scanning speed for beam-steering



# Experimental Facilities – Thrust Measurement



experiment

thrust measurement

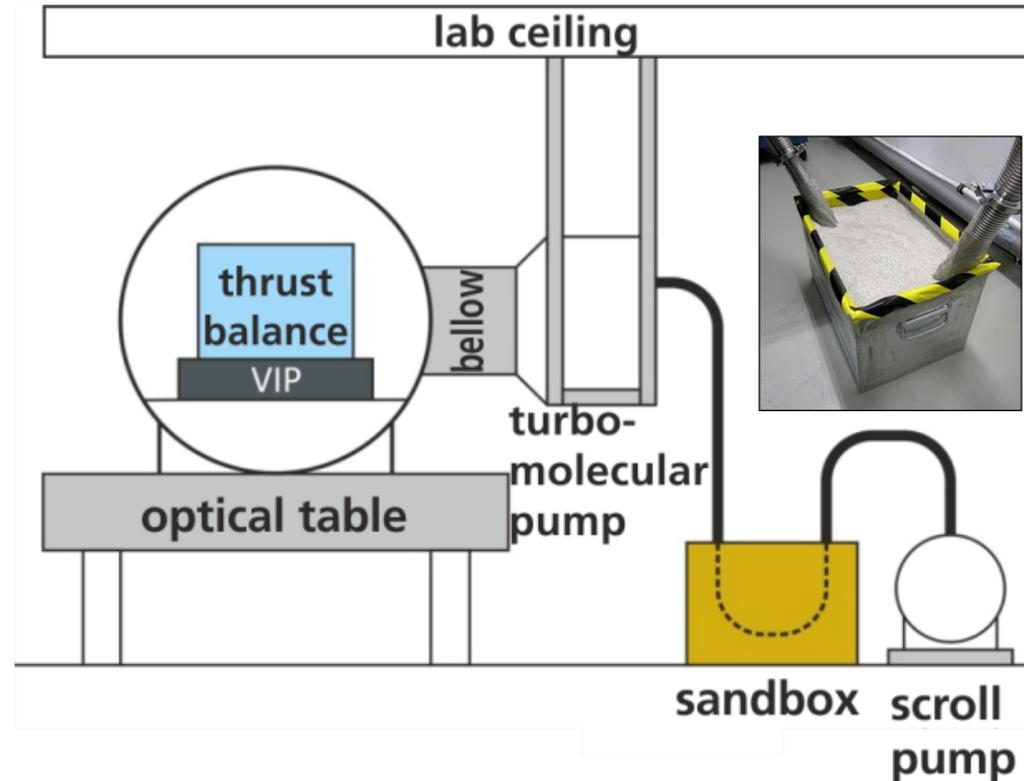
surface diagnostics

plasma diagnostics



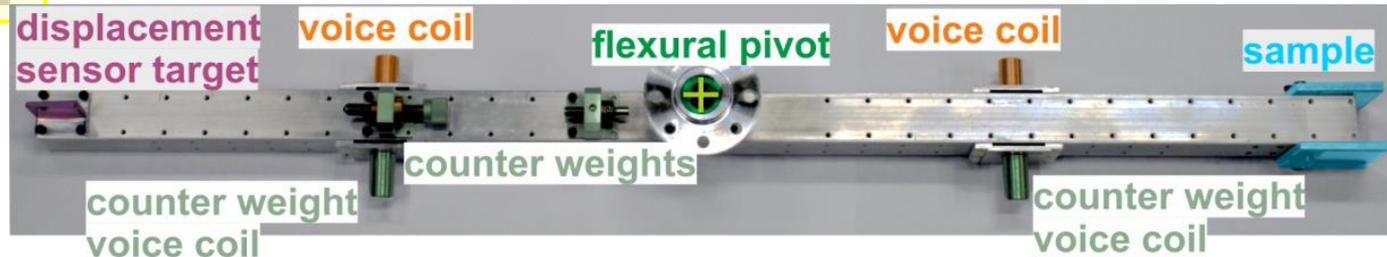
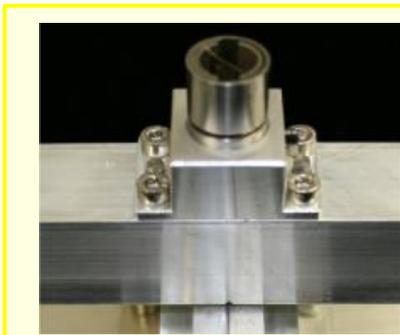
