Characterization of a Spatially resolved multi-element laser ablation ion source

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Date: 18/02/2022

WNPPC 2022

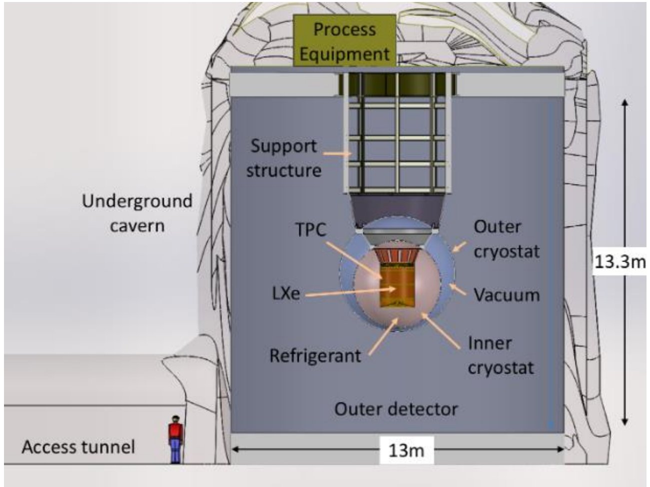
Overview

Context

- nEXO is a 0νββ experiment that uses a tonne-scale liquid Xe TPC.
- Ba-tagging is a potential future upgrade to nEXO, that aims to suppress backgrounds by extracting and identifying the daughter Ba ion of 0νββ decay.

$$^{136}Xe \rightarrow {}^{136}Ba^{++} + 2e^{-}$$

Extract from TPC volume and identify.



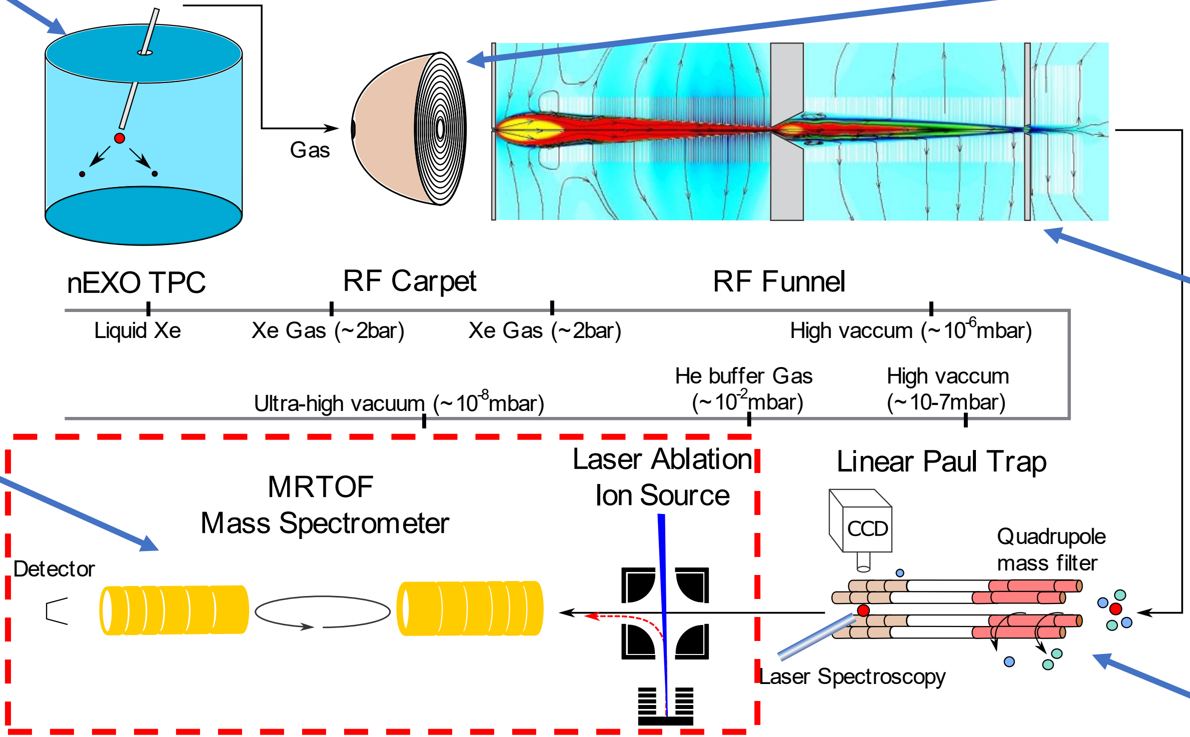
Source: nEXO Pre-Conceptual Design Report arXiv:1805.11142

<u>This Talk:</u> Discussion of the development of multi-element laser ablation ion sources and their application to Ba-tagging – specifically, mass spectrometry.