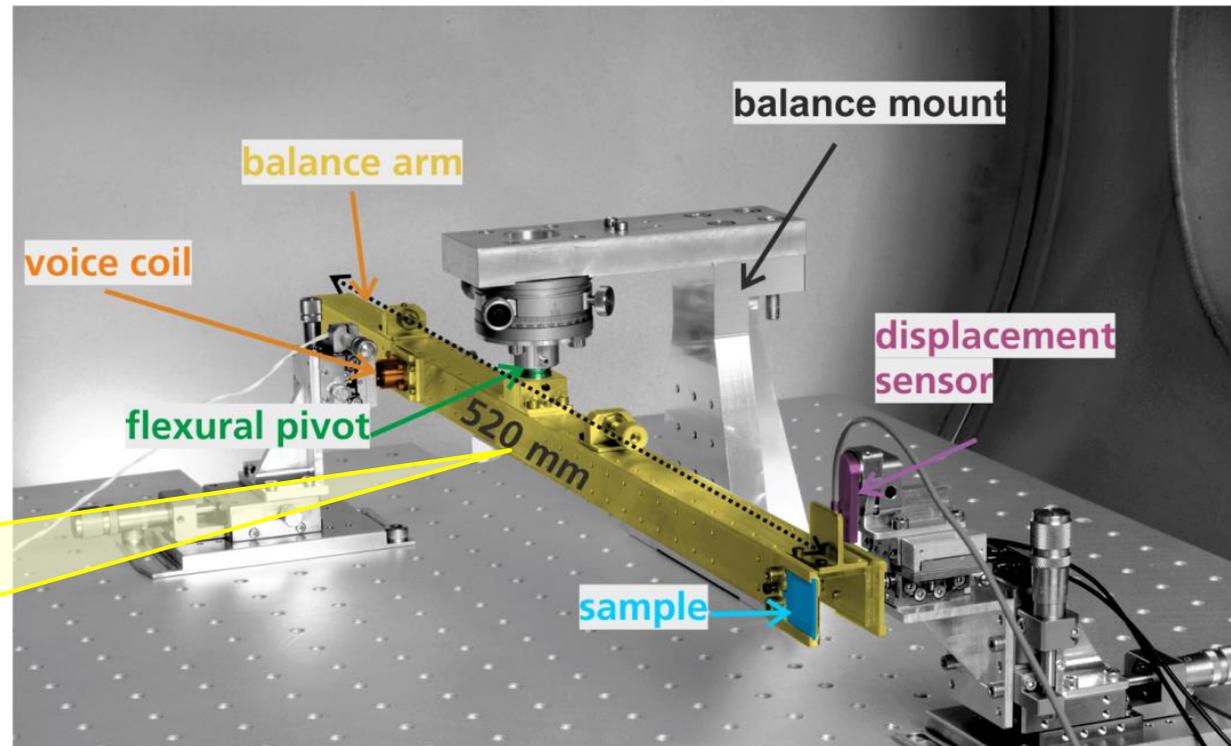
# Thrust Measurement – Vacuum Facilities

- approx. 500 l vacuum chamber (0.95 m x 0.8 m  $\emptyset$ )
- pumping system: 30 m<sup>3</sup>/h scroll pump, 2650 l/s (N<sub>2</sub>) magnetic bearing TMP



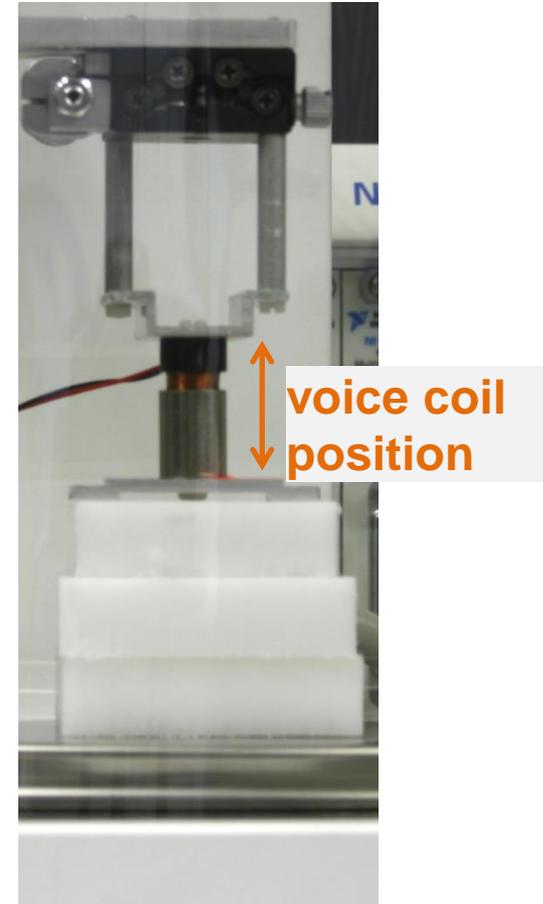
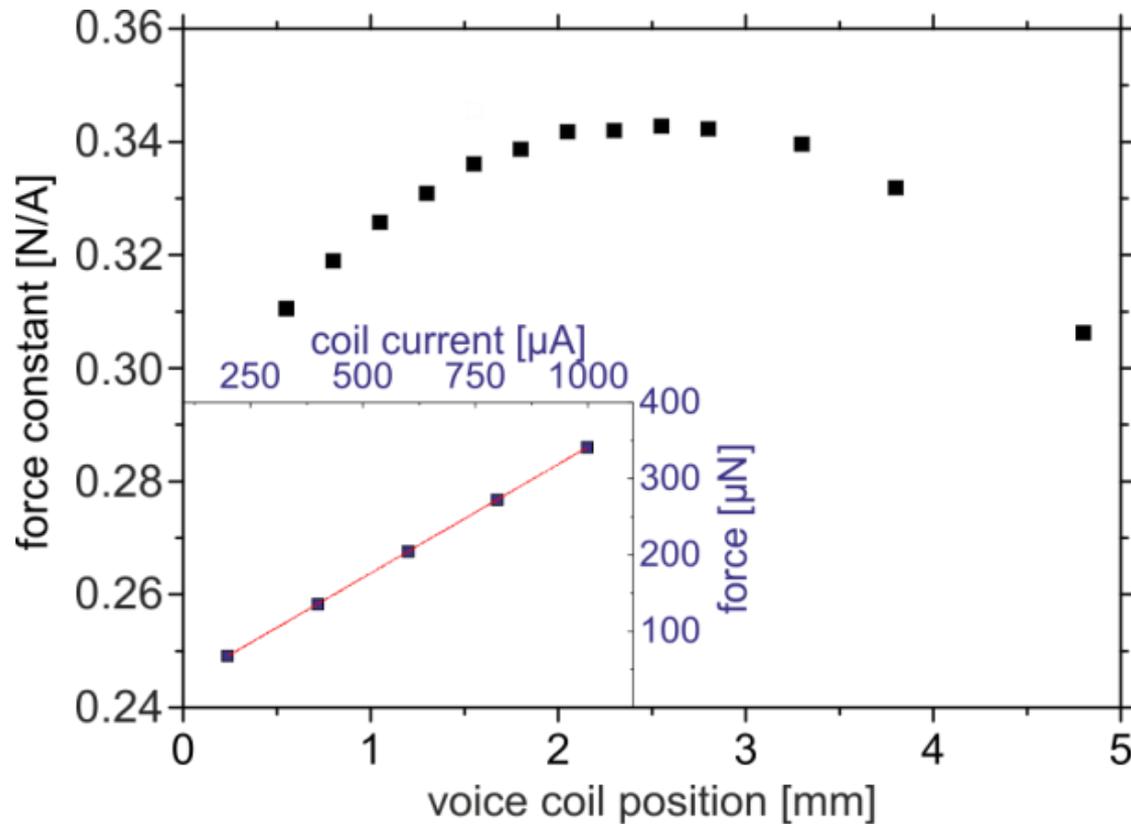
# Thrust Measurement – Balance Design