Barium-tagging in Canada

Stage1: Extraction of detector volume around the location of the decay to gas phase using a capillary tube.

Stage5: Multiple Reflection TOF Spectrometer for systematic studies and determination of ion mass.



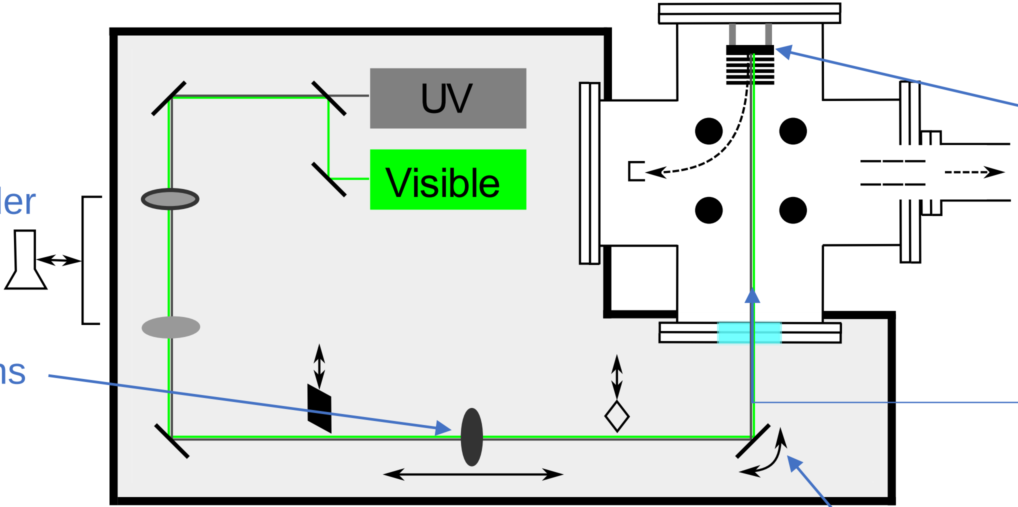
Stage2: RF carpet for efficient transfer of ion from capillary to RF funnel

Stage3: RF funnel facilitates separation of xenon accompanying the Barium ion.

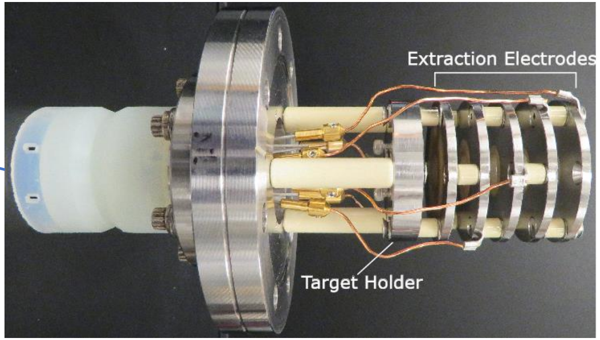
Stage4: The Linear Paul trap for detection of barium ion via laser fluorescence spectroscopy.

What is the LAS

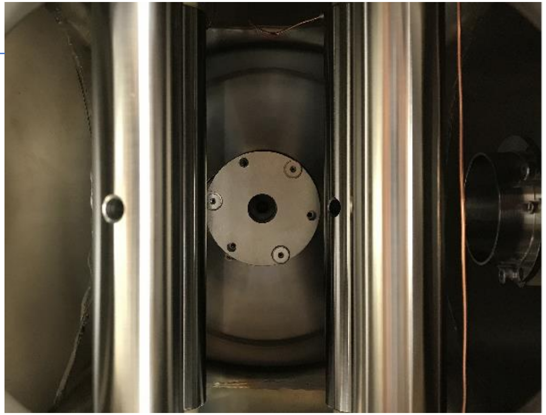
The Laser Ablation Ion Source (LAS)