- torsional pendulum
- flexible design
- no cable connections
- counter weights
- adjustable center of mass



# Thrust Measurement – Voice Coil Calibration

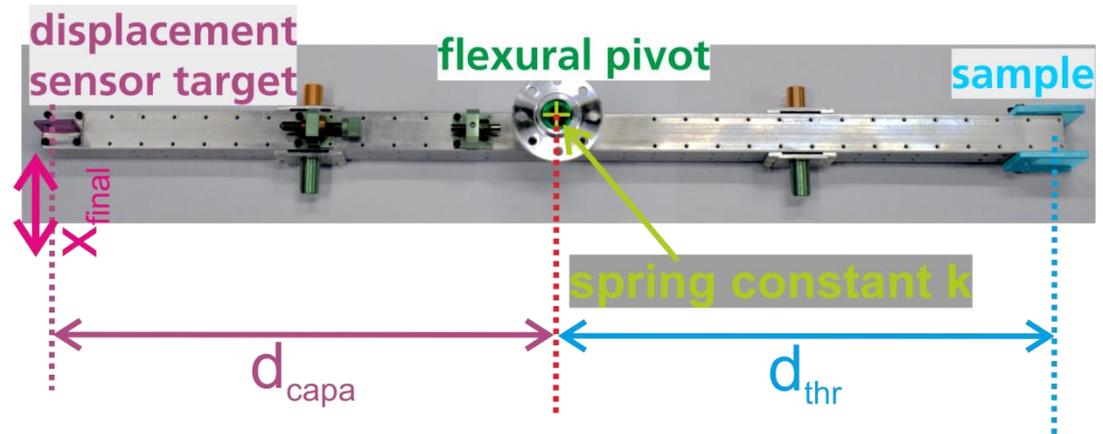
- microbalance  $\pm 0.02$  mg, equivalent to  $0.2 \mu\text{N}$   $\rightarrow C_{vc}$



# Thrust Measurement – Measurement Options

- *open -loop,*  
*open-loop with active damping*

$$T = \frac{\theta_{final} \cdot k}{d_{thr}} \approx \frac{x_{final} \cdot k}{d_{thr} \cdot d_{capa}}$$



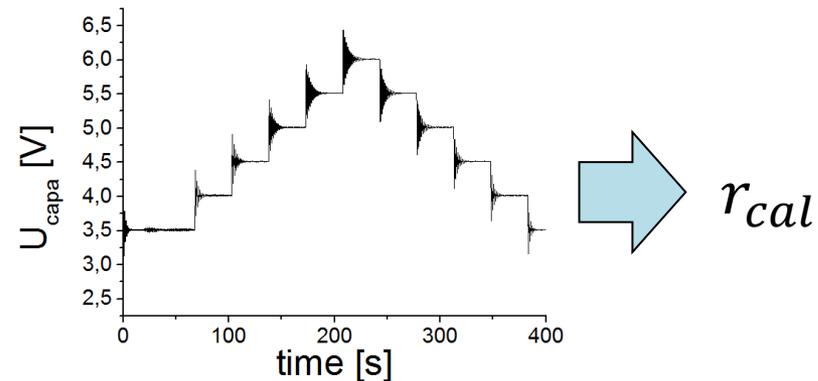
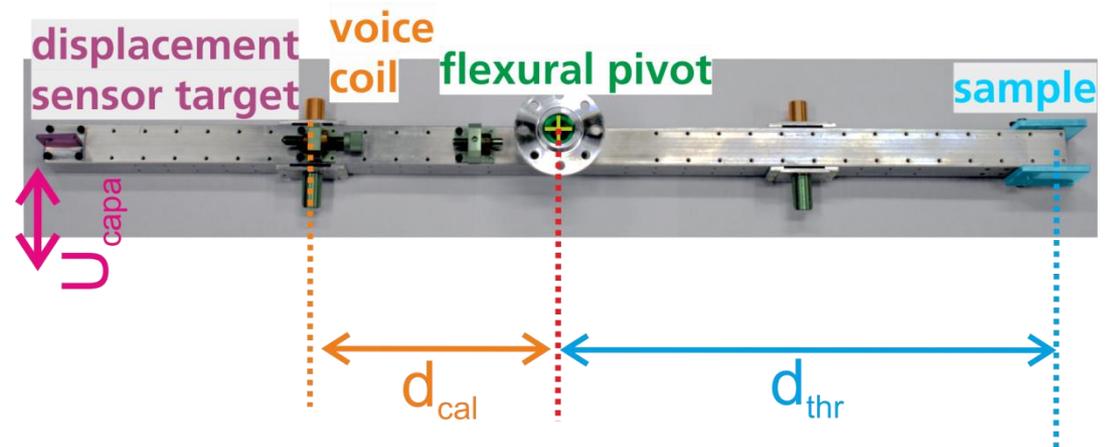
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voice coil calibration:

$$T = U_{capa} \cdot r_{cal} \cdot C_{vc} \cdot \frac{d_{cal}}{d_{thr}}$$



# Thrust Measurement – Measurement Options

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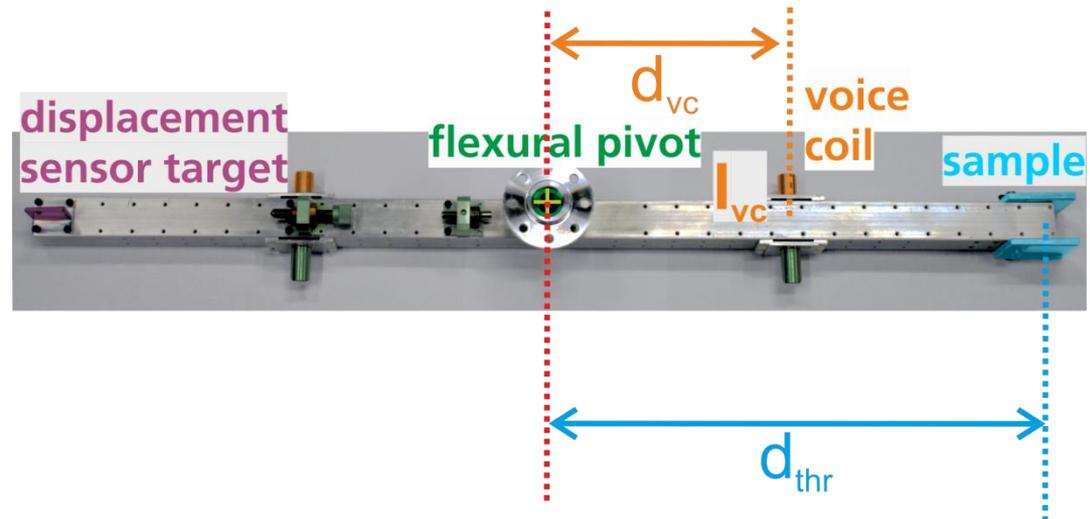
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- **closed-loop (PID)**