Ion source-assembly



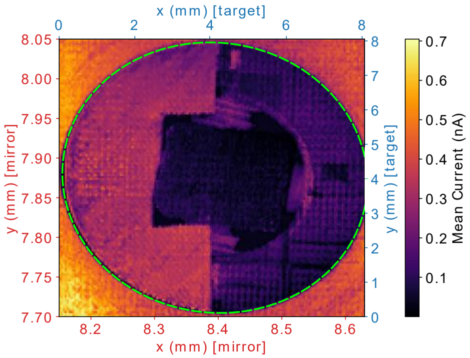
View through quadrupoles



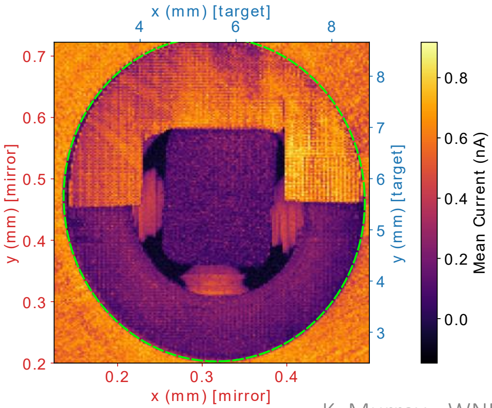
- Can form 2D rasterized images of the target.
- Can establish a coordinate system on the surface of the target.
- Can selectively ablate different materials on multi-element target (50 um res).

Establishing a Coordinate System

Thorlabs KS1-Z8



Physik Instrumente N-472



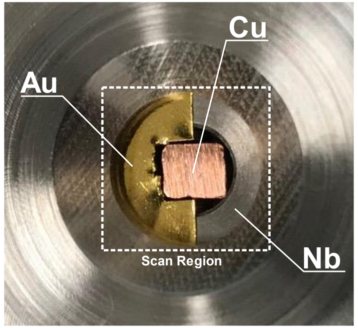
Measuring distances on the target surface is useful…

Coordinate Transformation: $(x', y') = (S_x x, S_y y)$,

(x',y') – coordinates on the target surface.
(x,y) – coordinates of the mirror actuators.

Measured Scaling Factors:

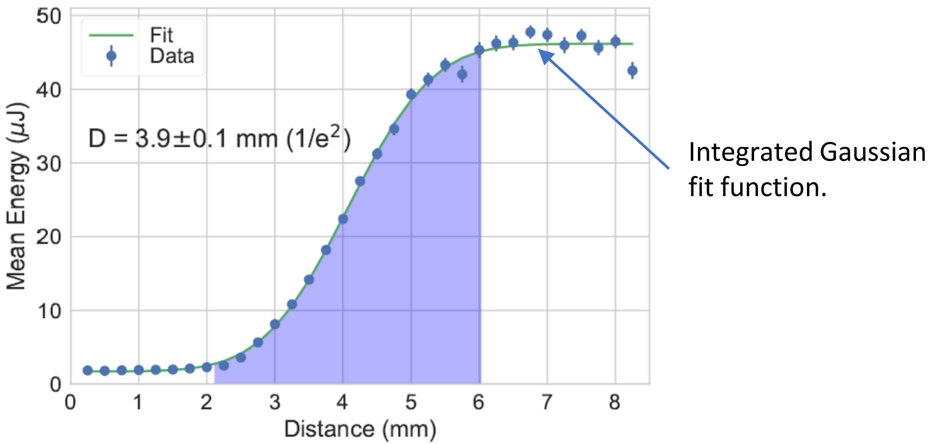
	Scaling Factor		Smallest Step Size	
Mirror Mount	S_x	S_y	$x_{min}(\mu m)$	$y_{min}(\mu m)$
TL KS1-Z8	19.2(3)	13.9(2)	3.84(6)	2.78(4)
PI N472	21.8(3)	14.9(2)	1.09(2)	0.75(1)



Spatial Resolution

Governed primarily by laser spot diameter on target surface – can be calculated theoretically.