$$T = I_{vc} \cdot c_{vc} \cdot \frac{d_{vc}}{d_{thr}}$$



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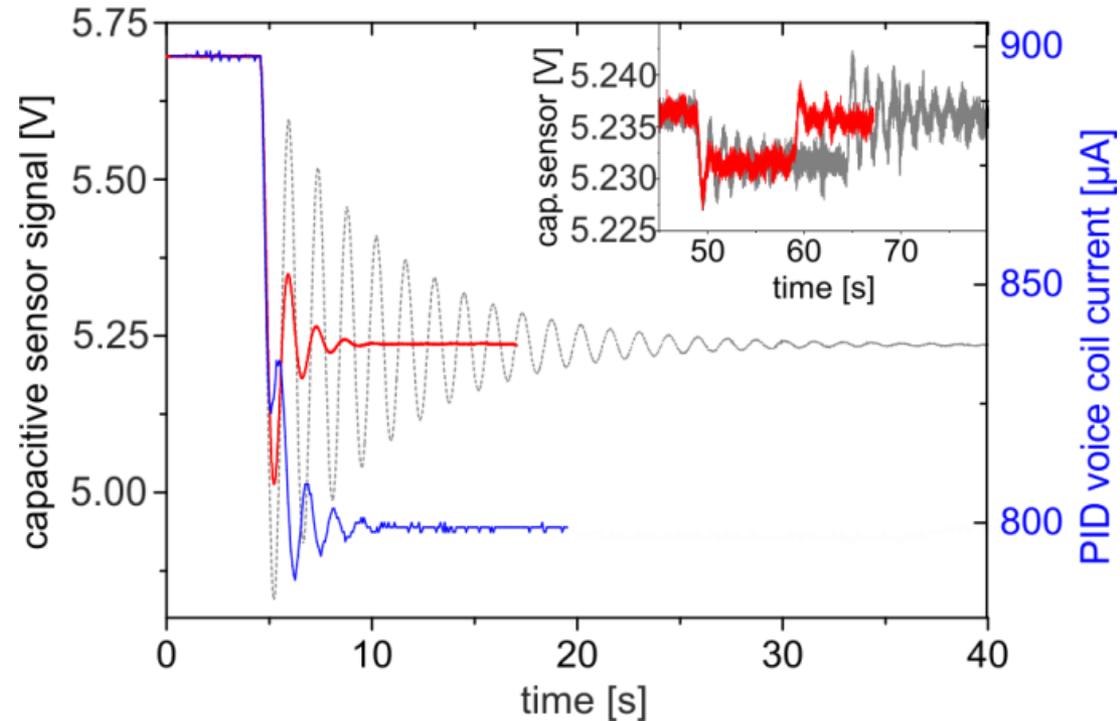
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$$T = I_{vc} \cdot C_{vc} \cdot \frac{d_{vc}}{d_{thr}}$$

100  $\mu$ A step, 1  $\mu$ A step,  $c_{vc}=0.342$  N/A



# Thrust Measurement – Calibration with Thin Disk Laser

- test of alternative calibration method based on radiation pressure
- 1 kW thin disk laser
- HR mirror on balance  $R > 99.98\%$
- power meter  $\pm 5\%$  accuracy

## **extra-cavity:**

beam from laser on HR mirror on balance

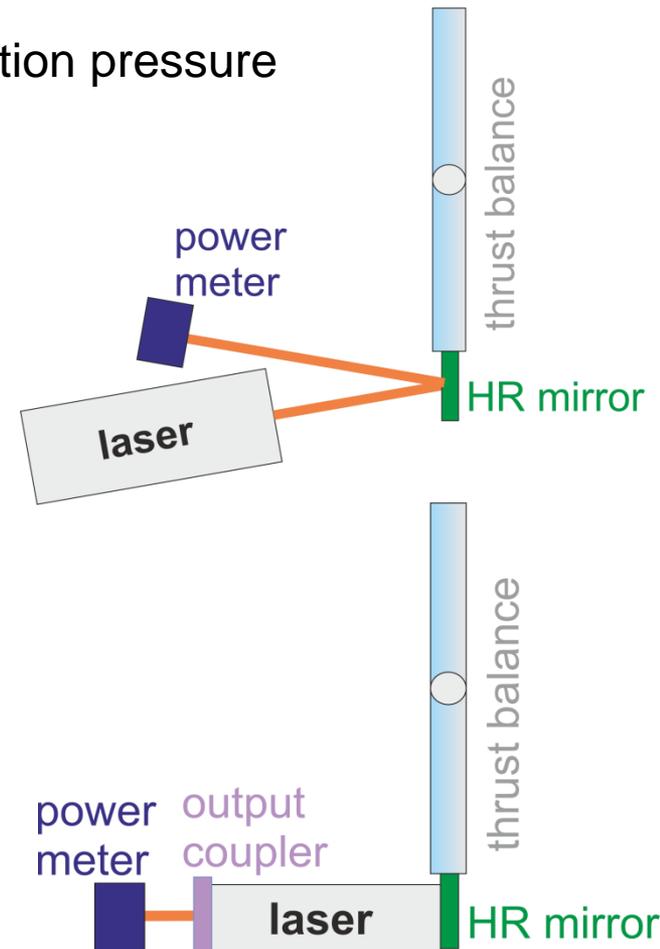
$$F_{radiation} = (1 + R) \cdot \frac{P}{c} \cdot \cos(\vartheta)$$

## **intra-cavity:**

HR mirror on balance = laser cavity mirror,  $\vartheta = 0$

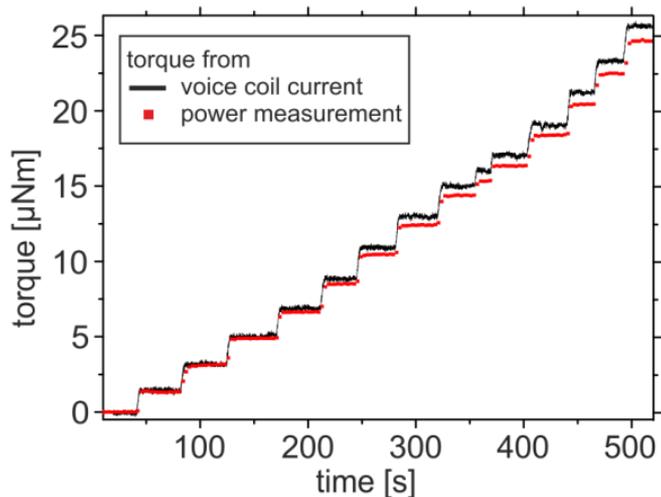
output coupler  $T = 2.4\%$ ,  $P = P_{int}$