Laser beam profile before focusing lens



$1/e^2$ beam diameter

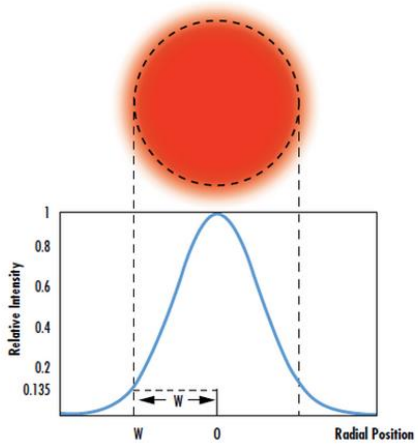


Image source: https://www.edmundoptics.ca/knowledge-center/application-notes/lasers/gaussian-beam-propagation/

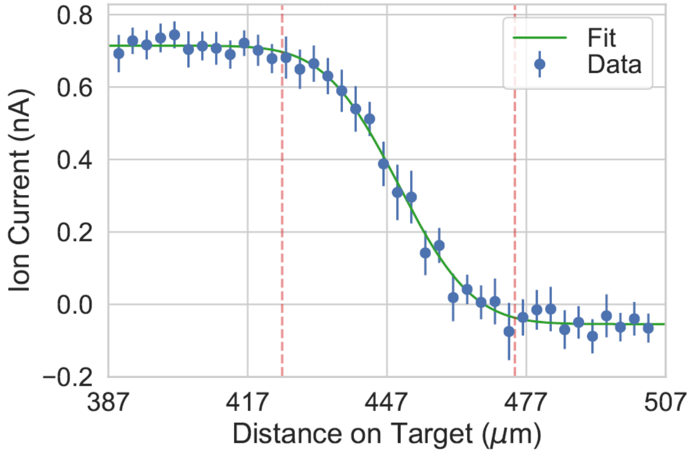
Beam quality: $M^2 = 1.32(7)$, F = 750 mm, λ = 349 nm, D = 3.9(1) mm

Spot diameter calculated as $\mathbf{133(7)\mu m}$. $$2w_0 = \left(\frac{4\lambda}{\pi}\right)\left(\frac{F}{D}\right)$$

Spatial Resolution ctd.

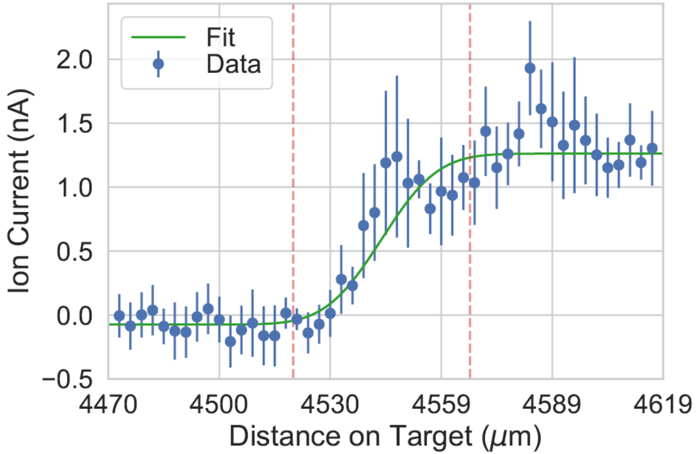
Diameter of ablated crater may be smaller than the laser spot 1/e^2 beam diameter – depending on the fluence.

Can be investigated by scanning laser spot over junctions between metals.