$$P_{int} = P_{ext} \frac{1 - T}{T}$$

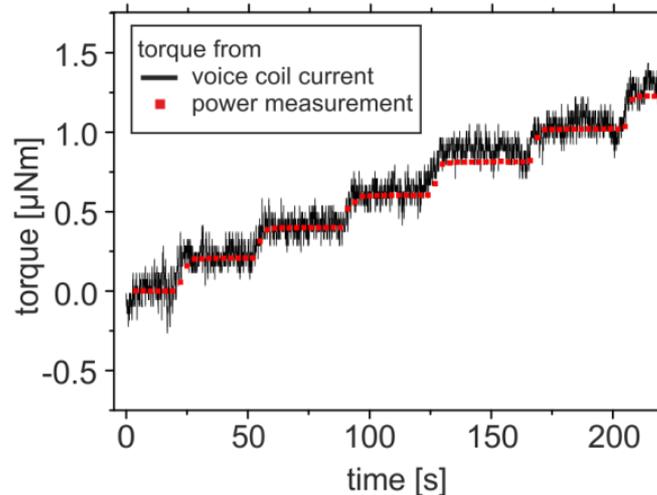


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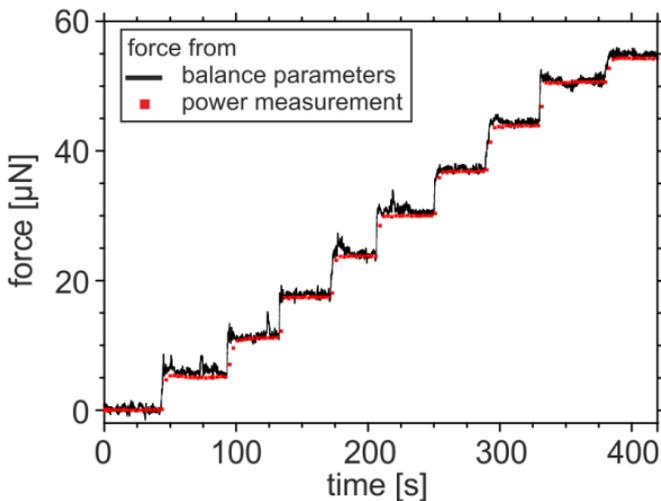
intra-cavity closed-loop



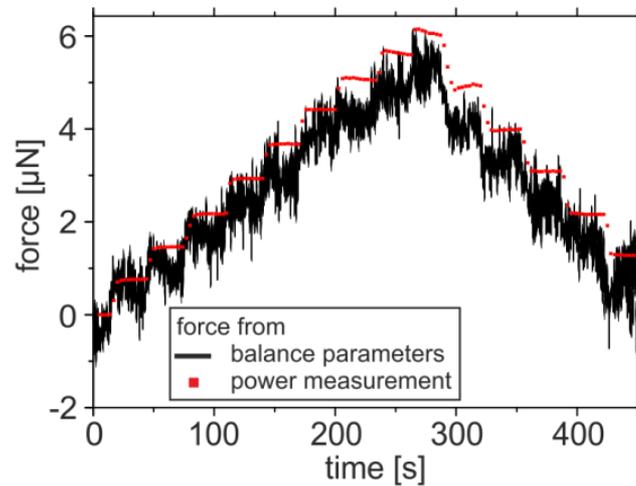
extra-cavity closed-loop



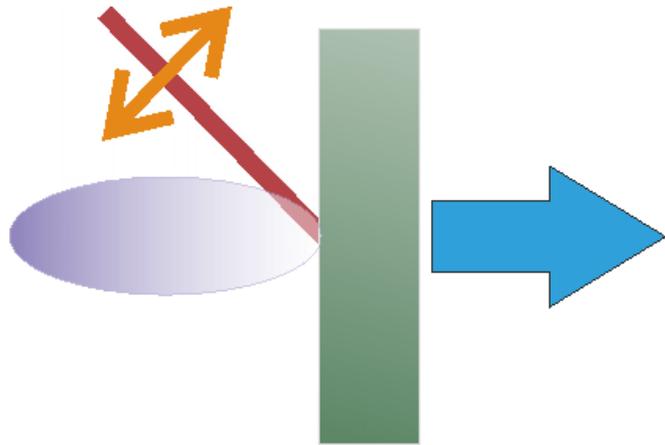
intra-cavity open-loop



extra-cavity open-loop



# Summary



experiment

thrust measurement

surface diagnostics

plasma diagnostics

- flexible design torsional pendulum thrust balance
- open-loop, open-loop active damping, closed-loop options
- calibration:
  - voice coils
  - test of thin disk laser based method

- commercial white light interferometer

- charged plume components: Faraday cups
- all plume components: test of PTFE substrate coating



# Outlook

- **microthruster:**

- *ablation pattern:*

- currently: evaluation of KTN crystal based electro-optical scanners
    - expanded study on ablation pattern and angle of incidence

- *laser parameters:* shorter pulse lengths (ps)

- *plasma diagnostics:* implementation of optical diagnostics (ICCD)

- *thrust balance:* further tests and improvements, also single shot for....

- **space debris:**

- higher pulse energies: large area single shot ablation



# Acknowledgements

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