Steel to Niobium

1/e^2 diameter: **50(3) μm**



Silicon to Gold

1/e^2 diameter: **47(7) μm**

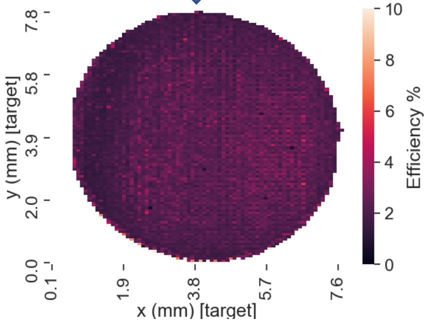
Ion Transport Efficiency

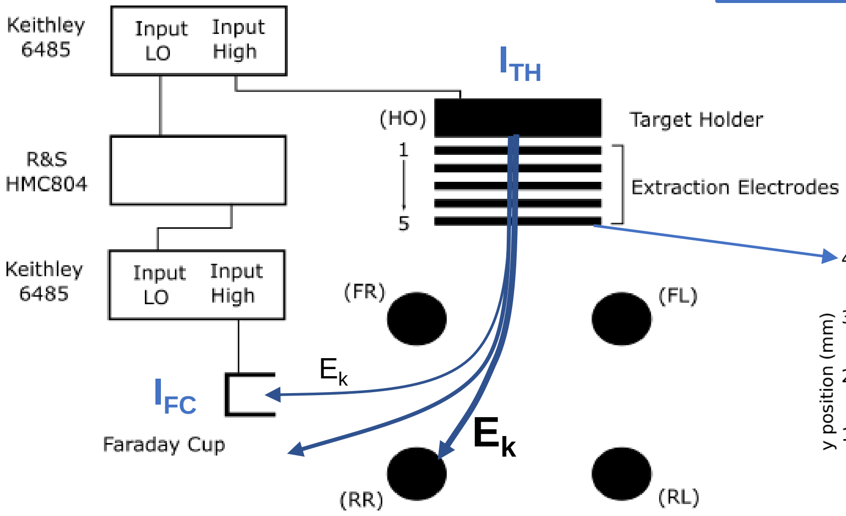
- What is the transport efficiency of the quad-bender and ion source-assembly?
- Eff = (ion current at Faraday cup)/ (ion current at target).
- Mean efficiency across the surface of the target 2.2(7)%.

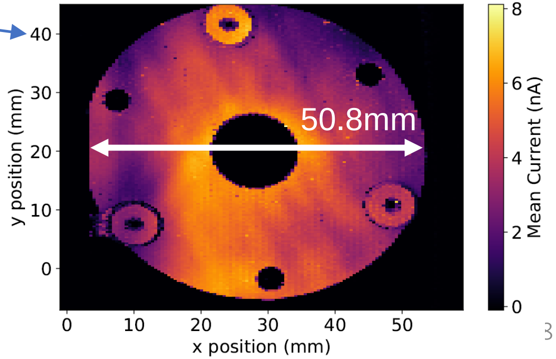
A wide quadrupole spacing results in a lower ion transport efficiency, but a larger scanning range.

Quadrupole electrodes can be brought together for higher bending efficiency, but a smaller scanning range.

$$T_{eff} = \frac{I_{FC}}{I_{TH}}$$







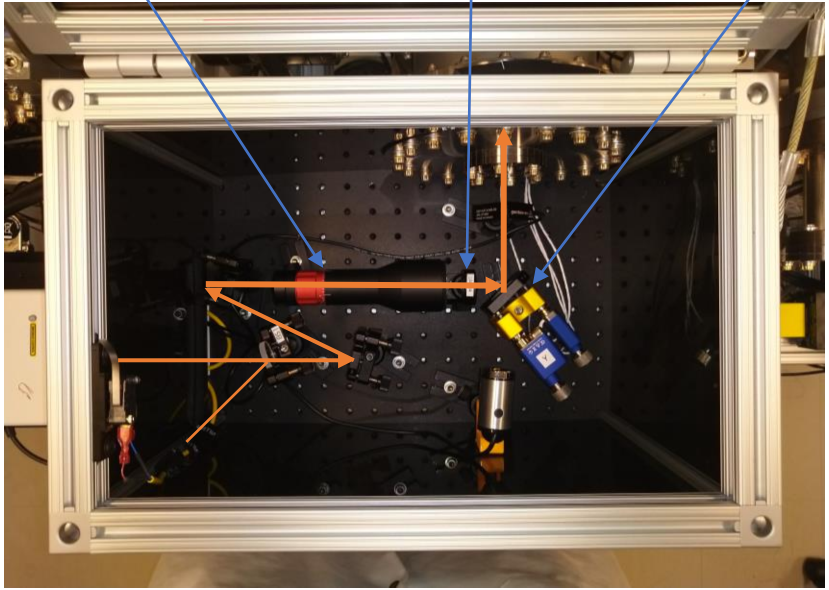
The MRTOF LAS

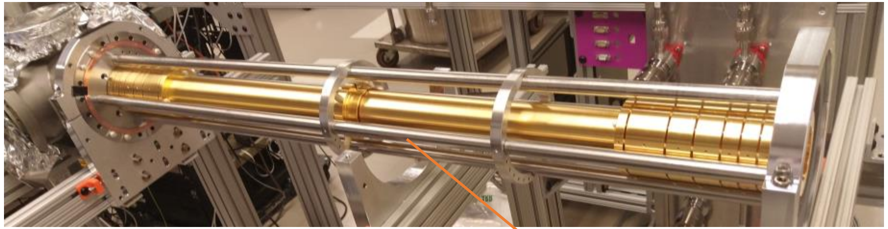
Condensed version of LAS used to commission the Multi-Reflection Time of Flight Mass-Spectrometer (MRTOF).

Beam expander

Focusing lens

Motorized Mirror Mount

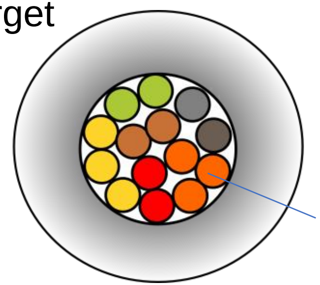




Outlook

Conclusions

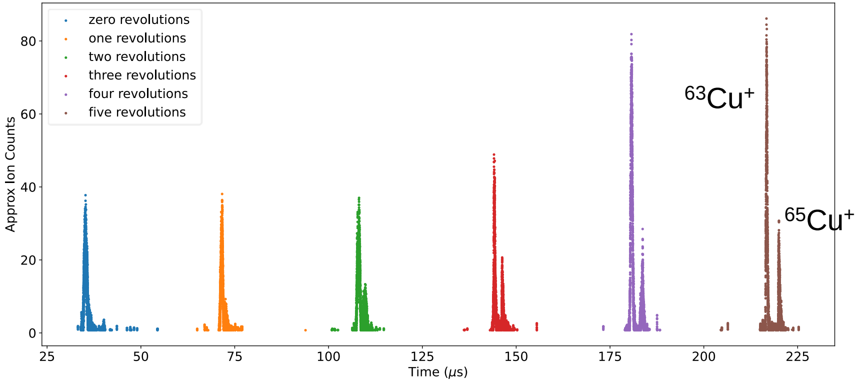
- Coordinate system allows for selective ablation of different materials.
- Materials in target can span large mass range – ideal for calibrating mass spectrometer.
- Spatial resolution characterized as 50µm – not limited by mirror steps.



Next Steps

- Increase the number of revolutions in the MRTOF.
- Tune the time focus for maximum MRP.

ToF Spectra for Cu ions



Copper selectively ablated and injected into MRTOF

Thank you for listening!

Acknowledgements

Thanks to all the work by many undergraduate and graduate students!

The LAS paper: Published in the international journal of mass spectrometry
https://doi.org/10.1016/j.ijms.2021.116763

Characterization of a Spatially resolved multi-element laser ablation ion source

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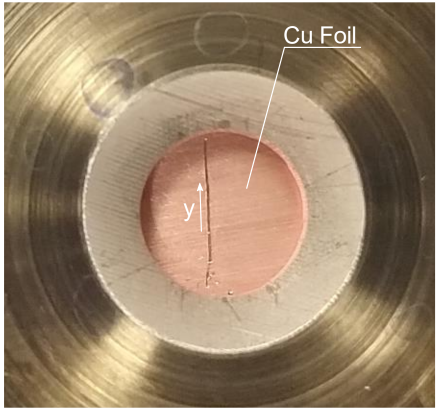
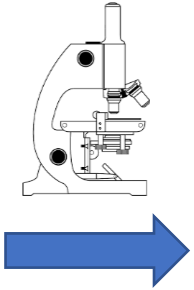
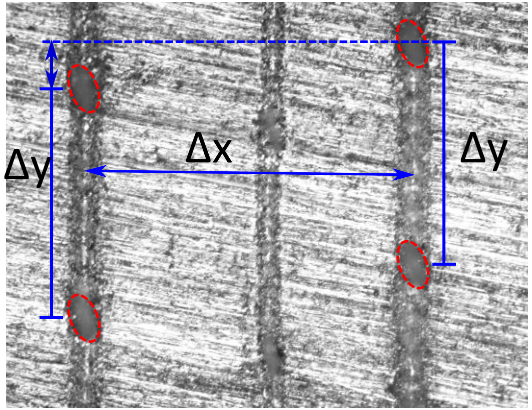
Microscope Measurements

Does the laser spot move on the target surface as expected?

- Ablation craters made by the laser spot are visible under an optical microscope.
- Distances between craters an be used to test the coordinate transformation directly.

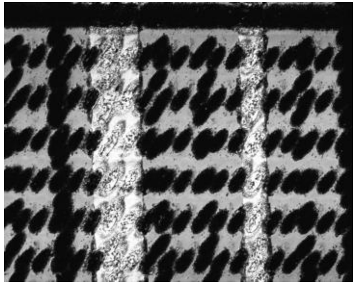




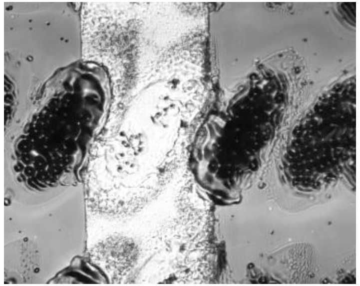


Measured: **Δx = 441.6(6) μm**, **Δy = 305.1(9) μm**

Calculated: **Δx = 438(6) μm**, **Δy = 302(4) μm**

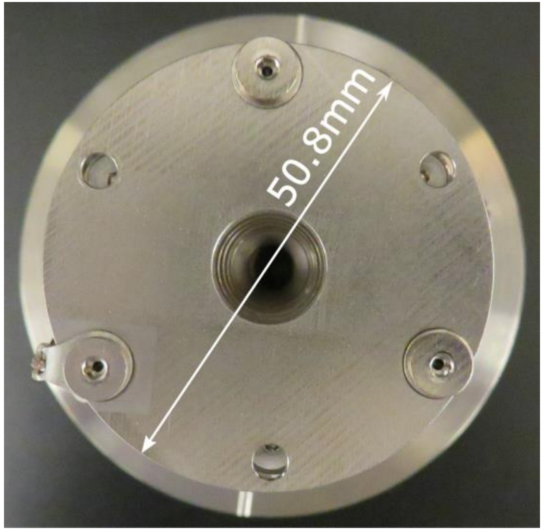


Ablation craters in silicon and silver target.

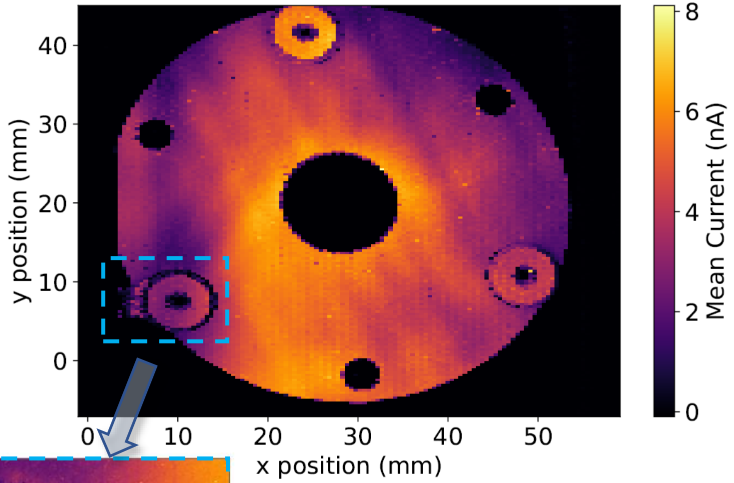


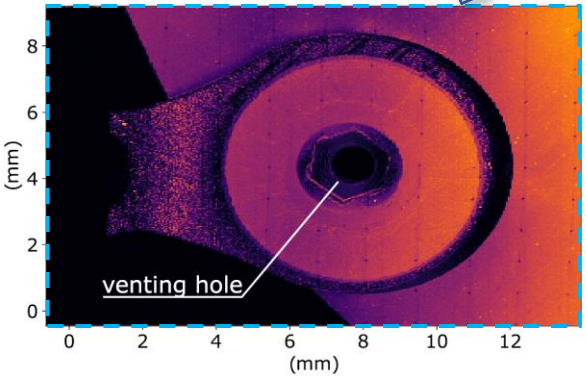
Scanning Range

Fifth extraction electrode



Wide quadrupole spacing supports a scan range up to 50 mm in width.





Factor of 10 smaller step size